Prehistoric Gold in Europe

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Prehistoric Gold in Europe

Mines, Metallurgy and Manufacture

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PREFACE

This book presents the results of the NATO Advanced Research Workshop on *Prehistoric Gold in Europe* held at Seeon in Southern Bavaria (Germany) from September 26 to October 1, 1993.

This workshop was designed to bring together archaeologists and other social scientists, geoscientists like geologists, mineralogists and geochemists, chemists, metallurgists and theologists to discuss our current knowledge of mines, metallurgy, goldsmithing and the role of gold and gold artifacts in the society of prehistoric Europe.

Archaeology seeks to reveal the past history of humanity, to raise the dead, to make our ancestors tell us about themselves and their social conditions and hope and fears for times that are well beyond the written record. Archaeology can be a voyage of the imagination and we should be aware that we can often interpret the remains of the past in more than one way.

Geosciences are faced with the problem of discovering how the earth works in producing not only the mineral deposits like that of gold, but also providing humans with the necessities of their daily life. It is evidence of the weight that we place on mineral resources that the terms "Stone", "Bronze" and "Iron" were used to describe the major eras of prehistory.

Both geosciences and archaeology are used to "read" both sites and the meaning of every individual object. Each sherd, each piece of rock is telling the geoscientist and the archaeologist a story. Looking at both sciences remarkable similarities in their evolution can be seen. The scientific situation in geological as well as in archaeological sciences changed dramatically in the late 1930s. From that time radiometric methods for dating archaeological and geological material by the radioactive decay of isotopes were developed. Hahn and Walling (1938) developed the rubidium/strontium method for the age determination of rocks and Libby (1946) developed the radiocarbon method for the age determination of organic remains. At that time also, experimental petrology started to add to the simple examination of the rocks by macroscopical and microscopical methods data on the pressure and temperature of their formation. From the same time also, analytical chemistry increased in precision and reliability, and non destructive methods like X-ray fluorescence and neutron activation made it possible to analyse archaeological objects without damage to valuable items and anxiety for museum conservators.

The techniques developed after the 1930s reduced not only the scope for speculation about the age and composition of the objects, but encouraged archaeologists to ask questions about tool uses, social context, behaviour and social groups, and geologists to look in every detail at how the earth works.

Gold and gold artifacts are excellent objects for unravelling the secrets of prehistory and its societies from their ambivalent character as condensed wealth and that basis of power, but also as transcendental symbols of eternal life and beauty, belonging more to the realm of the gods in heaven than to humans on earth.

The world's two million years of human history are the archaeologist's laboratory (Hayden 1992). About 4000 million years of rocks and minerals are that of the geoscientist. Studying the past in an interdisciplinary enterprise should not only increase our knowledge in specific fields of science, but help us to develop a sense of perspective about our present condition. Empires and cultures come and go like the species in the earth's history. What we see from prehistory to now is just a shadow of the grim reaping that occurred at the end of the Palaeozoic, 220 million years ago. At the end of the Permian period: "The face of death was to be seen everywhere, both on land and in the sea. Only one of every ten species survived the end of the Permian" (Ward 1992). Archaeology and geosciences are both fascinating sciences of once and future things. We feel that their cooperation is just at the beginning and in the future will produce remarkable results.

Special thanks go to the Scientific and Evironmental Affairs Division of the NATO. Without its financial support that meeting would never have taken place. Thanks also to Dipl.-Geol. Christine Preinfalk and to Dr. Gerhard Lehrberger of the Chair of Applied Mineralogy of the Technical University of München for assisting in the organization of the meeting. The help of Christine Preinfalk was invaluable during the editing of this book. Without her assistance this book would never have been printed. Thanks to Prof. Hermann Dannheimer (München) and Dr. Rupert Gebhard (München) for advice during the organization of the archaeological part of the meeting. Some of the manuscripts were reviewed by Dr. Peter Möller (Berlin) and Dr. Christiane Eluère (Paris). Thanks finally to all participants who, with their enthusiasm and competence, made that meeting so exciting.

Peter Northover *Giulio Morteani*

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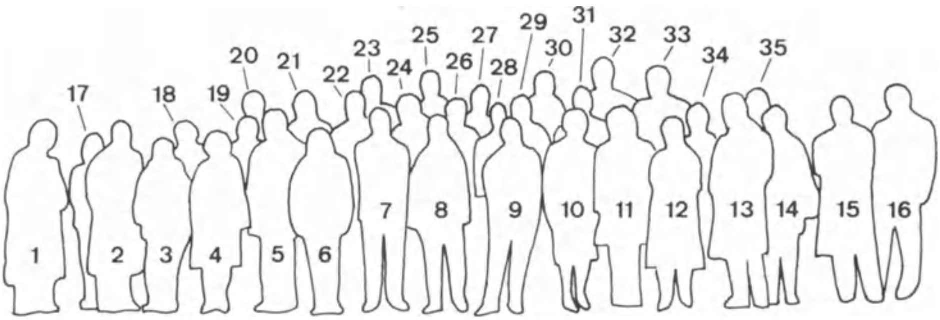
The Participants of the NATO-ARW Meeting in the Park of the Herrenchiemsee Castle (Southern Bavaria), September 1994



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CHAPTER 1

Chronology and Climatic Changes in Prehistory

Chapter 1

NOTES ON A GENERAL CHRONOLOGICAL SCHEME FOR EUROPE

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Today there is almost a general agreement on the relative sequence of archaeological cultures in Europe. During recent years the absolute chronology has been changing from a mainly historical chronology to a chronology based on the results of scientific studies. The historical chronology used objects correlated to historical persons or events that were mentioned in calendar systems such as those of the Egyptians, Greeks or Romans. These dates were linked to European cultures using typological criteria. Sometimes this method produced false links, in some cases with serious consequences for the relative synchronism of cultures. Nowadays most archaeological schools prefer the scientific chronology. Different preservation conditions result in the use of different methods. The most excact is dendrochronology which gives calendar dates. Calibrated ^{14}C-dates were cross-linked to dendrochronology, but they are in fact not exactly calendar dates but ranges of probability of when the sample last exchanged carbon with the atmosphere.

Table 1. First appearance of locally produced gold objects in different geographical regions.

Time BC	**6000**	**5000**	**4000**	**3000**	**2000**	**1000**
Near East	Copper Age					
Balkans and Carpathian bassin			Copper Age			
Eastern Mediterranean				Copper Age		
Iberian Peninsular				Copper Age		
Western Europe				Copper Age / Bronze Age		
British Isles					Bronze Age	
Central Europe					Copper Age/ Bronze Age	
Northern Europe					Bronze Age	

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Table 2. Chronology of the 1st millenium B.C.

Time B.C.*		Archaeological Cultures	Abbreviation	Archaeology	History
80-15	Time of the historic Celts			Decay of the Celtic world	58-51 Caesaric wars
120		Late Latène period	Latène D		about 120 Southern Gaul becomes a Roman province
220			Latène C2	Begin of the Oppida (towns)	218 Celtic mercenaries in Egypt
					225 Battle of Telamon
260		Middle Latène period	Latène C1		241-230 Attalos I of Pergamon defeats the Celts in Asia Minor
					279 Celts loot Delphi
330			Latène B2	Great celtic movements	335 Celts meet Alexander the Great
					before 379 Celtic mercenarys in Sicily
					about 385 The Celt besiege the Capitol of Rome
420		Early Latène period	Latène B1	First Celtic movements	
480		Ancient Latène period	Latène A	Ancient Latène Art	490-479 Persian wars
					Celts mentioned first by Hekataios of Milet
600	Time before the historic Celts	Late Hallstatt period	Hallstatt D	Chiefdom with fortified centers	about 600 Foundation of the Greek Colonie Massalia (Marseille)
750		Early Hallstatt period	Hallstatt C	Early Iron Age Inhumation burials Tumuli	753 "Foundation of Rome"
1000		Late Urnfield period	Hallstatt B	First iron decorations	
					1200-1100 Doric movement
1200		Early Urnfield period	Hallstatt A	Late Bronze Age Cremation burials	1200 Destruction of the homeric Troy

* The absolute dates B.C. mark the beginning of each Period.

Unfortunately there are no systematic dates based on either method for the period and regional expansion covered in this book. The articles in this volume show examples of precious metal working in the whole of Europe, including links to the Near East from the Copper Age until the Roman era. There never was a cultural or a technical homogeneity in Europe before the late 1st millennium BC. Technical evolutions were often locally very different (Table 1). The Mediterranean areas developed metal working technologies far earlier than northern Europe. Technologies could also have been developed independently under special regional conditions.

Finally it is very difficult to generalize cultural or chronological phenomena based only on one material group. Our knowledge of prehistoric gold is based mainly on deliberately buried objects, for instance in graves or hoards. An absence of gold objects in an archaeological context does not necessarily mean an absence of gold in the respective culture although this often appears likely.

Table 2 gives a general chronological scheme applicable to most articles in this volume. The terminology is based on the system that was orininally developed by Paul Reinecke at the beginning of this century for the area north of the Alps.

Chapter 1

OUTLINE OF CLIMATIC AND ENVIRONMENTAL CHANGES IN SOUTHERN CENTRAL EUROPE OVER THE PAST 20,000 YEARS

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ABSTRACT. Based on investigations of Bavarian lakes and the literature, a brief outline of climatic and environmental changes in the past 20,000 years is presented as an introduction to the prehistoric topic of this book.
The Late Glacial climate is characterized by a pronounced instability and fast changes, the Early Holocene appears as a more or less stable period where vegetational changes appear to reflect primarily natural developments. After the climatic optimum in the Middle Holocene with only minor climatic fluctuations, a distinct change to more unstable conditions occurs during the Subboreal period, where man's influence on the environment becomes more and more apparent.

1. Introduction

Over the past 20,000 years our European ancestors witnessed drastic climatic changes, from glacial to warmer conditions than presently which challenged their abilities to adapt their lives to changing environmental conditions sometimes within a few generations. Among others, Lamb (1982) has pointed out the extent to which climate has influenced man's activities and history both in modern and in prehistoric times. The purpose of this paper is to present a short descriptive outline of environmental changes as observed in southern Central Europe combining data from the literature with results from investigations in Bavarian lakes.

One key aspect for environmental reconstruction of the period considered is the development of vegetation as a complex reaction resp. interaction between climate, plant immigration, soil type, game and man. The appearance of distinct plant associations, and a characteristic succession observed over large parts of Europe have been used for the subdivision of the Holocene and Late Glacial periods (Tab. 1). This subdivision (zones) is based on Firbas (1949) work on the history of forests in Central Europe, which has been used for this compilation.

While vegetation was primarily controlled by climatic conditions and soil development during the Late Glacial and Early Holocene, man has increasingly influenced vegetation and even climate on a regional scale at least during the later Holocene period. Man's present potential to influence the climate on a global scale is beyond dispute (f.ex. Kellogg 1980).

The time scale (uncalibrated ^{14}C years B.P.) used in Tab. 1 has been adopted from Mangerud et al. (1974). Proposed as a supraregional scheme, it serves here as mere rough guideline, not considering the more recent precise results of dendrochronology overcoming the da-

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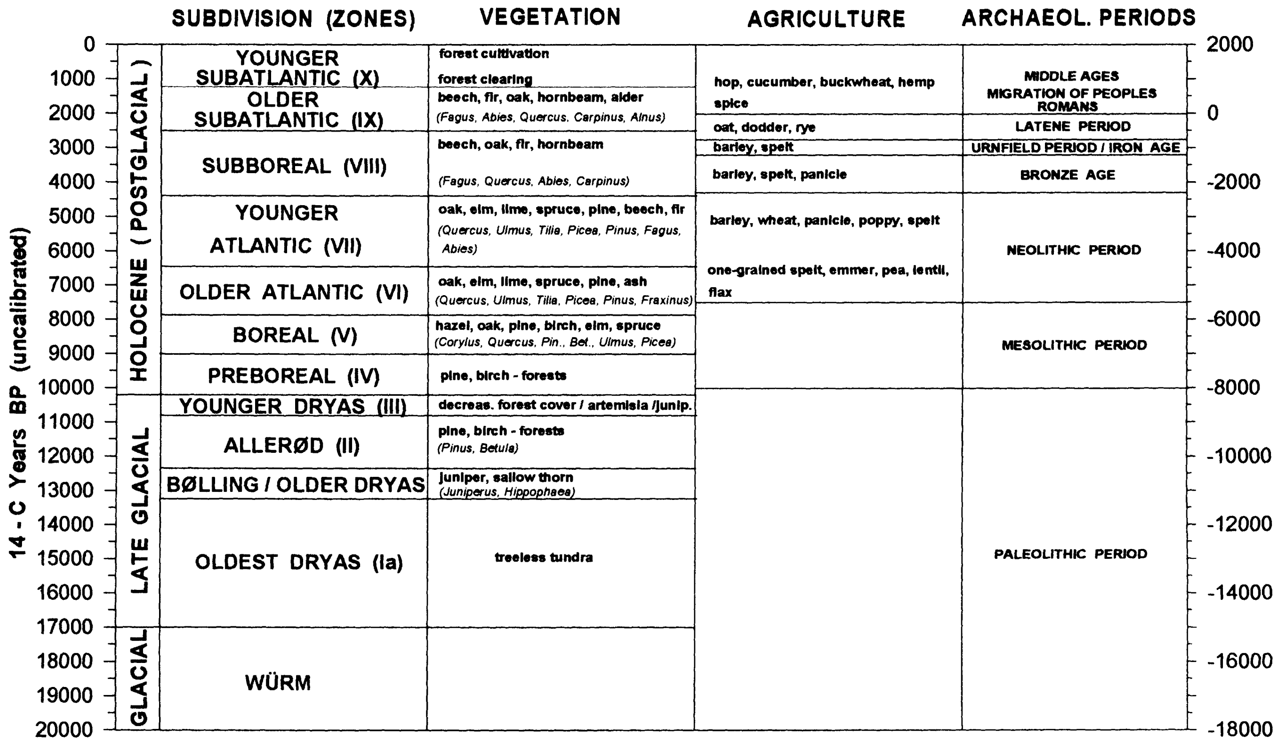

Tab. 1: Chronological subdivision of the past 20,000 years in Central Europe; Vegetation data after Firbas (1949), agriculture data after Körber-Grohne (1987) and Zohary and Hopf (1988).

ting problems due to natural atmospheric ^{14}C variations in the past (Bruns et al. 1983). As an example, the transition from Late Glacial to Holocene (i.e. the end of the Younger Dryas) has been established at 10,970 dendro-years B.P. (Becker et al. 1991). As a consequence the Late Glacial/Postglacial time scale is presently in a state of change.

2. The Würm

During the last glacial stade (Würm), Mid-European glaciers reached their maximum extent between 20,000 and 18,000 years ago. Alpine glaciers extended beyond the present day basin of Lake Constance, reached nearly the site of Munich and further to the east into Austria as a sequence of glacier tongues leaving the major alpine river valleys. Local glaciation occurred in areas like the Black Forest or the Bavarian Forest. The retreat resp. the decay of glaciers started 18,000 to 17,000 years B.P. (Husen 1987).

3. The Late Glacial

The subsequent Late Glacial period is characterized by rather unstable climatic conditions, where rapid changes interrupted the warming trend. Several re-advances of glaciers during these periods have been noted, where the snowline was depressed a few hundred meters with respect to the present snowline (Maisch 1982, Röthlisberger, 1986, Hirtlreiter 1992). However, by 14,000 B.P. major alpine river valleys, for example the Inn river, were free of ice (Patzelt 1983). Areas which had been covered by glaciers experienced substantial morphological changes: lakes appeared and rivers formed large braided beds due to the run-off of glacial meltwater. Some of these lakes were rapidly filled with sediments, erosion being aided by the lack of soil and vegetation. A huge lake reaching from Rosenheim into the Inn valley had thus vanished by the end of the Late Glacial period (Beug 1976). Another example is a former lake south of Wolfratshausen (Jerz 1979).

Significant changes in the Late Glacial vegetation occurred in the Bölling, approx. 13,300 years B.P., when pine forests and birch started to replace the tundra-like plant communities of the Oldest Dryas. There were, however, distinct regional differences with pine forests characterizing the eastern prealpine regions while juniper dominated in the western area (Frenzel 1983) This development, interrupted by a short colder phase during the Older Dryas, lasted to the end of the Alleröd. Mean annual air temperatures as reconstructed by stable isotope analysis (^{18}O) of benthic ostracod shells reached 6°C in southern Central Europe (Grafenstein et al. 1991). Hardwater lakes showed a distinct change in their sedimentation pattern. Sedimentation in the previous periods is characterized by allochthonous input forming warve-type sediments, during the Alleröd autochthonous chalk deposition (epilimnic biogenic decalcification) became the dominant sedimentation mode in this first warm phase (Schneider et al. 1987, Müller and Kleinmann 1987). Towards the end of the Alleröd, 11,000 years ago, a volcanic eruption in the Eifel (Laacher See) occurred, where tephra material was transported over large distances, forming millimeter thick layers of airborne glass shards in lake and bog deposits as far away as Switzerland, Austria, northern Germany and France (Bogaard and Schmincke 1984, Klee et al. 1993).

After warmer conditions had prevailed for a period of almost 1,000 years during the Alleröd, climate deteriorated abruptly, probably within a few decades, as suggested by rather sharp changes in the lithology of sediment cores. The cold temperatures (mean annual air temperatures dropped to almost 0°C in Southern Germany, Grafenstein et al. 1991) of the Younger Dryas induced by factors still under dispute caused a change in the vegetation pattern when in some areas tundra-like plant species reappeared, in other areas forest cover became less dense. Glacier advances in the Alps are indicated by moraines with a snow line depression around 200 m beyond the present one (Maisch 1982). Ice wedges and cryoturbation are reported for this period in Northern Germany, a decline in soil stability related to the vegetation changes is indicated by synchronous deposits of wind blown sand in Southern Germany (Brunnacker 1959). North of Munich, Feldmann (1990) described plates of frozen soils incorporated within gravel deposits of the Isar river which document the cold temperatures of this period and which suggest, that the Isar river had become a meandering river in this region. Autochthonous chalk sedimentation ceased in prealpine hardwater lakes, several indications suggest only short periods of seasonal thermal stratification in the lakes caused by the colder climate. Turbidite deposits within Younger Dryas sediments document the effects of frequent floods, their sediment yield being at least in part the result of the less dense vegetation conditions.

The cold climate of the Younger Dryas persisted for nearly 1,000 years, the change to more stable warmer conditions marks the end of the Late-Glacial and the beginnining of the Postglacial (Holocene) period 10,200 years (uncalibrated) ago.

4. The Holocene

4.1 PREBOREAL AND BOREAL

Temperature increases at the beginning of the Preboreal period are even more pronounced. Estimates based on ^{18}O analysis of ostracod shells (Grafenstein et al. 1991) indicate mean annual air temperatures in a range as the present ones in Southern Germany. Forests dominated by pine and birch spread, reducing thus mesolithic reindeer hunting and increasing collection of seeds and fruits (Clark et al. 1989). Allochthonous sedimentation in the prealpine lakes decreased to a minimum observed in the past 20,000 years, these low erosion rates being the result of the dense vegetation cover and apparently drier conditions. As a consequence, chalk deposition dominated in the prealpine lakes. This contrasts to investigations in Bavarian rivers, where frequent findings of trees in the sediments of the Isar (Feldmann 1990) or the Danube (Becker 1982) are interpreted as indications of increased fluvial activity.

The appearance of corylus (hazel) 9,000 years ago marks the next vegetation phase, the Boreal period. Stable isotope analysis (^{18}O) suggest increasing temperatures compared to the previous period. No significant environmental changes can be observed within lake sediments of this time. Cores from lake Ammersee show as an example one single major turbidite deposit for the period Preboreal/Boreal comprising > 2,000 years, again contrary to the above mentioned findings of increased fluvial activity of Bavarian rivers.

In contrast to the lower prealpine regions where the vegetation had formed a rather dense cover for more than thousand years, alpine and subalpine areas showed a time-lag with respect to vegetation, but also a different plant association and succession. For example, sediment investigations in lake Funtensee, situated in 1,600 m altitude in the Northern Calcareous Alps (near Berchtesgaden) showed primarily deposition of coarse sediments derived from glacial sediments during the Preboreal/Boreal period as a result of lacking soil and more open vegetation conditions in the drainage basin of this lake (Müller et al. 1985). The same investigation showed, that the occurrence of certain clay minerals resulting from soil formation coincided with the existence of a "closed" forest cover and a synchronous decrease in the accumulation rates in the lake.

4.2 ATLANTIC

The subsequent Atlantic period beginning 8,000 years ago shows a new vegetation type dominated by oaks and other deciduous trees (elm, ash, lime, maple) forming distinct regionally differentiated associations. Spruce started to occupy higher elevated regions in the eastern section of Central Europe. This period is generally called the "climatic optimum". Mean annual air temperatures in Southern Germany range around 10°C, more than 2°C above the present mean (Grafenstein et al. 1991). Lake sedimentation during this period is characterized by autochthonous chalk deposits, accumulating at rates greater than during the recent eutrophication. However, a first increase in the rate of allochthonous input compared to the previous periods is observed as well, suggesting increased precipitation.

The deposition of "alm", i.e. calcite precipitated on inundated meadows, appears to have been most intense during the Atlantic (Jerz 1983). It had started in some areas in the early Holocene. Higher precipitation, especially during summer led to a higher groundwater table, in some areas peat formation thus ceased, bogs were covered by "alm" (Jerz 1983).

A compilation by Feldmann (1990) of datings from river sediments (for ex. Danube, Isar) showed an increased frequency of tree trunks in the period between 6,700 B.P. and 5,700 years B.P., interpreted as further phases of increased fluvial activity. Wether this phase corresponded to a climatic deterioration during the Atlantic accompanied by glacial advances in the Alps remains to be settled (for discussion see: Buch 1988). According to Frenzel (1977), wet summers prevailed during this period in Southern Germany due to a shift to a more oceanic circulation, intercalated phases with colder winters occur as well.

By 6,000 years B.P., the beech (fagus) appeared in Southern Germany marking the beginning of the Younger Atlantic. Warm conditions persisted during most of this period. The tree-line migrated upwards as shown by pollen investigation of alpine lakes (f.ex. Müller et al. 1985). Accumulation rates in the prealpine lakes increased due to both, an increase in autochthonous precipitation of chalk as well as by a twofold increase in allochthonous input. Most of the larger prealpine lakes in Austria, Southern Germany and Switzerland show indications for lake level fluctuations. First settlements (pile dwellings) on the lake shores appear. For example, on Lake Starnberg (south of Munich) dendrochronological dating of wood piles gave an age of 3,720 years B.C. (Beer 1987). Oldest Neolithic settlements of this type on Lake Constance have been dated to more than 4,000 years B.C. (Schlichtherle and Wahlster 1986). Causes of these lake level fluctuations are still under dispute. Hydrological changes in the river systems have been considered where erosion phases followed accumulation phases thus influencing the height of the outlet of the lakes. The appearance of charcoal in lake sediments and changes in the vegetation pattern document man's activities and influence in the lake surroundings. For example, sediment investigation in Schleinsee, a small lake close to Lake Constance, showed an abrupt increase in charcoal 3,500 B.C. coinciding with a decrease in fagus pollen and a transition to corylus shrublands due to Neolithic settlements (Clark et al. 1989). In some lakes subaqueous mass slides were observed during the Younger Atlantic probably associated with the lake level fluctuations.

4.3 SUBBOREAL AND OLDER SUBATLANTIC

The subsequent Subboreal period beginning 4,500 years ago is considered as a transition time with respect to vegetation and climate. Climatic fluctuations during this period are indicated by a lowering of the alpine tree line and glacial advances (Patzelt und Bortenschlager 1973). Isotopic data (^{18}O) of benthic ostracods of Lake Starnberg and Lake Ammersee indicate also climatic instabilities with phases of warm and colder periods (Grafenstein et al. 1991). Lake sedimentation in the prealpine lakes changes distinctly, autochthonous chalk deposition decreases substantially, in contrast allochthonous input becomes the dominant sediment source as for the rest of the Holocene. Accumulation of allochthonous material shows a twofold increase compared to the preceding Younger Atlantic in Lake Ammersee. Turbidite deposits are observed in increasing numbers within sediment sequences of this time. The vegetation is characterized by an expansion of beech and a decline of mixed-oak forest, possible causes include increased precipitation, lower summer temperatures or soil acidification (Clark et al. 1989).

As for the preceding period, changes of vegetation or lake sedimentation during the Subboral are no pure reactions or signals of climate but were influenced by both, climate and man. The respective proportions have yet to be defined and quantified. Cereal cultivation in the considered area reaches back to 4,400 B.C. (Küster 1986) or even further (Kossack and Schmeidl 1974/75) not being confined to the fertile areas at the Danube were settlements had existed since even older times. Rough estimates of the changes in the proportions forest to open cultivated land can be deduced from the ratio arboreal to nonarboreal pollen. First results from detailed analyses from Lake Ammersee show a decrease in the ratio from 10 during the Younger Atlantic to around 3 for the past 300 years. It is obvious that forest clearances will affect the hydrological regime, surficial runoff and sediment yield, groundwater and evapotranspiration thus obscuring true climatic effects in the different records. Regardless of the causes, erosion increased substantially at the end of the Younger Atlantic throughout the following periods. As an example, Barsch et al. (1993) showed in an area of Northern Württemberg, where around 1/3 of the land had been cleared by Neolithic farmers, an average loss of 20 cm of surficial soil between 3,000 and 2,000 B.C.

Lake level fluctuations continue during the Subboreal. They are best defined with respect to timing and duration by the relics of pile dwellings found in the litoral zones. Although not always strictly synchronous, settlements of this type suggesting low lake levels existed around 2,500 B.C., between 1,700 and 1,600 B.C. and between 1,050 and 850 B.C. in Lake Constance and in Swiss lakes (Joos 1987). Roughly, this period corresponds to increases with respect to trees buried in river sediments (Danube, Isar). Feldmann (1990) suggests as sole causes climatic changes i.e. a pronounced instability (fast changing periods of years with dry summers and mild winters with years with wet summers and cold winters) indicated primarily by glacial fluctuations. However, for the period considered, monocausal interpretations appear premature. Thus, Becker (1983) concludes in an investigation of subfossil oak trees from the Main river that fluvial disturbances during the Bronze Age were caused by forest clearances aided by a general increase in flood frequency.

Aspects of man's activities and environmental influence during the first millenium B.C. were treated by Clark et al. (1989) in their investigation on lake Schleinsee. Based on charcoal and pollen data they observed a decrease in the slash-and-burn activities for clearances with the introduction of metal tools. Vegetation reactions included increases in herb and betula pollen. Synchronous decreases in corylus compared to the previous Neolithic period suggested more intense soil disturbance and changing agricultural techniques, also influencing the trophic state of the lake.

The above example shows environmental changes due to man's activities on a local scale. Forest clearances to gain arable land or locally for metallurgical purposes and farming represent major impacts on the environment in the period under consideration, caused by man's increasing need for land and resources. An example of supraregional effects of these activities was presented by Görres and Frenzel (1993) based on an investigation of ombrogenous bogs of Middle and Northern Europe. They present evidence for an increasing input beginning in the Bronze Age of marine elements as Br, Cl and Na suggesting an enhanced atmospheric circulation from the ocean caused by the clearings.

Except for general trends, environmental resp. climatic reconstructions referring directly to time sections of the last millenium B.C. are rather scarce. Clearly, more research is needed for this time sequence as for other Holocene or Late Glacial periods. Within several national and international research projects attempts are made for better differentiated environmental reconstructions, combining multidisciplinary approaches with improved dating techniques.

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CHAPTER 2

Gold and Society

Chapter 2

CONSIDERATIONS ON THE REAL AND THE SYMBOLIC VALUE OF GOLD

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ABSTRACT. The glint and glitter of gold have an eternal fascination. It has inspired admiration and amazement as much as the desire to win it. It appears in the myths and fairy tales and has an important place in the stories of the Bible. It could be seen equally as a blessing and a curse, it could be considered as an expression of the power of the sun, or as a sacred possession of the gods, always it has a place in human fantasy. On a human scale it was a symbol of power and wealth and then a precious material for the most sublime creations of artists and craftsmen. Beyond that, even, it was the ultimate symbol of perfection and incorruptibility, the goal of the transformations of the alchemists.

1. Introduction

In looking at gold and at the objects made from this metal very different aspects may be considered. One can study the composition of the alloy but also the way the objects were produced by the goldsmiths. One can classify the deposits and places where gold is found, listing their names. One may describe the physical and chemical properties of gold and its alloys, its use in artwork and the technical applications but also enjoy the aesthetic qualitites of gold objects. One can write the history of the gold diggers pushed to incredible adventures by the desire of gold; also of crimes committed for gold as well as that of the many disputes and wars between peoples produced by the desire for gold.

But there is also another aspect of gold that is worthwile considering. Gold in fact was, over the centuries, always a symbol of light and beauty, an incommensurable value materializing invulnerability and the immortality of the gods.

Any object on earth can in fact be transformed into a symbol if an additional meaning, a transcendental value is added to the simple material value.

In humanity there is a very secret system of relations connecting one thing with other things. This system of relations is the basis of understanding the whole system from the observation of single things. Kästner (1974) in this context writes: *"Figures are the only possibility for the incomprehensible to talk to us, only through such figures can it enter our immagination and awareness".* Finally we must ask ourselves: What is the value of gold, what do we connect with objects made of gold, what is the reason that gold has such a high emotional value for humans?

The answer to all these questions cannot come from geologists, mineralogists, metallurgists or chemists. We have to study myths and fairy tales to find in them the key to understanding why gold is so fascinating humans.

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2. Knowledge of the Golden Age

In many myths we find the idea of a long, long past heavenly "Golden Age". In those very old times, gods and humans lived in a golden peace without troubles and pains. Hesiod describes this time in his "Works and Days" as follows:

"Golden was the family of talking humans created by the immortal gods, the inhabitants of the sky. Those humans lived at the time when Kronus as a king ruled from the sky, and they lived like gods without fear far from trouble and pain and they did not to fear the quickly approximating old age, they were happy in banquets and without any pain they die like falling asleep and all desired things were given to them as a gift. Fruits and crops were given liberally to them from mother Earth, without limitation in time and quantity. Peacefully working inbetween abundant flocks and lifestock and believed by the blithful gods".

But this age ended and was followed then by the silver and iron ages. Those ages were no longer characterized by the happiness and ease of existence.

Similarly Ovid writes in his "Metamorphosis":

"But in the Golden Age of long ago
The orchard fruits and harvest in the fields
Were blessed boon and no blood stained men's lips."

The silver age as was still an eternal spring. The end of the silver age shortened that eternal spring.

Gold also stands for the uncorrupted beginning of the world, for the unspoilt integrity of its origin. At the beginning everything was "golden"; the course of the history produced the corruption. Nevertheless the ancient myths contain the hope that a new golden age may come in a future. Very clearly Virgil formulates this hope in his very famous fourth Eclogues:

"Born of Time, a great new cycle of centuries
Begins. Justice returns to earth, the Golden Age
Returns, and its first-born comes down from heaven above.
Look kindly, chaste Lucina, upon this infant's birth,
From him shall hearths of iron cease, and hearths of gold
Inherit the whole earth - yes, Apollo reign now."

A new magnificient era will rise and all traces of sins will be destroyed. This hoped for arising of the kingdom of peace has to be called "golden" while it originates in the glorious primeval time.

3. Gold of the Gods

Looking at the past and at the future, then we realize, that the present state cannot be the promised Golden Age. We realize that in such a situation it is very tempting if one promises a golden mountain. Terencias mentions the temptation of "Montes Auri Pollicens". It is a fact of history that an Eldorado, a fantastic land of gold, was promised to the Spanish adventurers on their way to the Americas. On the basis of such a fiction many adventurers start their journey.

But gold is really found. Earlier cultures show very clearly how highly prized gold was and how fast the art of goldsmiths developed. Already 6000 years ago Egyptians hammered gold grains to gold sheets and gave to those gold sheets on matrices different shapes producing leaves, fruits and crowns adorned with precious stones. The gold was produced from primary and alluvial deposits, separated from less precious metals. Very soon the discovery of melting, casting and alloying of gold with silver and copper enabled the goldsmiths to produce large gold objects.

Goldsmiths created ornaments, precious dishes and vases for profane uses and coins but the predominantly use was for religious objects to be kept in the temples.

As in Egypt the worship of the sun brought into the religious imagination the idea that shine of gold and of the sun were directly related. Gold was understood as the materialization on earth of the sun. The sun god Horus with his falcon head was worshipped as the god of gold, too. The Pharao taken as an incarnation of the sun god Horus, could claim this divine metal exclusively for himself. His throne, his adornments, his daily tools and, finally, also his coffin were made, at least in part, from gold.

That the temples and the statues of the gods were therefore decorated with gold is obvious. A gift of gold by the pharaoh to priests and important officers of the court was a special decoration meaning that they were kept in such high consideration by the ruler to merit participation in his power and his divine life.

Also, in many other cultures and religions, than the Egyptian one, gold was reserved for sacred objects. The Aztecs and Incas considered it to be a direct product of the gods. In taoistic China gold was considered to have a transcendental power. Such understanding definitely removes gold from profane desire, reserving it to the gods. As the Spaniards conquered and destroyed in Central and South America the kingdoms of the Aztecs and Incas the natives were very surprised by the unbelievable avidity for gold shown by the Spaniards. They asked themselves: Why do these white conquerers steal the property of the gods?

4. The curse and blessing of gold

The "neutralization" of the gold by connecting it to the gods seems never to have been successful for a long time. This glittering metal was too appealing, too big its economic power and the possibilities given to its owner. The accumulated gold lured the greedy neighbours, produced rebellions, corruption and intrigues. The history of gold is over the centuries a history of wars, of conquests, devastations, victories and defeats. Who was in possession of gold had power, could pay for troops, could construct fleets and start wars. This all in order to get more gold!

Herodotus tells that the Lydian king Croesus, who owned an incredible gold reserve, wanted to be praised by the philosopher Solon for his fortune. But Solon answered to the king that one has to wait for the end of the life of a human being before calling his life a lucky and happy one. Croesus sometime after that lost his aggressive war against Cyros, king of the Persians. He was condemned to death by burning. At the stake Croesus remembered Solon and called for him. Cyros noticed that and asked Croesus who is the god he asks for at such a terrible moment. As Croesus told him what Solon had said to him some time ago Cyros pardoned Croesus and both the kings could observe how the city was destroyed and plundered by the Persian soldiers. Looking at that, Croesus warned Cyros that on the gold there was a curse, and advised him to take the gold the soldiers got from plundering and to give them land for settling and farming. Croesus stressed that gold will never satisfy greed, one will always want more and more and therefore the soldiers will finally fight against their own king.

This curse of the gold is a continous motif in the history of humanity for hundreds of years. Plinius the Younger wrote: *"How nice it would be if one could ban from the life gold and the damned desire for gold! This gold, which is disdained and cursed by all good people was discovered to transform the men into criminals!"*

Obviously this is only a partial truth, because gold is also the basis of very developed cultures. When Alexander the Great obtained the immense gold treasure of the Persian kings he decided not to hoard the gold but used the treasure to construct cities, improve the conquered areas, and also to found the very famous library of Alexandria in Egypt. But the successors of Alexander the Great gave up the chance of a unique empire. The old rivalies and the usual gold envy quickly produced the ruin of Alexander the Great's empire.

There is no doubt that gold has an ambivalent character. It can produce happiness as well as disasters. From the fact that gold is easily transportable it can be the basis of the organization of gigantic empires such as the Roman one. With gold the soldiers can be paid in very remote provinces, roads can be constructed and so on. The survival of an empirial power, the political equilibrium of an empire very often depended on the controlled supply of gold. On the other hand, luxury based on gold leads repeatedly to immoderate extravagance. If revelry and luxury become the target of the humans morality is challenged.

5. Gold in the Holy Bible

The holy bible reflects ideas about gold that are similar to those found in other documents of the Time. We read the description of the conquest of Jericho that: *"All the silver and gold and things made bronze and iron belong to the LORD and must be saved for him (Josua 6, 19)".* Then the words of Croesus directed to Cyros come immediately to our mind, that gold and other precious metals should not be left to the soldiers but be taken in religious custody. Golden vessels and ornaments were found in temples and at the courts of kings. When the messiahs take over the reign, then the pilgrimage of the peoples to Jerusalem was to be expected: *"... People will come from Sheba bringing gold and incense, ...(Isaiah 60, 6").* Similarly in Ps. 72 it is given *"Long live the king! Let him receive gold from Sheba".*

With the beginning of the kingdom of the Messiahs according to the bible, it is expected that a golden age starts. In the last book of the New Testament the Apocalyps of John, the heavenly city, the new Jerusalem is described *"... and the city was made of pure gold ...."* (Revelation 21, 18).

But the Bible also warns us not to rely to much on gold. *"I have not put my trust in gold or said to pure gold, "You are my security""* writes Job (31, 24) and in the same context Job (22, 25) stresses: *"The Almighty will be your gold and the best silver for you".* What God gives as a gift is of a different quality from the precious metal: *"Your teachings are worth more to me than thousands of pieces of gold and silver"* (Ps. 119, 72). *"I love your commands more than the purest gold"* (Ps. 119, 127); compare also Proverb 16, 16 *"It is better to get wisdom than gold ..."*.

In the Bible the idea of the examination and purification of gold is very popular. The humans are in the same situation as gold. First they have to be subjected to an examination in order to test how their quality is *"A hot furnace tests silver and gold, but the LORD tests the hearts"* (Proverb 17, 3).

Humans have to be tried in the fire in order to check their quality: *"The third that is left I will test with fire, purifying them like silver, testing them like gold"* (Zech. 13, 9); compare Mal 3, 3; 1 Peter 1, 7.18).

Very instructive in this context is a chapter in Exodus. In this chapter it is written that Moses climbed on the Mount Sinai to be instructed about the laws. But the peoples of Israel are unhappy with an "abstract" idea of God that is unconnected to a figurative representation. They wish a concrete and visible symbol of the presence of god. So the people collect their gold ornaments and all melted and Aaron is forced to produce the statue of a calf so that this statue can be venerated and danced around. When Moses returned back he became very angry. *"Then he took the calf that the people has made and melted it in the fire. He ground it into powder. Then he threw the powder into the water and forced the Israelites to drink it"* (Ex 32, 20). If the statue is called "the golden calf" then this is done in order to make the whole thing ridicolous. Moses complains that *"...They have made for themselves gods from gold"* (Ex. 32, 31).

The very strict law in the old Israel that one may not make a picture of God could not always be sustained. A visible ideal, a golden object should bring god from the distance near to the humans. The most precious things that the people had was gold and this should be used to symbolize god. Moses felt this as unbelief and heresy: Israel should be different in its conception of god from all other peoples.

6. What language and popular wisdom tell us about gold

What makes gold so incredibly appealing? Why do all humans react in similarly astonishing ways to this metal? Obviously it is the beauty and the shining colour of gold that contributed to the fascination of this metal. But also the facts that is very rare and difficult to find and to get contributed to this mythic value. Gold is concealed in minerals like pyrite in quartz veins. Only when you dig to the depths, you can find it there. Additionally, it is resistent to degradation by oxidation and does not blacken with time such as silver. The rulers made gold coins with their image. Goldsmiths found many different ways to work the gold, they chased, they worked with chisel and file, they engraved, cut thin gold sheets with scissors, stamped ornaments in the gold sheets, granulated and enamelled and produced filigrees with thin gold wires.

But this is not all; in its etymological context it is related to yellow, gloss, glass, smooth, glowing. The yellow colour and the glossy character always had a paramount importance.

Most of the things on our earth get shabby and unsightly with time. They get rotten and putrified. Therefore the apparant incorruptibility of gold was marvelled at. Gold maintains always and forever its golden shine. Gold was therefore considered *Rex Metallorum*, i.e. the king of the metals.

Our language with its proverbs, popular songs and phrases collected and summarized a lot of the worship and the danger of gold. *"Gold and silver we like very much ..."*, so we have sung as children. We would like very much to find a gold mine and we would like very much too, to have golden fingers, so that we will have everlasting good luck. If somebody is unrivalled than he cannot be *"paid with gold"* Plautus writes accordingly: *"hunc hominem decet auro expendi"*. But there is also a popular proverb that tells us *"all that glisters is not gold"* (Shakespeare). One should not rely on shiny things. Some words have to be put first on the "gold balance" in order to detect their value. On the other side we should not put all on the "gold balance" mainly when things are not so important. Goethe formulated as follows:

"The happiness of your days
Do not determine with a gold balance
If you use the merchants balance
You be ashamed and be happy".

The corruptibility of judges produced the idea that *"a handful of gold is much heavier than a pack full of laws and truth"*. A proverb says *"the doctor has money, the lawyer has gold"* and so saying money was considered to be silver coins, whereas gold was supposed to be ducats. Of gold the poor could only dream, therefore the following rhymes from Goethe's Faustus could become a proverb:

"To gold it tends,
On gold depends,
All, all! Alas, we poor!"

With his eloquent and acute tongue Abraham a Santa Clara summarized the situation: *"in the latin language "numen" is the name for God, "nummus" that of gold. From this similarity gold, this yellowish piece of soil, this pale cipher, got so much power that a ruthless world sighs " oh omnipotent God" as well as "oh omnipotent gold""*.

Sachs is much more sober in his thinking when he writes:

"Gold is neither good nor bad;
it depends of the person, who uses it".

7. Gold in fairy tales

In the tales gold is mentioned in many occasions. The hero in fairy tales has golden attributes e.g. a golden star on the forehead or golden hairs, sometimes the heroines or heros are even completely golden. The hero, as the long awaited carrier of good hopes, is recognizable very often just by his external features. Every very important thing that has to be stressed in a fairy tale is defined as golden: a golden castle, a golden sword, a golden carriage. Even trees can be of metallic gold, and obviously they then bear golden fruits. A golden bird brings news from a secret kingdom, where a king rules sitting on a golden mountain. When the hero departs to find the three golden hairs of the devil, he must enter into the kingdom of the death crossing the river of the death. In this way he visits the Hades i. e. the realm of Pluto, the god of the hell but also of wealth. Pluto was considered in fact not only the ruler of the kingdom of death, but also of wealth from the fact that the wealth, symbolized by the gold, was found in the depths of the earth belonging to his kingdom.

That the beauty in the tales very often is symbolized by gold, glitter, especially metallic brilliance, gives it additional qualities like perfect, undestructible, timeless, absolute and so that of transcendentality. Gold was considered practically, at all times and in all countries, a symbol of the sun, or at least, as closely related to the sun.

The journey to the sun and other planets, that in many tales is performed by the heroes, is a jouney to another world. The sun illuminates the things of the earth, but she remains celestial. The golden glitter that characterizes things and persons that are considered of special beauty in the fairy tales demonstrates that: *"beauty in the tales is a supreme value"* (Lüthi 1975).

Dealing with the fairy tales we should not forget that these fairytales transmit - in changed form - the figurative world of the myths. Behind the golden apples of the fairy tales we discover the apples of the Hesperides. Those apples Heracles had to bring from the end of the world. They carry the secret of the eternal youth and beauty, no wonder that those apples were extremely difficult to get. That a golden bird tells of another world, may remind us the myth of Zeus coming as a swan or as a golden rain to meet a human woman. Gold points at things that are supposed to exist outside of our known world, things that may come from a better, celestial, world or from the depths of the earth where friendly but also terrible creatures - dwarves and demons are the custodians.

The fairy tales are born from a violation of the borders of the world in which we live in all directions, the journey goes to the north, to the south, to heaven and to hell. The journey is always very dangerous, and the hero has always to pass tests. Such a journey is necessary because only behind the given material borders one can find salvation.

Like the argonauts starting their journey to find the golden fleece, so the hero of the fairy tale is obliged to start his journey. Incidentally, why is the fleece called golden? The owners of the fleece put the fleece in the quickly flowing waters of a river carrying in its sands fine gold particles. Those particles were captured by the oily wool so that it became with time golden. Who ever wants to get this golden fleece has to survive the perils of the journey alive - a nice tree is the place where the treasure is hidden, but a dragon is the guard.

8. Alchemistic dreams about transformation

From our childhood we all know the fairy tale of "Rumpelstiltkin". In this fairy tale the story of the poor doughter of a miller is told. She has to solve an insoluble problem - the problem is that she has to spin gold from straw. A tiny man appears offering help, but she has to promise him for his help that she will give him her first child. Only with an enormous effort can she free herself from this promise by finding out the very secret name of the tiny man. That fairy tale fundamentally refers to a very old dream of humanity, the dream to produce pure gold from much less valuable materials. For hundreds of years people wanted to transform worthless material like straw into gold.

To the motif of the hidden treasure of gold that can be found only with the help of the divining rod or with that of animals whose language one had previously to learn, the alchemistic transformation is added.

In some fairy tales elves and other transcendental beings give to a person insignificant gifts like pieces of coal, earth, straw or even dung as a present or for fun. The human that accepts these gifts and brings them home will be surprised to find them consisting of gold. In other fairy tales the hero is challenged to find the magic potion of long life. In the Chinese tale "The benevolent magician" (Wilhelm 1921) the magician's apprentice has to look carefully at the golden flame of an oven fired with herbs. He should not fear supernatural phenomena and not speak a single word, but he fails at the last moment and so loses the chance to become immortal.

Behind this motif there is the age-old desire of the alchemists to learn the art of gold-making often supported by observations made during metallurgical processes. The alchimists supposed that the very different substances found on earth are composed by a *"primordial element"* a *"materia prima"* that was also considered to be the matter used for the creation. By repeated heating and mixing of different substances the alchimists tried some way to produce in gold. On their way they found very different products, but no gold. Johan Kuncke produced in that way ruby glass, Johann Friedrich Böttger discovered how to make porcelain, Leonhard Thurneysser realized some basic rules of hygiene and could therefore give some advice how onto fight epidemics.

But there are reasons to suppose that behind the very materialistic desire to produce gold from much less valuable materials there was something else, namely the desire to transform the self, and to gain some esoteric knowledge. The motive of that was summarized in the sentence of the alchimists that *"aurum nostrum non est aurum vulgi"* i. e. *"our gold is not that of the mob"*. The production of the "noble gold" was a measure of high human morality and intellectual quality. Gold under this condition is a "philosophical substance" a "stone of the wise" and not at all comparable to other materials - it stands for another type of existence, another and much more valuable being will be formed in the alchemists laboratory.

In the old mythology the symbolic leader of the person in search of the "transcendental gold" was the god Hermes or Mercury. He typically accompanied the soul in its journey from the subterranean unconsciuous depths to the shining height of the spirit. The "lapis philosophorum" is the new way to exist, that once it is held cannot be lost at all.

The element quicksilver was considered, with its high mobility the materialization of the spirit of Mercury. Gold is the materialzation of the light of the sun, of God. Gold and quicksilver have a high affinity quickly forming amalgams. The spiritual transformation wanted by the alchimists was the combination of the matter with the spirit, a sort of "quadratura circuli" producing in this way a person with similarities to God.

Already at the time of the minnesang the burgrave of Rietenburg wrote:

"So I became like gold
that is tested in the fire".

This idea is found continually in the history of thought and demonstrates how the idea of the transformation in pure and tested gold is a familiar topos and symbol. In the "Handbüchlein" i. e. the "booklet" of Ringwald (1686) it is given:

"God will test you,
If you can, like pure gold,
Stand the fire".

9. Ambivalence of gold and luck

The history of mankind can be described as the history of gold, too. The search for happiness is often connected with the search of gold. Unfortunately the discovery of gold did not always bring happiness. The moodiness of luck is directly reflected by the ambivalent character of gold. Gold can carry happiness but also despair. As the Phyrgian king Midas got from the Gods the gift to transform all the things he touched into gold, he realized soon that all his food would be transformed into gold and he would die by starvation. Only a bath in the Lycian river Pactolus freed him from that originally so-much wanted gift. A myth tells that from this time on in the river Pactolus abundant gold is found.

In popular medicine gold is often used for medicinal properties. It was supposed to be a tonic; as an amulet it was considered an infallible protection against withcraft and magic. The carrier of a golden ring around the neck was reliably protected from the evil eye.

Hildegard von Bingen introduced gold, too, in her medical repertoire. She writes: *"Gold is warm and has something of the sun but also of the properties of the air. A person that is plagued by gout shoud boil gold for so longer time that nothing impure is adhereing anymore. Then he should pulverize the gold, take half a hand full of flour, knead the flour with water and add gold in the weight corresponding to an obolus. If this mixture is eaten in the early morning, and also the day after, gout will be chased away for a whole year. The gold will stay in the stomach for two months, produce no harm, purify and warm also the stomach in the case it gets cold".*

This shows again that gold was supposed to have astonishing properties. On the one side there is the terrific desire for gold, the careless fight to get more gold, the power based on gold *"gold and money rule the world"*, on the other side gold is the symbol for light and sun, for a happy and full life and it stays for the otherwordly heavenly things. From this latter aspect medieval icons stay on a background made of gold that symbolizes their heavenly life. If the ancient Greeks put a coin of gold on the tongue of their dead, then this was done in order to give to the dead somthing precious to pay Charon for the transportation on his ferryboat - gold was considered the fee - to the final entrance in "another world".

In his alchemistic lexicon the Master Ruland wrotes (1612): *"The ignoble gold is dead, but the philosophical is still alive and will nourish me in the future".*

The material gold was hidden as a gold ore for millions of years in the depths of the earth until the ores were mined, washed, treated and the extracted gold was finally cast into bars. Now those bars are again hidden in the safes and vaults of the banks and of wealthy private persons, and closely guarded.

The metaphorical gold on the contrary is omnipresent. One speaks of the golden section, of the golden rule; historians tell the story of the Golden Horde and the Golden Bull. On the fruit market golden apples appeal to us and the evening sun makes the horizon shine, gold. Still the ancient Romans had the proverb: *"aurora habet aurum in ore".*

In the fairy tale Goethe summarizes, in a wonderful short dialogue between a golden king and a snake, the high but, at the same time, only very low value of gold:

"From where do you come?"
"From the caverns where the gold dwells." replied the snake.
"What is more magnificent than gold?" asked the king.
"Light", anwered the snake.
"What is more refreshing than light?" he asked.
"Discourse" she answered.

Chapter 2

GOLD AND SOCIETY IN PREHISTORIC EUROPE

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ABSTRACT. Man discovered gold in the course of the fifth millenium B.C., a time when there was a new curiosity towards minerals and coloured stones, coinciding with the major technological step of the extraction of copper carbonates. In Europe this was especially developed in the metallurgical environment of the Balkans (Mohen and Eluère 1991). A fuller use of gold spread during the Copper Age, and developed and expanded during the Bronze Age, a time characterized by craft specialisation, a more defined sense of social class, as well as by long distance travel and trade, and strong religious beliefs. Later, during the Iron Age, gold would serve to enhance the power of princes, before a new age arose with the earliest coinages (Eluère 1987).

1. Gold in Europe

Gold in society may be linked to many questions:

- What about the specialisation of the prospectors or goldminers? How could some individuals acquire, however empirically, geological and metallurgical science, a technical knowledge?
- The same questions apply to the expertise of prehistoric goldsmiths and metallurgists? What was their social status in Ancient Europe? We know, for example, that some Celtic goldsmiths had probably travelled south of the Alps to learn some Mediterranean techniques (Eluère, 1989, 1994).
- What about the tradesmen who carried the raw material in regions like southern Scandinavia where there is an abundant production although gold sources were naturally scarcer or, in Denmark, absent?
- A general overview of prehistoric gold production in Europe shows that different cultural groups could support a large production of gold with numerous applciations.

Why did these European societies use so much gold?

- Europe had a lot of gold deposits that could be and were exploited at this time (Eluère, 1990, 60-67);
- This is not the best or only reason; more obviously, there was a social and religious need- two principal uses of gold have always been for the dead and for the gods.

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2. Social messages beyond death

Let us first, through some examples, show how gold items discovered in burials may particularly reflect the social rank or duties of some individuals, something also discernible through other high-status material. The gold items may have been worn during their life, or may have been gifts, or decorative pieces made specially for the funerals. Some symbols of power are obvious: sceptres, richly decorated weapons, symbolic jewels, precious vessels. The earliest examples of goldwork from the Chalcolithic cemetery of Varna (Bulgaria) (mid-fifth millenium B.C.) are impressive (catalogue: Varna 1989): not only ornaments but symbols of power are already pre-eminent at that time in chiefs' tombs- the gold decorated sceptre and bow in burial 43.

This feature is also to be found in central and western European groups between the middle and the end of the third millenium B.C.. At that time a new phenomenon appears in several cultures, with some warriors of high rank whose burials reflect a particularly high social status, e.g. the burial discovered at Mala Gruda with a golden dagger (Primas, in this volume). In countries like Czech Republic and Slovakia, or in Atlantic Europe, the earliest traces of gold appear in some individual burials, those of the so-called Bell-Beaker warriors, but more frequently in developed Early Bronze Age contexts. Among their wealth local chiefs possessed weapons decorated with gold; some also have vessels and ornaments of precious metals. Examples are numerous and widespread, but are especially concentrated in Brittany, in Southern England, in Saxony, as well as in Southern Spain and in Portugal (Clarke et al. 1985).

During the Middle and Late Bronze Age, the tradition of marking the power of heroic warriors intensified in some regions, such as the Mycenean world, and Nordic Europe but declined in others such as Britain. The symbolic items also involve luxury gold vessels as already seen long ago in Varna. At the same time, similar items are also used for votive offerings: gold daggers or axes, vessels.

With the early Iron Age, from the 6th century B.C. the use of gold is changing and becomes the private property of some chiefs, like Celtic princes, or rich Etruscan owners or merchants. With an accumulation of goldwork in their burials and the disappearance of religious treasures in some regions, a small number of individuals playing an important role in their district seem to have monopolized gold. Early Celtic gold collars are reserved for some princes buried under huge barrows from Austria, South Germany, to Burgundy. Drinking services with gold and silver vessels (cups and drinking horns) are also a typical part of the funerary material dedicated to chiefs in the European Iron Age. More prestigious items are introduced from the 4th century B.C. onwards: some rich Celtic helmets decorated with pure gold like that from Agris (Poitou), corresponding to a similar phenomen in Dacia and Thracia. The gold diadems and crowns, the most typical being the Hellenistic examples from Macedonia, Etruria, or South Italy, are of course evident symbols of power or, at least wealth. Gold as a symbol of wealth is obvious in some rich female burials, for example in Etruscan burials (Cristofani and Martelli 1983). Nevertheless some burials of Celtic women contain also the symbols of power: for example, the well known Vix Lady (in Burgundy) and the Reinheim Lady (in Saarland) (Eluère 1987, 1989).

3. Symbol of eternity, symbol of magic

Very closely connected to the feeling that gold was symbolic of power, an important social role of gold was of course that of guaranteeing and symbolising eternity. It too begins at Varna with gold hammered sheets on the eyes and mouths of clay masks representing the dead. Gold applied to the face or on certain parts of the body of the deceased appears among the very well-known burials at Mycenae (Late Bronze Age). Later, during the Early Iron Age, the same use of gold on the face, the hands and the feet existed not only in Greek countries but also in Illyria and with the Celts (the shoes of the prince from Hochdorf were covered with gold sheets).

A series of pendants of schematic female form was produced in beaten gold across a wide area, from Anatolia to Slovakia. Already used in the cementary of Varna, these pendants are found both in shrines and around the neck of some individuals; their use seems to have been traditional over a long time. Their dating extends from the fifth to the third millenium B.C., the most recent being found around Lake Balaton. Some gold artifacts mirror religious symbols known elsewhere, such as in the bull cult or the sun cult. During the Bronze Age, between the early second and the early first millenium B.C. gold was be most often dedicated in religious offerings. A large number have been discovered in Central and Atlantic Europe. Some of these offerings, like discs or vessels, can be related to a probable sun cult.

Hoards of jewels are more problematic: are they votive or may they also have had an economic role? The most impressive in the West are some heavy jewel hoards; in particular, in the Iberian peninsula some collars may contain more than 1kg of metal. These pieces were intentionally buried or thrown in bogs.

During the last centuries B.C. gold was again used for offerings. Treasures of gold torcs of neckrings, sometimes associated with early coins, are found throughout Europe. Also we think that some isolated finds of large gold torcs might have adorned some wooden statues of gods. Lastly hoards with only a mass of gold coins may be the latest descendant of the prehistoric rites.

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Chapter 2

THE MONETARY ASPECT OF GOLD FROM PREHISTORIC TO MODERN TIMES

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ABSTRACT. Gold was in all times and by everybody very high priced. It was used therefore very early in the history of humanity as an exchange medium and as money to pay for goods and services. The present paper gives a condensed history of gold as coinage metal as well as selected prices and wages from Roman to modern times. A critical evaluation of the data shows that a consistent picture of the purchasing power of gold over the centuries is very difficult if not impossible.

1. Introduction

In a letter to the Catholic monarchs Ferdinand and Isabella of Spain Christopher Columbus wrote:

"Gold is excellent above all; from gold comes great wealth, and whoever it possesses can do in the world anything that he wishes... ".

Even if the fleets subsequently arriving at the harbour of Seville carrying the gold and silver treasures of Peru and Mexico did not, as prophesied, bring lasting wealth and power to the Spanish kingdom, they and the later Portuguese precious metal imports from Brazil were nevertheless decisive in shaping the development of the monetary economy and financial and commercial structure of the European states. With the unprecedented but successful voyages of discovery, the economic centre of gravity first shifted westward from the Mediterranean area and the Upper Italian cities (Florence, Genoa, Venice) to the Iberian peninsula and then moved northward to the Netherlands, and later to England.

2. Prices and wages, the value of gold

It is very difficult to determine the purchasing power of gold since no information on prices and wages exists. Steady high or low prices were on the one hand the result of supply and demand but on the other hand depend much more than nowadays on agricultural success or failure, technical development and the political constellation. Losses from crop failure, cattle disease, natural phenomenom and war could be the reasons for changes. As a result the price data preserved from earlier periods can only reflect terms at the moments specified and permit no conclusions at all to be drawn about conditions shortly before or after the years in question. The situation is similar with regard to information on wages. It can be seen that even the figures for one and the same time can vary considerable. Wages and prices are normally snapshots which can only tell something about conditions in a given place at a given time. Information on the economic and social situation in a larger region can only be gained

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from the analysis of a large number of facts. But for earlier times these are, as a rule, unavailable. It is nearly impossible to determine for instance the value of the gold in the ancient world or in middle Ages in present-day terms. The economic and social changes which, have taken place are so profound that not even an approximately correct figure can be calculated.

At least the value of gold depends on stock, availability respectively shortness of this material. The German poet Goethe expressed his view in verse: *"To gold it tends, on gold depend, all things"* (Faust I, 2802 ff.).

Nevertheless, several examples shall demonstrate the value of goods and earnings at a price of money respectively gold.

3. Ancient Mediterranean world

Any object can become "money" which serves as a generally accepted medium of exchange in a particular trading area, thereby assuming - if only temporarily - the properties of money. In other words, the coin is by no means the only form in which money appears. On the other hand, however, in its primary function as a circulating medium, the coin is always "money". This was invariably the case in the ancient Mediterranean world. Thus, its concept of money differs to some extent from that of the modern world; through the centuries, the concept of money, has, of course, continued to evolve. In the ancient Mediterranean world, a long process of development led from "money" to the coin of gold as a specific form. Many different stages and varieties of monetary forms were developed, utilised and finally discarded before the process came to a temporary end with the emergence of the coin. The various forms of money which preceded the coin did not come into use according to any set pattern. Older and newer forms was always a possibility. Nevertheless, one thing seems certain: the various types of natural money for instance foodstuffs such as salt, or livestock such as cattle and sheep, are, generally speaking, older standards of value than metallic money in any form. Metallic money has great advantages over the natural forms: it is not subject to the vicissitudes of nature; transport is relatively uncomplicated; sizeable assets can be stored in a small space, carried on one's person and, if necessary, hidden. Metallic money appears in a number of forms, e.g. jewellery, which is, and always has been, a thing of value. Good tools and weapons were always items of value. The same is true of metal vessels. Money in the form of metallic implements is obviously very durable; it is also something which many people need and use. This, too, is a necessary prerequisite for the widespread use of a particular kind of money. Metal as such - gold, silver, copper, iron - is perhaps even more suitable as a standard of value than finished goods. It can be hoarded, easily weighted and divided, and processed as desired. It can be cast into bars. A piece can be cut off as required, and one can exchange - pay with it - even the smallest remaining piece for other goods. Here, of course, one thing is absolutely necessary: the metal must be pure; if alloys are involved, their composition must meet the customary or established standards. Therefore, it is not surprising that marks had already begun to appear on bars in prehistoric times. Those were undoubtedly the marks of individual workshops, intended to guarantee the purity of the metal; but they may very well have been the marks of individual owners, as there was a great variety of forms. In the mid-eighth century, BC an Aramean king in the Middle East had his mark placed on his silver bullion, thereby guaranteeing the purity of the metal in recognisable form, Such authorities begin to set and guarantee its weight, what we have is the coin or "money" in coin-form. The ancient Mediterranean world used only metallic currency.

To be sure, the coin's subsequent development continued to reflect its evolution from bars of precious metal. The value of ancient gold coins was determined by the weight and the type of metal involved. The system of weights was always established by the policy, which assigned to it a fundamental importance, based on and supported by the authority of wise and venerable laws. Therefore, it was necessary for coins to conform to the weight standards of the coining authority concerned or those of a particular trading area. Coins were circulated on the basis of their real value. The historical roots of the ancient coin remained visible in still another respect. The coin always retained the latent character of money in bullion form. This has greater implications than one might think. Coins immediately reverted to a form of bullions whenever more sophisticated economic and financial structures, for whatever reason, entered periods of crisis or turmoil. At such times, scales once again became indispensable for monetary transactions; the gold metal was cut up and weighed, even if it was in coin form. If necessary, coins were halved and quartered in order to obtain small change at least from Roman times onwards. This explains the abundance of half-coins found in the military camps of the early Roman Empire in the Rhineland. But coins were also cut up and weighed during periods in which the system of nominal values could no longer be relied upon. In the years AD 260-270, the most severe period of crisis in imperial Rome, the distinctions in value between the individual gold coins became so blurred that there is a cut coin from this period for nearly every conceivable decigram unit of weight. It was no longer possible to make a clear-cut distinction between a whole and a half piece; cash assets could no longer be counted, they had to be weighed. Thus, during periods of financial crisis, the minted coin could, for a time, once again become a form of bullion. The "monetary" properties of the coin had still other consequences. Once a standard of value had been established, it was initially valid in a particular trading area at a particular time. In other words, the metal of coinage could vary, depending upon a number of factors; the particular region and historical period involved established tradition or the customs of the market-place. This principle applied to all parts of the ancient world.

Gold was not particularly important for coinage in an area, for example, where the standard of value was based on copper or silver, for instance many Greek cities preferred to employ silver as their metal of coinage.

While the Greeks in Asia Minor and the motherland were astute traders, they were also very dependent on commerce. The use of coins enabled ships' captains and caravaneers to carry sizeable assets in a minimum amount of space. They not only utilised the maritime trade routes but the Greeks of Asia Minor, as well as the Lydians, also took advantage of the added opportunities afforded by the territorial expanse of the Persian Empire with its well-developed system of overland trade routes, extending far into Central Asia and the Middle East. It is not surprising that the gold coin first emerged in the Lydian-Ionian region in the seventh century BC (as a mixture of gold and silver, called: electrum).

One has to admire the flexibility with which Greek polities were able to adjust and readjust to new economic opportunities. The so-called Solonic coinage reform in Athens introduced a new system of coinage, weights and measures. The reform measures were clearly designed to facilitate the exchangeability of coinage not only in the immediate area, but also in more distant regions, such as Southern Italy and Sicily. As an outgrowth of this overall pattern of development, it was quite logical that, relatively early on, two or more metals of coinage came to be employed simultaneously. In the years after 561 BC, King Croesus implemented a coinage reform; the relation of gold to silver coinage was 1 : 13. He had coins struck in gold and silver as separate issues, instead of minting electrum coinage as had been the customary practice hitherto. Here, for the first time, gold emerged as a metal of coinage in its own right. Smaller denominations of the golden Croesus staters - Croesioi - half and one-third pieces, were struck as well. It is still not clear why two parallel systems of weight were employed simultaneously, with heavy staters and light staters, weighing approximately 10.8 g and 8.1 g, respectively. Copper and/or bronze also came into use in some places during the fifth century BC. Historically, the trimetallic systems of coinage were the last to evolve; as in the late Roman Empire, they employed gold, silver and copper alloys (brass and bronze) simultaneously. Under Philip II of Macedon (359-336 B.C.), gold production increased considerably; as a result, the ratio of gold to silver dropped to 1 : 10. Athens itself issued gold coins only as an emergency measure in the years following 407/406 BC, toward the end of the fateful Peloponnesian War. In order to finance a last, desperate purchase of arms, the Athenians removed the golden statue of Nike from the Acropolis and brought her to the mint, where she was melted down for coinage. The Philip stater, and even more so, the stater of Alexander, were popular and widely circulated far beyond the borders of the Greek territories. They formed the basis for the various tribal issues in gold on the northern fringes of the Mediterranean coastal regions; these issues have been classified generally as "Celtic coinage", although the term is not, strictly speaking, accurate in all cases. These highly individual issues are a classic example of the phenomenon of the temporary orientation of local coinages to certain Greek and Roman money zones based on gold and silver. Before the tribes developed their own coin types, they copied those of the Greek and Roman coins, which were prevalent in their trading areas: the Philip stater at first in the west; and in the east, the stater of Alexander, in addition to silver coins. To cite just one example: a striking change took place in Gaul when the Romans in the south established their first Gallic province - Gallia Transalpina (later known as Narbonensis) - in the last quarter of the second century BC. The gold currency of the tribes which inhabited the area was suppressed and subsequently fell into disuse; the tribes who cooperated with Rome modelled their issues on the denarius, the silver currency of Rome.

Rome arrived at a brilliant solution to its primary problem in the area of monetary policy: the city sought to become the dominant power in the Greek regions of the east, and thus had to find an advantageous means of adapting its currency to the financial conditions of that area. The denarius, the silver currency of Rome, was cleverly integrated into the coinages of the eastern Mediterranean area. This area utilised the Attic, Rhodian and Cistophoric standards.

Gold coins were issued only in exceptional cases, and only outside of Rome, namely, whenever the Roman generals (imperators) waged war in areas in which e.g. the Alexander stater was in circulation. The extensive gold issues of Julius Caesar, as well, were based on this right of coinage exercised by the Roman imperator. These issues were characteristic of the fundamental transformation which took shape during the final decades of the Republic, when Rome had already gained control over the entire Mediterranean area; for, as of roughly the mid-first century BC, Roman currency became trimetallic: gold, silver, and copper alloys were employed simultaneously. All denominations - including the aureus were struck according to need. The aureus - actually the denarius aureus, the gold denarius was issued over a remarkably long period, while it did not appear until approximately one-and-a-half centuries after the silver denarius, the main Roman denomination introduced around 211 BC, the aureus was in circulation from roughly the midfirst-century BC until the late third century AD. The fluctuations in weight of Roman gold were not significant; the fineness of the metal remained consistently high. During Caesar's reign, the aureus weighed 1/40 of a Roman pound, or roughly 8.19 g; its weight ended to decline slightly in subsequent years. Nero fixed the aureus at 1/45 of a pound, or about 7.28 g, a weight which remained in force for nearly 120 years. The gold-silver ratio ranged from approximately 1 : 12 to 1 : 12.5.

Gold coins practically reverted to bullion during the crisis of the mid-third century AD. Roman gold coinage remained unstable until the reforms of Diocletian and Constantine around 300 AD. After a number of fluctuations, the aureus of Diocletian was fixed at 1/60 of a Roman pound, i.e. ca. 5.5 g. As a result of Constantine's reforms, a new gold coin was introduced whose weight was set at 1/72 of a Roman pound, or 4.5 g. The old aureus was no longer struck, and the new coin most certainly proved worthy of its name: (aureus) "solidus" = stable.

From that time on, this last gold coin of antiquity remained in circulation for some 1000 years in Byzantium, during which time its fineness (980/1000) and weight (4.5 g) did not change. In the course of time, silver lost its earlier significance as a metal of coinage. In the fourth century, the ratio of gold to silver was probably about 1 : 13.9; and later, perhaps 1 : 14,4. Tab. 1 gives with the aid of prices of selected commodities an idea of the wages and prices in the fifth century in Greece and during the Roman Empire (Anonymous, 1975,1980).

Table 1. Wages and prices in the fifth century in Greece and during the Roman Empire and gold equivalent in grams; 1 stater contains between 8.2 and 8.6 g of gold.

Greece 5th century BC				Au (in grams)
wages				
	- annual salary of a leading architect	175	staters	1505-1435
	- for the design of a statue received a sculptor	30	staters	258 - 246
	- a good craftsman got for one days effort	1/2	stater	4.3 - 4.1
	- an unskilled worker got for one days effort	1/6	stater	1.4 - 1.3
costs				
	- minimum subsistence level of a family (1 slave daily)	1/12	stater	0.7 - 0.6
	- visit of the theater	1/6	stater	1.4 - 1.3
	- a bull	2.5	staters	21.5 - 20.5
Roman Empire				
wages				
4 AC:	Daily earnings of a roman legionary	1/25	aureus	0.32 *
200 AC:	Daily earnings of a roman legionary	3/25	aureus	0.87 **
301 AC:	Wage of a farm laborer inclusive board per month	4/5	aureus	3.88 - 4.36 ***
	Wage of a craftsman per month	1 3/5	aureus	7.78 - 8.74 ***
costs				
301 AC:	One roman pound of meat	11/25	aureus	2.09 - 2.31 ***
	One unit of wheat	4/25	aureus	0.76 - 0.84 ***
	One pint of whine	3/5	aureus	2.92 - 3.28 ***
	One pint of beer	4/25	aureus	0.76 - 0.84 ***
	One pair of sandals	4	aurei	19.44 - 21.84 ***
	One roman pound of purple silk	600	aurei	2916 - 3276 ***

Time dependent weight of the aureus: *: 8.19 g Au: 27 BC - 14 AD; **: 7.28 g Au: 200 AD; ***:4.86 g Au: 300 AD

4. Middle Ages

In 1426 Conrad of Weinsberg (1426), hereditary chancellor of the German Empire, commented, in an exhaustive memorandum on the improvement of the currency in Germany as follows:

"nota bene, that the traveller needing to maintain himself always should have gold".

This was meant literally, since gold coinage had come to be accepted universally, and unlike the small silver coinages, whose currency was merely local, did not have to be constantly exchanged. Weinsberg's shrewd observation, however, was not valid everywhere in the Old World at the same time. On the contrary, gold was of very varied significance as a coinage metal at different places and times. While in some countries gold coinage dominated the exchanges for centuries, in others it did not exist at all. In the course of a few centuries, changing economic and political conditions reversed this relationship almost completely. From the Carolingian period in the Christian European States north of the Alps a pure silver currency was dominant, with a single monetary unit, the denar or penny; the solidus was solely a unit of account of twelve pence or in some areas (for instance Bavaria/Germany) of 30 pence. The gold coinages of the Mediterranean countries were of course known and named after their origins "bezant" or "mancus" - which in Arabic signified struck coinage - and were valued at 30 or 40 pence. They were imported as gifts through diplomatic relations, such as existed with Byzantium as early as the time of Charlemagne; likewise as loot, for instance from the Avar campaigns of the end of the eighth century and later through the crusaders. The sale of slaves to the Arabs also presumably brought in gold. But gold coins evidently were not used in monetary exchanges. Even this metal was not required for trade, the sumptuous product nevertheless found other uses, as we see from cult objects (for instance the great reliquaries), royal insignia and jewellery. The situation in those European countries bordering the Mediterranean which stood in direct contact with Byzantium and the Islamic countries was completely different. In Italy, gold coinage had never ceased: the Lombards and the Byzantine emperors had produced coinage in their possessions in the southern half of the peninsula, and the Arabs in Sicily. In these regions, the Normans continued the issue of gold coins of Arabic type, striking the $^{1}/_{4}$-dinar, or tari. In the thirteenth century, the monetary relations between the Islamic world and Europe began to change. There was already in the twelfth century an increasing outflow of silver from Europe to North Africa and the Levant, on the one hand because of the higher price of silver in these areas and the profits to be had from this, and on the other in connection with the crusades and subsidies to crusader states. In the other direction, gold came to Europe especially from West Africa, mainly through Genoese merchants, which together with the discovery of European deposits led to the beginning of a "period of gold".

The city-states of Genoa and Florence issued their own gold coinage for the first time in 1252, and Venice followed in 1284. This marked the beginning of a new phase of European coinage. The timing was surely also influenced by the death of the Staufer Emperor Frederick II in 1250, since gold coinage had since ancient times been an imperial prerogative and therefore no one dared to begin to strike gold coins during the emperor's lifetime.

The progenitor of many European gold coins was the fiorino d'oro or florenus aureus of Florence. It represented the value of the pound of account there (libra) and thus the amount of silver that was contained in 240 Florentine pence. The intermediate stage was the shilling (soldo), worth 12 pence; twenty shillings worth one florin. It was struck in Florence as the fiorino d'argento. The gold coins thus weighed 3.53 g and were struck from gold which was as pure as could be made. The florin was apparently produced in large numbers from the outset: annual outputs of 350,000 - 400,000 pieces are recorded from the fourteenth century. It engendered a series of further gold coinages, at first in Italy, of which the most important was that of Venice, which was worth the same as the florin. Under the term ducat, it became one of the most popular gold coins ever. Three quarters of a century passed before these Italian developments reached Central Europe. Here, besides trade, the Church played a significant role, since it sought to receive the church tithes in gold, which was easier to transport. But in Salzburg, for instance, this brought in only eight florins in 1283, and in 1318 the Papal tax-collector had to transport the silver he obtained to Venice in order to exchange it into gold.

While the florin circulated in the north, the Venetian ducat followed the trade of the Adriatic metropolis in the eastern Mediterranean, where it not only became the dominant means of exchange but was also extensively imitated. It is known in the literature as the Eurodollar of the Near East in the fourteenth and fifteenth centuries, in succession to the Byzantine solidus and the Islamic dinar. For a time Venice sent about 300,000 ducats or about 1000 kg of gold to the Levant every year alongside of rulers, which acquired its raw materials exclusively from commerce, there was a second, which had gold mines of its own. To this belonged Hungary, which had the largest gold deposits in Europe and which took up florin production in 1325, followed by Bohemia. Salzburg and Austria coined Alpine gold and the Silesian deposits were exploited from 1345 by the dukes of Liegnitz und Schweidnitz. In Germany the gold coinage encountered a monetary system which was still heavily dependent on the penny. Here, as in Italy, intermediate pieces were introduced in silver shortly before or simultaneously with the gold. These were the groats (Groschen), which represented the accounting unit of the shilling (= 12 pennies).

A temporary shift in the gold-silver ratio in favour of gold from 1 : 14 at the beginning of the fourteenth century to over 20 after 1320 brought considerable gains for the gold coinage of the mining states, but made coining more difficult for the others, who were unable to begin about twenty years later, when the relationship had settled down again at around 1 : 11 to 1 : 12.

The Gulden (the golden penny) was declared to be the principal trading coin in Germany. While in 1400 it stood at a weight of 3.54 g and a fineness of 22.5 carats or 937/1000, by 1490 it had sunk to 3.34 g and 18.6 carats or 770/1000, by today's standards a modest decline. The Gulden issued did not always achieve the prescribed standard, but frequently remained below it, partly due to insufficient technical expertise and on other occasions as a result of fraudulent manipulations by mintmasters seeking to maximise the profits conceded to them. The lowering of the fineness resulted from the universal view that the coinage should yield a profit, which was only possible if the purchase price of gold (primarily in the form of foreign coin) and the cost of manufacture were balanced by reducing the gold content of the coinage. Only the owners of gold mines were in a better position, since they could themselves set the price of the metal. Towards the end of the fifteenth century the number of authorities striking gold coinage increased, above all in the German Empire, but for most of these the need for display was the prime motive, since their issues were often so small as to have no economic significance. At least a coinage system with gold at the top of the scale had evolved in Europe by the end of the Middle Ages; it originated in Italy, and largely superseded a barter economy, bringing with it the beginnings of a banking system. After the discovery of the New World precious metal supplies from the discovered countries influenced the economic and financial structure of Europe.

Tab. 2 gives an idea of the wages and prices in medieval Europe (Anonymous 1975, 1982).

Table 2. Wages and prices in Europe around 1400 AC (1 Gulden = 240 pennies) and gold equivalent (in grams).

				Au (in grams)
wages				
	- daily earnings of a bricklayer (summer time)	40	pennies	0.56
	- daily earnings of a bricklayer (winter time)	32	pennies	0.45
	- daily earnings of a unskilled worker (summer time)	22	pennies	0.31
	- daily earnings of a unskilled worker (winter time)	18	pennies	0.25
	- settlement of a meeting for a town-councillor	18	pennies	0.25
	- daily charges of a town-councillor for an official journey	60	pennies	0.84
	- amount of costs of one bread	1 - 2	pennies	0.01 - 0.03
costs				
	- One fish	1	penny	0.01
	- One pound of butter	2	pennies	0.03
	- One pound of roast beef	4	pennies	0.06
	- One ham	5	pennies	0.07
	- One cow	960	pennies	13.35

5. Modern times

Impressive though the quantity of gold which flowed into Europe may have been, in the context of the various national monetary systems it was only of secondary importance. As in the Middle Ages, it was silver - of which many territories had their own supplies - that provided the real basis of the currency. Until the beginning of the 19 th century, when many countries went over to the gold standard, coins made of gold were used mainly for two reasons: firstly as a medium of exchange in international relations of the most diverse kinds, and secondly - as mentioned just before - to satisfy the rulers' desire to project a prestigious image by the issue of large and magnificent coins.

In Germany the coinage of Goldgulden continued far into the 17th century. In some cases Goldgulden and ducats were issued simultaneously, while in others the ducat superseded the Goldgulden, as in the cities of Frankfurt and Magdeburg, in Austria, Hungary and the Northern Netherlands.

The Augsburg Imperial Coinage Decree of 1559 declared the ducat to be the imperial gold coin and laid down the conditions for its issue as follows: 67 pieces were to be struck from the Cologne mark of 233.856 g and the fineness was to be 23 carats 8 grains. This meant a nominal weight of 3.49 g and a fine weight of 3.44 g. "Ducat gold" became established as a term for the fineness of 23 carats 8 grains or 986.111/1000.

With two gold types of differing fineness, dealings in everyday monetary circulation were certainly not easy, especially since values were not shown on the coins. Nevertheless, the ducat was worth 104 Kreuzers, whereas the Goldgulden was officially rated at 72 Kreuzers.

In Venice the ducat was struck until the end of the Republic in 1797 with an unaltered design (the Doge kneeling before St. Mark, and Christ standing), from 1526 with a gross weight slightly reduced to 3.494 g. The ducat was frequently also called zecchino, from the Italian word zecca (mint). Many of the larger and smaller Italian states aligned themselves to this coin and struck this type with their own designs, which were thus able to hold their own as trading coins in Germany as well during the early modern period. The numerous multiples were conspicuous: in Venice these attained their highest value in coins of 100 zecchini, with a weight around 350 g, struck under the last Doges in the second half of the 18th century.

The rich imports of gold from West Africa and its trade with overseas territories helped Portugal to economic prosperity in the second half of the 15th century, and this is reflected in the coinage as well. The first issue of the large 23 $^3/_4$ - carat gold pieces called Portugues in 1499 coincided with Vasco da Gama's homecoming from his voyage of discovery to India. This gold coin was worth ten cruzados, which were likewise gold. Reduced in weight to 35 g, it was comparable to ten ducats, and the cruzado to one ducat. The Portugues also reached other countries in the course of trade.

In Brussels, during his journey to the Netherlands in 1520/21, the painter Albrecht Dürer received two of these pieces, amongst other gold coins, which he described as "large Portuguese Gulden". As well as the single, there were double, half- and quarter-Portugalöser, worth 20, 5 and 2.5 ducats respectively. However, they were not so much intended for monetary circulation, but rather as gifts. A massive drain of gold out of the country, which had various causes, forced the Portuguese king John to a coinage reform. The high-purity coins left the kingdom and were replaced by a flood of foreign gold coins of lesser value. In addition there was, for example, the cost of maintaining the Queen mother and of two dowries (John's sister Isabella became the Emperor Charles Vth's wife, and his eldest daughter married the later King Philip II), which are said to have amounted to 1 400 000 cruzados; as well as the Emperor Charles Vth's later attempt, prompted by the lack of money occasioned by his permanent wars, to get his hands on as much Portuguese gold as possible from his brother-in-law.

The principal gold coin in France was the écu d'or, already struck during the Middle Ages. From 1519 the fineness of the écu remained constant at 23 carats, while the number of pieces to be struck from a Paris or Troyes mark (244.753 g) was increased in 1575 from 71 $^1/_6$ to 72.5, meaning a slight reduction in the nominal weight to 3.38 g. In contrast to this, the value of the coin was constantly raised, as a result of the increases in the price of gold. While in 1519 it was still set at 40 sols (sous), in 1640 it amounted to 5 livres 4 sols tournois (104 sols tournois), i.e. it had more than doubled. At first the gold came via Portugal from the Sudan and Ethiopia, and after the Spanish conquests from the American territories. The escudo created in 1537 became the standard gold unit in Spain. King Philip II, son and successor of the Emperor Charles V, introduced the double escudo or doblon and the fourfold escudo in 1566. The eightfold multiple, the onza or quadrupla, with which Philip III enlarged the series in 1614, was coined particularly frequently in the Spanish-American colonies. Its weight of about 27 g reflected the vast gold wealth of the New World. The double escudo in particular influenced the monetary system of the European countries in the 17th and 18th centuries. It was imitated from the island of Malta in the south to Norway in the north.

France played a decisive part in this wide dissemination, by introducing the Louis d'or. The fineness of 22 carats, laid down by law, was as a rule not achieved. A year later a silver coin was created, also to the Spanish standard: the écu d'argent, which corresponded to the German Taler.

In 1663 in England the guinea was introduced as the principal gold coin, taking its name from the country of origin (Guinea) of the gold chiefly used at first. In 1816, when gold standard was introduced in England, a new sovereign replaced the guinea. The guinea, calculated as 21 shillings, survived until our days for the settlement of fines in English courts.

Foreign gold streamed into the territories not only through trade and commerce, but also in the wars, as soldiers' wages and in the form of subsidies. Political and religious connections, dynastic entanglements and personal relations promoted the influx and distribution of foreign types, which circulated to a greater or lesser extent alongside a country's own issues. Since the value of a coin depended on its fineness as well as its weight, regular examinations whose results were published, were required for all circulating coins (domestic and foreign). These so-called valuation tables or coin tariffs, which fixed the value of foreign coins in the local currency, first appeared in printed, placard form in the Netherlands at the end of the 15th century. They were the forerunners of the exchange list. A last great tariffing of all domestic and foreign gold and silver coins in circulation took place for the German Empire during the Imperial Diet at Regensburg in 1737-1738. The gold : silver ratio was set at 1 : 15.10, and the ducat of four Gulden placed on a par with two Reichstalers, each of two Gulden. For example, according to the report, which runs to many pages, a royal Spanish quadrupla had an actual fineness of 21 carats 7 grains and from this value of 28 Gulden 45 Kreuzers; a Louis d'or was 21 carats 10 grains (22 carats was prescribed by law) and was tariffed at 7 Gulden 3 Kreuzers.

For merchants, who needed good knowledge of the circulating money for their business, books appeared from the end of the 16th century, some of them voluminous. In these the authors listed the coins available to them with their appearance and details of value.

Tab. 3 gives an idea of the wages and prices in Germany in the seventeenth century and in 1900 (Anonymous 1975, 1985).

In the nineteenth century new rich gold mines in various parts of the world led to an alteration in the basic of the currency in many countries. Silver was replaced by gold as the standard currency metal. For example, England officially went over to the gold standard in 1816: as a sign of this change-over, the sovereign suspended the guinea. In addition, there was during the century a gradual transformation of the systems of nations in Europe, for instance in Italy, Belgium, the Netherlands and the north Balkans. Germany established after the German-French war 1870/71 the gold standard (1914 annulment).

The twentieth century rotated once more the monetary system all over in Europe. Paper money and coins of "inferior quality" displaced "gold" money. The national banks/govervements used their gold stock to accumulate reserves in support of stabilization of currency.

From 1934 up to 1967 the price of gold was fixed at 35 US $. After the suspension of the price control in 1967 violent fluctuations in the market during the 1970s and 1980s happened. Those fluctuations produced the vertiginous height in gold price around 1980. The exceptional price in 1980 and all the fluctuations resulted from the ebb and flow of sentiments on the part of the officials, as well as private sector holders of gold. Those changes derived from a combination of economic and political developments, which often overwhelmed the fundamentals of gold as a commodity (Anonymous 1987a, 1993; Murray et al. 1993).

Table 3. Wages and prices in Germany in the 17th Century and in 1900 and equivalent in gold (in grams) (1 ducat = 104 Kreuzer; 1 Goldgulden = 72 Kreuzer; 1 Taler = 72 Kreuzer).

17th Century				Au (in grams)
wages				
	- annual salary of a cook	720	Kreuzer	24.19
	- annual salary of a town-councillor	86400	Kreuzer	2903.04
	- annual salary of a juryman	108000	Kreuzer	3628.88
costs				
	- 1 pound of roast beef	6	Kreuzer	0.20
	- 1 pound of butter	7	Kreuzer	0.24
	- 1 chicken	8	Kreuzer	0.27
	- 1 goose	32	Kreuzer	1.07
	- 1 pound of laces	15	Kreuzer	0.50
	- One jacket	20	Kreuzer	0.67
	- One pair of ladies' shoes	68	Kreuzer	2.28
	- Annual fee for the high school	144	Kreuzer	4.84
1900				
Wages				
	- Monthly salary of a dock labourer	61	Mark	21.84
	- Monthly salary of a chemistry labourer	120	Mark	42.96
	- 1 kilogramm of roast beef	1.50	Mark	0.54
	- 1 kilogramm of horse meat	0.50	Mark	0.18
	- 1 kilogramm of butter	1.86	Mark	0.67
	- 1 litre milk	0.20	Mark	0.07
	- 1 kilogramm of sugar	0.65	Mark	0.23
	- 1 kilogramm of coffee	4.15	Mark	1.49
	- 1 litre of beer	0.24	Mark	0.08
	- 1 hundredweight potatoes	2.63	Mark	0.94
	- 1 hundredweight coal	1.20	Mark	0.43
	- 1 chair	3.75	Mark	1.34
	- 1 table	8.75	Mark	3.13
	- 1 gentleman's suit	10 - 75	Mark	3.58 - 26.85
	- 1 jersey	1 - 6	Mark	0.36 - 2.15

The past few years have now seen an erosion of the fears that led many investors to gold in the 1970s and 1980s. The end of the cold war was probably the most important development in this regard. Similarly, inflation, a phenomenon hardly experienced during the working lives of many of the traders in the worlds financial centres, is widely regarded as a past.

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Chapter 2

FROM GIFT TO COMMODITY:
The changing meaning of precious metals in the later Prehistory of the Iberian Peninsula

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ABSTRACT. Recently Sherratt and Sherrat (1991) made the point that precious metals used as a standard of value, played a key role in inter-regional exchanges well before their first use as a coinage metal. This agrees with the "social storage" model elegantly developed by Halstead and O'Shea (1982, 1989). After these authors, food surpluses from good years were exchanged for non-perishable items that could be transformed again for food in bad years. This allowed the stabilization of the economic system but, at the same time, it created the basis for social differentiation.
This paper applies such ideas, as well as Goody's (1973, 1976, 1982, 1984, 1990) ones on agricultural technology and marriage and inheritance systems, to four different case studies from the Beaker Age/Bronze Age transition to the Second Iron Age/Eve of the Roman Conquest of Hispania: The Caldas de Reyes and Villena treasures; the massive Late Bronze Age gold neck rings and the pre-Roman northwestern torques. All of them share some common points: their use of precious metals as a symbol of prestige and power, but also as a mean of accumulation. Nevertheless, each case is different and should be understood in relation to the economic background of the societies who displayed and accumulated them.

1. Introduction

In the 1980's, Halstead and O'Shea formulated an elegant model on the origin of differences in rank. According to this, in areas with marked interannual variability in agricultural production various mechanisms for dealing with scarcity would have been developed. This strategy would have been particularly vital amongst the peasant populations of semi-arid regions, such as the Mediterranean basin. A very efficient way of tackling this problem would be what the authors call "social storage", i.e. converting the surpluses of years of good harvests into non-perishable items of social value, capable of being re-converted into food in bad years. Of course, in normal years, food and items of social value would have circulated in different spheres of exchange and would not have been interchangeable. But in bad years equivalences would have been established to enable the exchange of prestige items for food. Both the planning required to obtain surpluses, and, more particularly, exchange them through a social network, would have required a complex organization, leading in turn to centralization, redistribution, accumulation of wealth, and social inequality (Halstead 1981, O' Shea 1981, Halstead and O'Shea 1982, 1989). This idea is implicit in Briard's interpretation (1987) of the Breton socketed axes as currency, and explicit in the Sherratts' study (1991: 360) of trade in the Aegean during the Bronze Age. These authors show how the capacity of precious metal to become a reserve of value susceptible to storage and exchange by weight was recognized in the Aegean world long before its appreciation as a precise standard of value.

However, the interpretation of precious metal as a reserve of value implies, as has been shown, a complex organization which must have rested on an efficient farming technology enabling the long-term planning of surpluses. Therefore, one should bear in mind the ideas of Goody (1973, 1976, 1984, 1990) on the relationship between farming technology and property, lineage, marriage and inheritance systems. This author has shown how, in primitive agricultural systems based on hoe farming, population densities are low and social distinctions based on the size or productivity of the plot of land cultivated are minimal. In these systems bridewealth and unilateral lineage, generally agnatic predominate, since most of the labour is provided by wife and children. The woman does not transmit property, which remains within the clan or lineage. In contrast, in complex agricultural systems, with plough or irrigation, the labour required, which is far less, is mainly male, plots of land are larger, population density is higher, and the pressure on cultivable land and differences in wealth increase. These systems are characterised by endogamy and marriage with dowry that facilitates homogamous and hypergamous alliances, by the concentration of wealth into a few hands and by its transmission within the family. Then bilateral systems predominate, in which the woman transmits property.

Goody (1986, 1990), maintains that institutions based on the transmission of wealth and parental status to children regardless of sex, existed in prehistoric Europe after the emergence of an advanced agriculture in Eurasia during the Bronze Age, where the plough or irrigation replaced shifting agriculture. This would have been maintained, until the triumph of Christianity in the 4th century A.D., when the dominant systems of amassing and transmitting wealth within the family began to conflict with the interests of the Church as landowner.

In applying these ideas to the present case studies, it should be pointed out that the reliability of prehistoric weight systems is limited and generally presents some degree of deviation from a standard value. Besides this, one has to face other problems due to post-depositional factors (see Kruse 1988). Despite this, in the following it will be shown that four case studies display both a social appreciation of precious metal and the accumulation of reconvertible wealth, and can be interpreted within the context of the societies that produced and manipulated them.

2. Case study 1: Caldas de Reyes

In Fig. 1 the location of the places named in this text is given.

The treasure of Caldas de Reyes (Galicia) was discovered by chance in the course of farming work. What remains of the hoard recovered weighs more than 15 kg, but those who discovered it confessed to melting down and selling much of the gold, so the original hoard may have been, on their word, nearer 50 kg (Fig. 2). Although the most spectacular items are perhaps the drinking set and the comb, it is the enormous, heavy torque with expanded terminals, almost 25 cm in diameter and weighing 870 g, the massive neck rings weighing almost half a kilo and the robust and crudely made bracelets, some weighing more than 700 g that will be analysed here, for in view of their weight and crude workmanship, they cannot have been objects of practical use, but were used as ingots (Fig. 3, Table 1).

Fig. 1: Location of the places named.

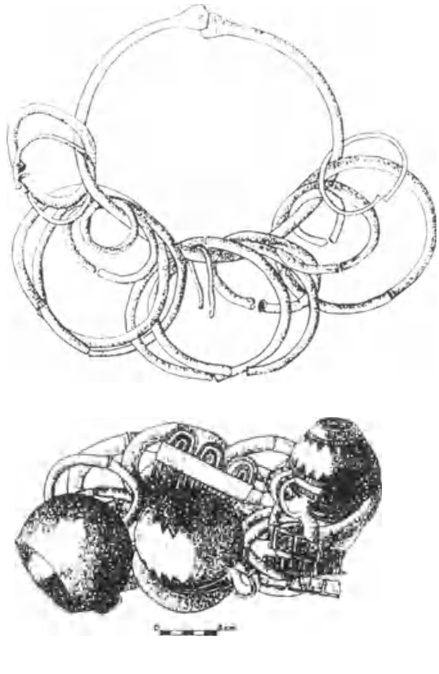

Fig. 2: The Caldas the Reyes treasure.

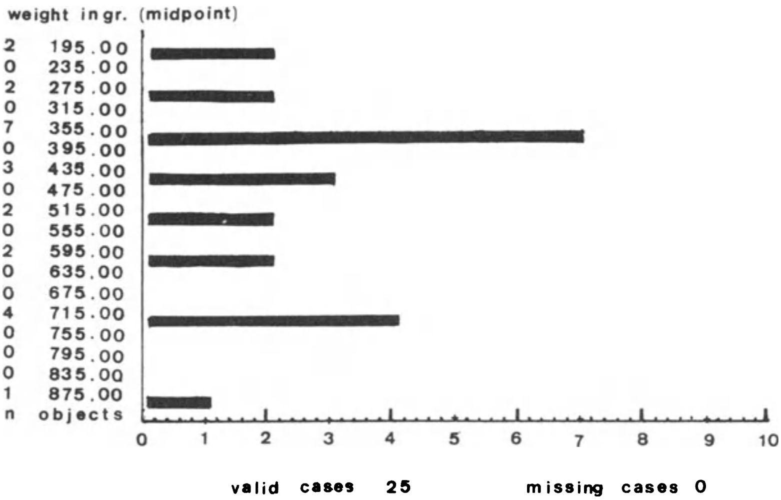

Fig. 3: Histogram of frequencies of the objects of the Caldas de Reyes treasure.

Table 1. Listing of weights and dimensions of the objects of the Caldas de Reyes treasure according to Ruíz-Gálvez (1978).

References	Register	Type	Diam cm	Weight gm
Ruíz-Gálvez 1978	nº 1245	Neck ring	22,6	870
" " "	nº 1246	Neck ring	14,5	472
" " "	nº 1247	Neck ring	13,95	475
" " "	nº 1248	Neck ring	13,98	380
" " "	nº 1249	Neck ring	14,15	495
" " "	nº 1250	Neck ring	14,15	458
" " "	nº 1251	Arm ring	9,65	730
" " "	nº 1252	Arm ring	10,05	525
" " "	nº 1253	Arm ring	10,7	622
" " "	nº 1254	Arm ring	10,35	680
" " "	nº 1255	Arm ring	10,85	730
" " "	nº 1256	Arm ring	10,3	568
" " "	nº 1257	Arm ring	10,7	670
" " "	nº 1258	Arm ring	10,3	715
" " "	nº 1259	Arm ring	9,75	740
" " "	nº 1260	Arm ring	8,9	330
" " "	nº 1261	Arm ring	9,6	283
" " "	nº 1262	Arm ring	8,8	320
" " "	nº 1263	Arm ring	8,75	390
" " "	nº 1264	Arm ring	9	380
" " "	nº 1265	Arm ring	8,3	265
" " "	nº 1266	Arm ring	7,85	355
" " "	nº 1267	Arm ring	9,05	320
" " "	nº 1268	Arm ring	8,35	210
" " "	nº 1269	Arm ring	8,0	232
" " "	nº 1270	Arm ring	7,7	75
" " "	nº 1271	Arm ring	7,75	72
" " "	nº 1275	Arm ring	7,9	275

Every weight has been plotted on a graph, except for three small bracelets that look different because of their shape and lower weight - 72,75 and 275 g - and could actually have been worn as bracelets (Ruíz-Gálvez 1978, Fig. 2n 2, 3, 7). Two main groups were apparent: the first around 300 g; the second, around 700 g. The average of both concentrations was found, the first with an average weight of 353.5 g; the second with an average of 728.75 g which is a little bit more than twice that of the first. So taking as a unit a number ca. 355/360 g, bracelets and neck rings fall into order as multiples or fractions of that unit (Fig. 3). From the analyses made it is difficult to deduce with certainty a weight unit, since there are no other sets of the same chronology with which to make comparisons. Anyway, this subject will be treated at the end of this paper.

Although the treasure has no archaeological context or absolute data, the drinking vessels and comb allow to date it to the transition from the 3rd to the 2nd millennium B.C. (cal). Precious drinking vessels and rich items of personal adornment in metal, became widespread in western Europe in Beaker and Early Bronze Age contexts. A vessel like that of Caldas, but in silver, from the Armorican tumulus of St. Adrièn, has a ^{14}C date 2138/1932 B.C. (cal) (Briard 1978). Other dendrochronological data confirm these datings for Wessex and Central European contexts, where similar drinking sets appear (Krause et al. 1989).

The convergence of associated drinking, dress and adornment patterns, that in funerary contexts were related with the male warrior, was favoured by a process of agricultural intensification resulting from innovations such as the ard or the woolly sheep. These would have enabled a demographic increase, the colonization of marginal lands and the increase of livestock sector (Sherratt 1981). This process is also visible in the northwest of the Iberian Peninsula. Thus, one can observe a trend in some megalithic tumuli of the mid-3rd millenium B.C. (cal) to spread from the highlands with light soils, which could be worked by slash and burn towards the more productive but of heavy soils lowlands, that needed the ard. This would have been accompanied by a reduction in visibility and in the size of the tumuli but also by the deposition of richer grave goods. This process would lead to the single burials of the Early Bronze Age (Criado and Fábregas 1989). But, despite the introduction of new farming technology, hardly any settlement sites are known and those recorded display a pattern of mobility. This is also the case in Wessex and Brittany, where rich tumuli are known, but little or nothing of the settlements. The data indicate (Thomas 1991: 27-28, Earle 1991: 81-84, Ruíz-Gálvez 1991: 286), that the introduction of the ard could have encouraged extensive colonisation and a brief demographic increase, rather than agricultural intensification and stable, permanent occupation of the land. The reason could lie in the fact that, in the absence of large quantities of manure, the ard produces rapid erosion and soil exhaustion (Jensen 1982: 99, Gould 1992: 108).

Thus despite the introduction of the ard, it is difficult to imagine that the changes in land ownership and transmission of property predicted by Goody (1973, 1990) occurred, in view of the apparent inability of the population to remain, generation after generation, on the lands they cultivated. That is why Wessex has been interpreted as a simple chiefdom (Earle 1991) in which power would have derived more from the control of labour than from the ownership of land. This power would have been obtained by controlling arcane and ritual knowledge concerning the farming cycles, and the exotic objects used in the establishment and maintenance of social relations. This model would also be applicable to the Breton Early Bronze Age, where, as in Wessex, there is the precedent of huge ceremonial megalithic monuments and where gigantic E.B.A. tumuli are known such as la Motta and others, which involved mobilizing a great deal of labour just for the burial of a single person and which sheltered rich and exotic grave goods. None of this is applicable to the northwest of the Peninsula, where calculations of the amount of work invested in the construction of the megalithic tumuli and of the cists and tumuli of the Early Bronze Age indicate a limited mobilization of labour. Likewise, the grave goods of the Early Bronze Age in the northwest are more modest than those of contemporary Brittany or England.

For this reason the Caldas de Reyes is believed to be the greatest concentration of gold in the whole of the Early Bronze Age in western Europe, it reflects an accumulation of personal wealth, typical of a "Big Man" and is similar to the great copper and bronze hoards that in Central Europe were then concentrated near mineral veins (Sherratt 1976, Harding 1984).

3. Case study No. 2: Villena

Villena (see Fig. 1) is another find without an archaeological context or absolute date. The treasure, weighing about 10 kg, contains a gold and silver set for eating and drinking, bracelets and other items of gold, amber and iron (Soler 1965) (Fig. 4). The analysis has been concentrated on the bracelets (see Armbruster this volume), for various reasons:

1. Their shape and decoration could be a visual indication of the unit or fraction of weight they represent;
2. The fact that their ends are open might mean that they are not unfinished pieces, but that they could have been designed to be sub-divided, perhaps as means of payment.

In fact, similar bracelets such as that of Portalegre (Portugal) (Cardozo 1959), or that of the National Museum in Madrid (Almagro Gorbea 1974), have been intentionally cut. Unfortunately, the analyses only indicate a correlation between the diameter and the weight of the pieces. All the weights (Table 2) have been plotted on a graph and found the average of the greatest concentrations. These fell into two groups: the first with an average weight of 131 g; the second, with an average of 262 g, i.e., twice that of the first. Thus, taking 131 g as a unit of weight, the bracelets fall into order fairly well (Fig. 5, Table 3), as multiples or fractions of this amount. Incidentally, 131 g x 2.5 = the Roman pound of 327.5 g. So, perhaps a Mediterranean weight system might have been evolving in that area from the later prehistory on.

Villena is, like Caldas de Reyes, a personal treasure. The similarity of the bracelets, but, in particular the bowls and bottles, indicate that they belonged to a single set and that it was the personal possession of a single individual, certainly male. Nevertheless, it can be interpreted in a different way from the Caldas set.

Villena is situated in the southeast of Spain, a region that, in contrast with the rest of the Iberian Peninsula, witnessed a dense and permanent settlement from Los Millares onwards. This would have been the result of the use of an efficient farming technology that included the ard, nitrogen-fixing plants such as pulses, manure and, possibly, Mediterranean polyculture. In the long term, this would have provoked changes, as much in the systems of property and inheritance as in the organization of society, along the lines described by Goody (1973, 1990).

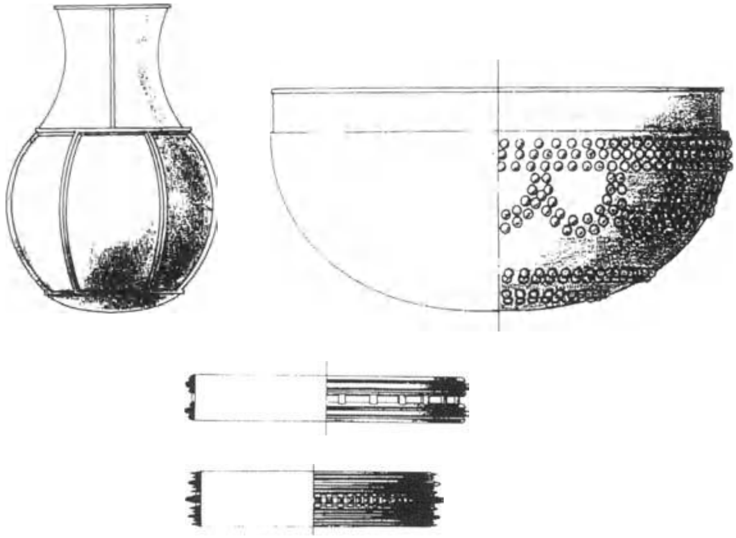

Fig. 4: The Villena treasure. Photograph from the Ministerio de Cultura, Madrid.

Table 2. Listing of weights, dimensions and decoration of the objects of the Villena treasure according to Soler (1965).

References		Register	Decoration	Diam cm	Weight gm
Soler	1965	nº2	Plain	5,7	138,3694
"	"	nº3	"	5,8	226,0796
"	"	nº4	"	7,3	262,0000
"	"	nº5	"	5,9	359,1000
"	"	nº6	1 row perft.	5,6	129,7252
"	"	nº7	1 row perft.	5,9	110,2588
"	"	nº8	1 row perft.	6,0	112,1298
"	"	nº9	" " "	6,0	114,6556
"	"	nº10	" " "	5,5	102,5024
"		nº11	" " "	5,5	161,98[illegible]6
"	"	nº12	" " "	5,0	175,6798
"	"	nº13	" " "	5,5	123,2742
"	"	nº14	" " "	5,8	100,5706
"	"	nº15	" " "	5,9	147,5104
"	"	nº16	" " "	5,8	157,3070
"	"	nº17	" " "	5,6	168,7624
"	"	nº18	" " "	6,5	384,5000
"	"	nº19	" " "	[illegible],2	69,5016
"	"	nº20	" " "	4,7	56,4730
"	"	nº21	" " "	5,5	253,3000
"	"	nº22	" " "	6,0	122,9966
"	"	nº23	2 rows perft.	6,0	270,6000
"	"	nº24	2 rows perft.	6,0	269,7000
"	"	nº25	5 ribs+2 rows prickles	6,0	94,9400
"	"	nº26	Ribs + 2 rows prickles	6,0	203,6050
"	"	nº27	4 ribs + prickle+ perft.	5,5	133,9176
"	"	nº28	2 ribs + 1 row prickles + perft.	5,7	261,4000
"	"	nº29	5 rows prickles + 2 ribs + 1 perft.	7,0	459,9500

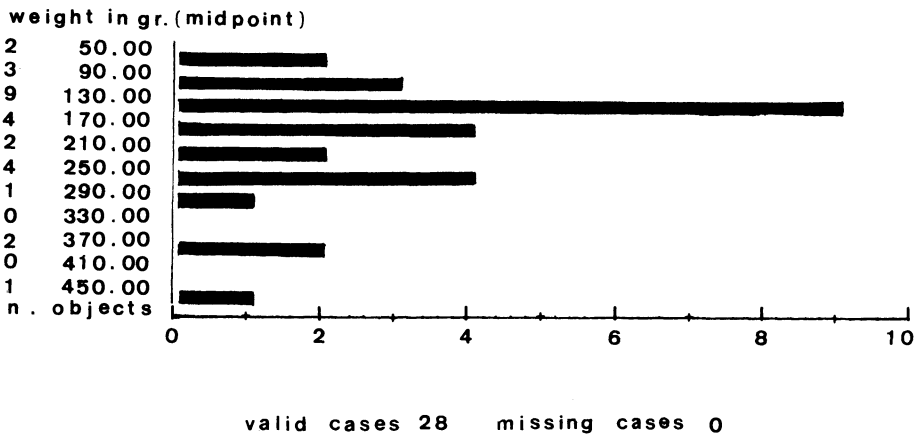

Fig. 5: Histogram of weight frequencies of the objects of the Villena treasure.

Table 3. List of weights and units of the objects of the Villena treasure.

Weight List	%	Unit.
56,47	.43	1/2
69,50	.53	1/2
94,49	.73	3/4
100,57	.77	3/4
102,50	.79	3/4
110,26	.85	
112,13	.86	
114,65	.88	
123,00	.95	1
123,27	.95	1
129,72	1.00	1
133,92	1.03	1
138,37	1.06	1
147,51	1.13	
157,31	1.21	1.1/4
161,99	1.25	1.1/4
168,76	1.30	1.1/4
175,68	1.35	
203,60	1.57	1.1/2
226,08	1.74	1.3/4
253,30	1.95	2
261,40	2.01	2
262,00	2.02	2
269,70	2.07	2
270,60	2.08	
359,10	2.76	2.3/4
384,50	2.96	3
459,95	3.54	3.1/2

It would also explain the paucity of most of the Argaric grave goods in a region that was nevertheless rich in metal, and the fact that there are some rich child and female burials. That means, that the differences of wealth in grave goods are not related with the sex or age of the deceased. This would indicate that social positions were inherited and not acquired in life (Ruíz-Gálvez 1992). Furthermore, Villena is situated in the centre of a rich and strategic region with important resources for stockraising, such as pasturage and salt deposits. It controls several natural routes and cattle tracks towards the grazing lands of the Meseta, the mineral resources of the Upper Guadalquivir and the coast. Incidentally, this was 4000 years ago closer than it is today, since the "Sinus Ilicitanus", a seawater gulf at the mouth of the river Vinalopó, which runs through Villena, had not yet silted up (Cuenca and Walker 1976). The control of these resources and cattle routes would explain the dense settlement of Villena, particularly in the Bronze Age, and would explain why bracelets such as those from Villena are found at points along the cattle tracks between the Meseta and the southeast, such as Abía de la Obispalía (in the Cuenca mountains) or Sepúlveda (Almagro Gorbea 1974) (see Fig. 1). These bracelets might have served as the means of payment along the length of these cattle routes.

The gold and silver dishes, on the other hand, reflect the pattern of consumption and display in hierarchical societies with endogamous marriage, described by Goody (1982). Within them, not just the kind of food but also the tableware distinguished the elite from the common people. Finally, although the treasure lacks a context or dating, it is believed that it should be put in the Post Argaric Bronze Age. There are three reasons for this:

1. The presence in Villena of an iron object inlaid with gold, which suggests it was appreciated for its use value, i.e. its exotic nature, and not for its exchange value, i.e. its practical value (Renfrew 1986). For this reason it probably must be dated prior to the 8th century, when iron began to be smelted in Phoenician factories in southern Spain.
2. The presence of iron, amber and the appliqué technique using nails in some of the Villena objects, suggests that the treasure included Mediterranean imports.
3. The idea of a set of dishes made from precious metal is also Mediterranean, even if, according to Schüle (1976), it was produced locally and imitated Post-Argaric Bronze Age pottery.

For these reasons, the Villena treasure should be dated in relation with the Post Argaric Bronze Age settlement, well documented in the Villena region, but before the Late Bronze Age, for which there is no record in the region. That is, between the 13th and 10th centuries B.C. This would coincide, moreover, with the first Mediterranean voyages to the Peninsula, whose precedent can be seen in the ceramics of the LH III A-B of Montoro (Cordoba) (Martin de la Cruz 1988).

The Villena chief's wealth would be based on the control of the natural resources mentioned above and in his ablility to provide salt, hides, meat and perhaps metals from the Upper Guadalquivir and a mooring point to the Mediterranean sea-travellers (Ruíz-Gálvez 1992).

4. Case study No. 3: The Late Bronze Age massive neck rings

The Late Bronze Age massive neck rings (Fig. 6), well studied by Almagro Gorbea (1977), are concentrated in the west and southwest of the Iberian Peninsula and have good parallels within the Atlantic goldwork of the Late Bronze Age. As in the previous cases, they are found in hoards or single finds without an archaeological context. The sample - 10 - is too small to be significant, but the enormous weight of most of them, unrelated to their shape, does attract attention. And it is tempting to note that Berzocana 2 weighs twice as much as that of Valdeobíspo; Berzocana 1, almost 2.5 times more; Penela, approximately 5.25 times more; Sagrajas, 5.5 times more etc. (Table 4).

No less interesting is the fact that those analysed show wear traces (Perea 1991) and that, as Hawkes (1971) and Almagro Gorbea (1977) have pointed out, their small diameter indicates that they belonged to women. Therefore they should be interpreted as women's dowries. Until recently, in parts of Spain such as Ibiza or the gold-bearing areas of León and Salamanca (Fig. 1), the heavy jewellery worn by women was used as a dowry. Its display on social occasions, such as Sunday mess, enabled the potential suitor to calculate the value of the dowry (Fernandez 1992). The same practice is described amongst the Greek women of Smyrna at the beginning of the 19th century by an English traveller in the Ottoman Empire (Kinglate 1991). Moreover, this jewellery acted as "social storage". Thus, in León or Salamanca, jewellery was used as something to fall back on in times of hardship (Fernandez 1992). Such practices still survive amongst the pastoral communities of the Maghreb, Sudan and Saudi Arabia, amongst others (Fisher 1987). It must be remembered that, in basically stockraising communities, livestock has the same meaning as the land for agriculturalists (Goody 1973: 28).

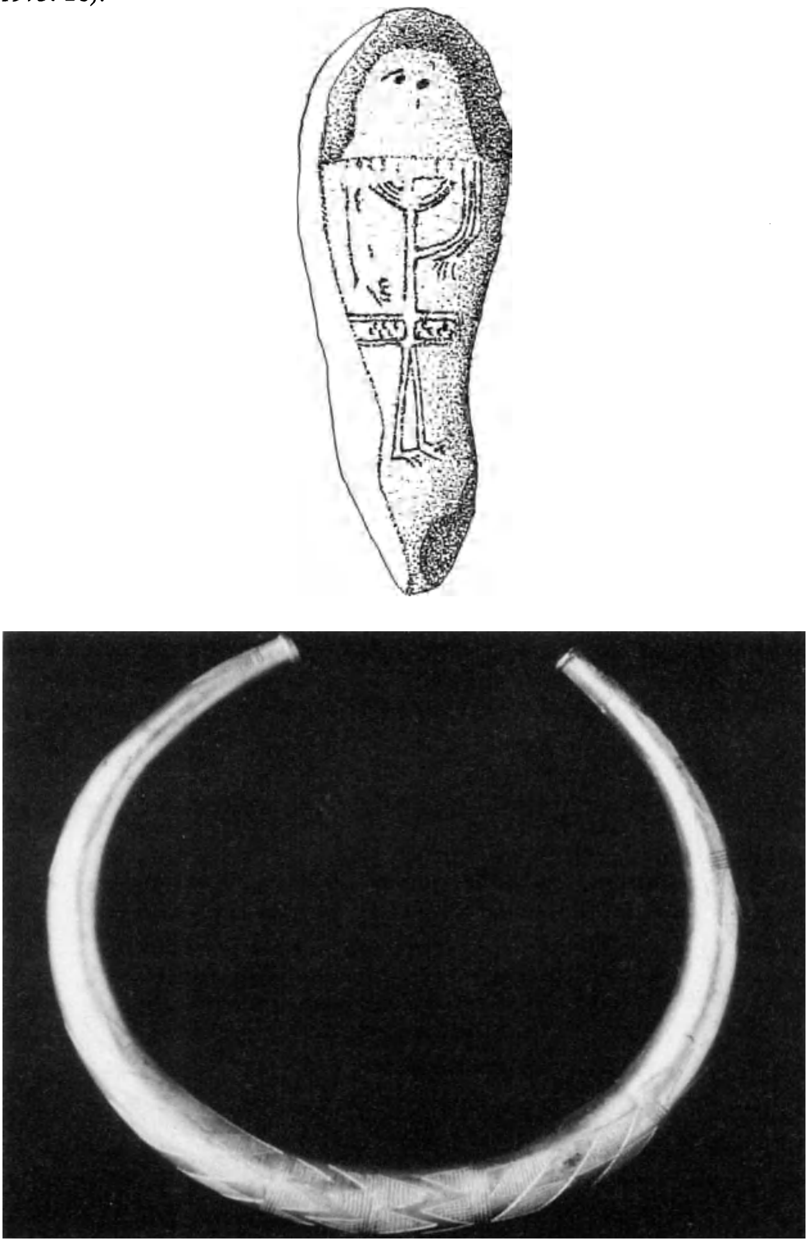

Fig. 6: Female depiction in Late Bronze Age SW. Stelae (above) and the massive gold neck ring from Berzocana (Spain). Photograph from the Ministerio de Cultura Madrid.

Table 4. Weight and diameter of Late Bronze Age massive gold neck rings (torques).

References	Finding place	Type	Diam cm	Weight gm
Almagro G. 1977	Portel (Port.)	1 bar torque	--	2300
Almagro G. 1977	Penela (Port.)	1 bar torque	--	1800
Hawkes 1971	Sintra (Port.)	3 bars "	14	1262
Cortez 1948	Baiões (Port.)	1 bar "	13,6	582,5
Cortez 1948	Baiões (Port.)	1 bar "	14	591,6
Severo 1905/8	Serrazes (Port.)	1 bar "	13,8	574,4
Almagro G. 1977	Berzocana (Esp)	1 bar "	15	950
Almagro G. 1977	Berzocana (Esp)	1 bar "	14	750
Almagro G 1977	Sagrajas (Esp)	2 bars "	14,2	2004,60
Enríquez 1991	Valdeobíspo(Esp)	1 bar "	12,7	375,75

375 x 1.5 = 562,5 **Baiões & Serrazes** = ca. 1,5x **Valdeobíspo**
375 x 2 = 750 **Berzocana 2** = 2x **Valdeobíspo**
375 x 2.5 = 937,5 **Berzocana 1** = ca. 2x **Valdeobíspo**
375 x 4.75 = 1781,25 **Penela** = ca. 5.25x **Valdeobíspo**
375 x 5,5 = 2062,5 **Sagrajas** = ca. 5,25x **Valdeobíspo**
375 x 6 = 2250 **Portel** ca. 6x **Valdeobíspo**

Other interesting aspects are:

1. That the hoards containing these female neck rings coincide, as Almagro Gorbea (1993: 134) shows, with the depiction of women on the carved stelae of the southwest (Fig. 6).
2. Their location is not a matter of chance, but complements that of swords found in rivers and they are sited overlooking strategic points for an eminently stockraising region such as the southwest: fords or cattle tracks, for example (Ruíz-Gálvez 1992). That is why these treasures should be interpreted as the grave goods of high rank women, whose male equivalents would be swords consigned to the waters. Redeeming them would have served to avoid inflation (Bradley 1990) and maintain their high value in times of hardship in comparison with food and items of basic necessity.

The evidence relating to high rank women and dowries in the west of the Peninsula from the Final Bronze Age onwards indicates changes in agricultural technology, including the more widespread use of good nitrogen-fixing crops with a high nutritional value, such as beans, etc. This resulted in stable and permanent settlement there as well as throughout western Europe (Ruíz-Gálvez 1991, 1992).

This intensification of farming, much more than the actual introduction of iron, marks the Late Bronze Age/Iron Age transition (Thomas 1989). Its consequences in the long term were changes in the system of ownership and inheritance and with them, as seen in the role played by precious metals, in the definition of an individual's position in society.

Chapa Brunet and Pereira Sieso (1991) drew recently attention to the disappearance of gold from the Second Iron Age Iberian tombs, despite the fact that the chroniclers of the Roman Conquest relate the large quantities of precious metal obtained as loot in the region. Something similar can be said of the Meseta, where jewellery and sets of dishes in precious metal appear in hoards or are described as loot or tribute, but never appear in Celtiberian tombs.

This not only reflects, as Chapa Brunet and Pereira Sieso (1991) pointed out about the Iberian, that the exchange value of metal predominated over its use value. It is, above all, a consequence of the changes in property ownership and inheritance. For this reason, precious metals no longer serve to define an individual's position in society, since this is inherited. The possession of precious metal would be the result of this social position rather than the way of acquiring it. Hence its value as a commodity would predominate.

5. Case study no. 4: The pre-Roman torques of the NW

The value as a commodity may also explain the pre-Roman gold torques of the northwest, some of which, because of their enormous size and weight (Table 5), appear to have had a much more symbolic than practical value.The fact that they are painstakingly decorated gives them an added value that makes one reject the idea that there are simply ingots and consider the possibility that one is dealing here with a weight system. In this way, Gaimster (1991) reminds that the Russian weight unit "grivna", originally meant "neckring" (see also Fitzpatrick 1992).

Table 5: Weight list of pre-Roman torques from the NW.

	References	Finding place	Weight gm
1	Monteagudo 1952	Burela (Lugo)	1812
2	Monteagudo 1952	C. de Recadeira 2 (Lugo)	1460
3	L. Cuevillas 1951	Cú de Castro (Lugo)	805 (ca.)
4	Monteagudo 1952	Melide (Coruña)	678
5	L. Cuevillas 1951	Foxados 2 (Coruña)	593
6	L. Cuevillas 1951	C. de Recadeira 1 (Lugo)	590
7	L. Cuevillas 1951	Astorga (León)	502
8	Luengo 1979	S. L. Pastor 2 (Coruña)	464
9	da Silva 1986	Vilas Boas (N.Portugal)	387,3
10	Bouza Brey 1965	S. L. Pastor 1 (Coruña)	370
11	L. Cuevillas 1951	Ortigueira (Coruña)	363
12	Monteagudo 1952	S. M. do Porto (Coruña)	340
13	Luengo 1979	S. L. Pastor 3 (Coruña)	304,20
14	Quiroga 1991	Ashmolean Museum 2	275.68
15	Bouza Brey 1965	Valadouro 1 (Lugo)	259
16	L. Cuevillas 1951	Valentín (Asturias)	241
17	Bouza Brey 1965	Valadouro 2 (Lugo)	232
18	L. Cuevillas 1951	Pontevedra	218
19	da Silva 1986	Codeçais (N. Portugal)	212,2
20	da Silva 1986	Lebuçáo (N. Portugal)	199
21	da Silva 1986	Montalegre 1 (N.Portugal)	182,88
22	Monteagudo 1952	Viladonga (Lugo)	180
23	Quiroga 1991	Ashmolean Museum 1	173,47
24	L. Cuevillas 1951	Orense	165
25	da Silva 1986	British Museum 2	151
26	L. Cuevillas 1951	Unknown	137
27	da Silva 1986	British Museum 1	119,4
28	L. Cuevillas 1951	Sta. Mª. Rendar (Lugo)	112
29	da Silva 1986	Montalegre 2 (N.Portugal)	93,73
30	L. Cuevillas 1951	Foxados 1 (Coruña)	91
31	L. Cuevillas 1951	Coruña	75
32	da Silva 1986	Lanhoso 1 (N. Portugal)	54,8
33	da Silva 1986	Viseu (N. Portugal)	38

A recent publication of Galician silver ingots (Perez 1992) makes it possible to calculate an average weight of 365 g. Silver does not exist in the area. Therefore it is assumed that the same weight system could have worked as well for gold as for silver. If it is taken as a unit, a random sample of 33 torques from the northwest can be arranged almost perfectly as multiples or fractions of that amount (Fig. 7, Table 6). These, by the way, match those of Caldas de Reyes (Fig. 8, Table 7). So, perhaps the same weight system could have been working in the northwestern area from Beaker times on.

Northover (this volume) pointed out the emergence of local weight systems in Britain from the Later Bronze Age on, although they would not imply the use of a precise weight standard for currency use. Yet, one can agree with Malmer's (1992) statement: "*Standardized metal types occur abundantly in all Bronze and Iron periods and cultures, and it will in fact be impossible to separate currency from non-currency without a guidance from written sources. Our only chance to prove the existence of prehistoric currency or money is, therefore, to find weight systems*".

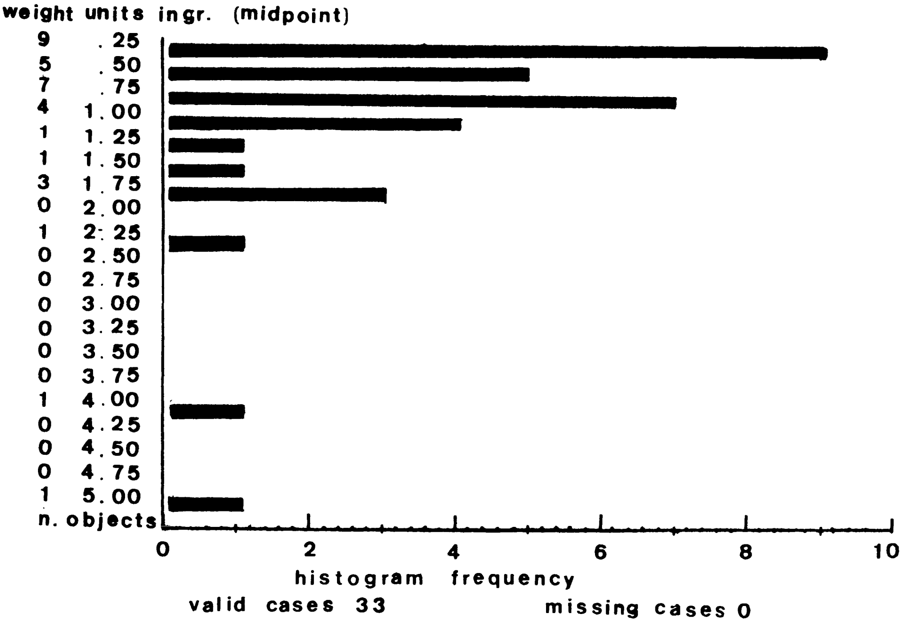

Fig. 7: Histogram of frequencies of the torques from the NW.

Table 6. List of weights and units of the northwestern torques.

Weight List	%	Unit
38,1	.10	
54,8	.15	
75	.20	1/4
91	.25	1/4
93,73	.25	1/4
112	.30	
119,4	.32	
137	.37	
151	.41	
165	.45	1/2
173,47	.47	1/2
180	.49	1/2
182 88	.50	1/2
199	.54	1/2
212,2	.58	
218	.59	
232	.63	
241	.66	
259	.70	3/4
275,68	.75	3/4
304,20	.83	
340	.93	1
363	.99	1
370	101	1
387,3	106	
464	120	1.1/4
502	137	
590	161	
593	161	
678	185	
805	220	2.1/4
1460	400	4
1812	496	5

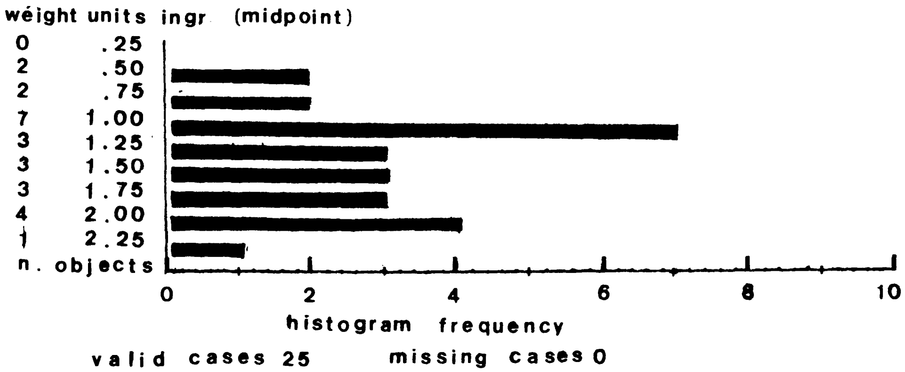

Fig. 8: Histogram of frequencies of the objects of the treasure of Caldas de Reyes.

Table 7. List of weights and units of the objects of the treasure of Caldas de Reyes.

Weight List	%	Unit
210	.57	1/2
232	.63	
265	.72	3/4
283	.77	3/4
320	.87	
320	.87	
330	.90	
355	.97	1
380	1.04	1
380	1.04	1
390	1.06	1
458	1.25	1.1/4
472	1.29	1.1/4
475	1.30	1.1/4
495	1.35	
525	1.43	
568	1.55	1.1/2
622	1.70	1.3/4
670	1.83	
680	1.86	
715	1.95	2
730	2.00	2
730	2.00	2
740	2.02	2
870	2.38	

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Chapter 2

THE RISE AND FALL OF GOLD METALLURGY IN THE COPPER AGE OF THE CARPATHIAN BASIN: THE BACKGROUND OF THE CHANGE

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ABSTRACT. The paper deals with the different use of gold and copper in the Early and Middle Copper Age on one side and the Late Copper Age cultures of the Carpathian Basin on the other side. Transylvania was in the antiquity one of the richest gold mining areas of Eurasia. This is demonstrated on the basis of Roman and Medieval texts, expecially on hand of those about the Decebalus gold treasure found by the troups of Trajan in 106 A.D.
In strong contrast to the wide use of gold (and also of copper) in the very gold rich area of Transylvania during Early and especially Middle Copper Age cultures (i.e. the Tiszapolgár and Bodrogkeresztúr and their corresponding cultures in other parts of the Carpathian Basin, among others the Lasinja culture in Transdanubia with its gold discs) there is no trace of the use of gold in the Late Copper Age. In the Late Copper Age also a very strong decrease in the number and also weight of the copper artifacts can be observed, too, and it is very remarkable that the few copper objects were daggers. This stays to indicate wartime or at least a continuing armed unrest during Late Copper Age. Invasions, conquests and similar events never promote production, accumulation, hoarding and public use of gold.

1. Introduction

This paper will briefly outline the main archaeological facts concerning the earliest use of metals in the Carpathian area. Of all the base and precious metals, it was copper that was first used here, preceding the use of gold by centuries. The earliest, Late Neolithic, copper industry evolved between 3000 and 2500 B.C. (traditional dating) (Bognár-Kutzián 1972, 138-148 and 201-202, Makkay 1989, 101-102, Makkay 1976, 291-292, Makkay 1985, 6-11, Makkay 1990, 157, note 46, Makkay 1991, 119-123). This date was generally accepted in archaeological circles until 1967 - 1981, when some sites from somewhat earlier, i.e. Middle or even Early Neolithic contexts were added to the list of the earliest copper finds, as for example Balomir, the Iron Gate area, Vinča and Szarvas (Vlassa 1967, Fig. 6, Makkay 1969, 28 Chapman and Tylecote 1983, 373-374, Tylecote 1987, 9 and 23). For the present, oldest copper (malachite?) ornaments in Hungary see the finds from Csanytelek from the Szakálhát period (Hegedüs 1981, 9-11). This has not happened in the case of gold since the traditional relative dating of the first occurrence of gold in the Carpathian area to the Early Copper Age (ECA, i.e. the Tiszapolgár culture and its contemporaries: Makkay 1989 and 1991) has not changed in the last two decades.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 65–76.

2. The wealth of Transylvania

One of the richest gold-bearing areas of Eurasia lies in the centre of Transylvania, in the metalliferous mountain-range (i.e. the "Erzgebirge", Hungarian Érchegység, Muntii Apuseni). Tylecote erroneously identifies seven of the once richest gold-bearing localities, belonging to the "Golden Quadrangle" (Tylecote 1987, 47) with the "Seven Towns" (i.e. "Siebenbürgen") of Transylvania. The different names of the localities with gold mining are given in Table 1 and shown in Fig. 1.

Table 1. Romanian, Hungarian and German names of the most important gold mining localities in NE Romania.

Sacavamb	Săcărîmb/Nagyág/Gross-Astdorf
Zlatna	Zlatna/Zalatna/Goldmarkt
Baira de Aries	Baia de Arieš/Aranyosbánya/Offenburg
Rosia Montana	Rošia Montană/Abrudbánya-Verespatak/Goldbach-Rotseifen
Caraci	Căraciu or Căraci near Baia de Criş/Karács near Körösbánya
Baita	Boiţa or Boica/Kisbánya/Botzen
Brad	

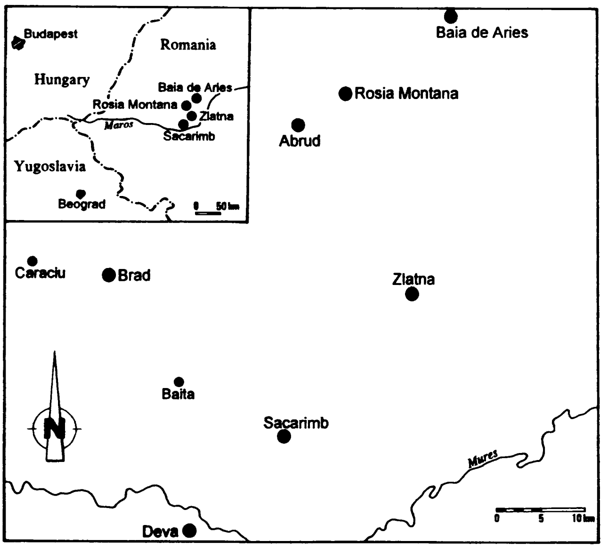

Fig. 1: The main gold mining centres in the "Golden Quadrangle" in Romania.

The richness of these Transylvanian gold sources can be demonstrated by a rough estimate of the total quantity of gold (and silver) extraction in ancient Roman and Late Medieval times. According to the somewhat legendary, but partly reliable sources (Johannes Laurentius

Lydus, 5th - 6th centuries A.D. in his work "de magistratibus", II.28). Five million Roman libras - each libra weighing 327 g equivalent to 1650 metric tons of gold and additionally 3310 metric tons of silver have been the total amount of gold and silver mined and panned in the mines of the Agathyrsoi and the Dacians in Pre-Roman times in Transylvania, accumulated in the royal treasury of Decebalus and hidden before the arrival of the Roman army in 106 A.D. (Carcopino 1924). In the available French translation of the original Greek the emperor Trajan: *"ayant été le premier à vaincre les Gètes et leur roi Décébale, ramena à Rome cinq cent fois dix mille livres d'or, le double de livres d'argent, sans compter un nombre de vases et coupes défiant toute évaluation, des troupeaux, des armes, et plus de cinquante fois dix mille valeureux guerriers, avec leurs armes"* (Carcopino 1924, 31).

After a thorough analysis of the text of Lydus, Carcopino (1924) reduced the quantity of gold and silver to the more believable amounts of 165 tons of gold and 331 tons of silver that Transylvanian mines could have produced. Recent research and sporadic data from the 18th century A.D. coupled with archaeological finds confirm these latter estimates of the output of the mines of the Dacian kings since the total production of the Transylvanian "Érchegység" is given in Table 2 (Köleséri 1717/1780, Böckh et al. 1920, 17, Carcopino 1924, 33).

Table 2. Gold production of the mines of the Dacian kings.

years	gold in kg	silver in kg
1717/1780	10,000	
1906	2,660	2,232
1913	1,921	1,241
1914	1,833	920
1919/1923	1,400	2,100

By this time, however, the oldest and most famous gold and silver mines of the Golden Quadrangle were exhausted (Böckh et al. 1920, 17).

Concerning ancient evidence, it is known that during Trajan's campaign in 106 A.D. the gigantic treasury of the Dacian king Decebalus was hidden in the valley of the Sargetia stream. As Diodorus Cassius (Romaiké istoria, ed. Cary, London, 1968, ixviii, 14,4-5) reports *"The treasures of Decebalus were also discovered, though hidden beneath the river Sargetia, which ran past his palace. With the help of some captives Decebalus had diverted the course of the river, made an excavation in its bed, and into the cavity had thrown a large amount of silver and gold and other objects of great value that could stand a certain amount of moisture; then he had heaped stones over them and piled on earth, afterwards bringing the river back into its course. He also had caused the same captives to deposit his robes and other articles of a like nature in caves, and after accomplishing this had made away with them to prevent them from disclosing anything. But Bicilis, a companion of him who knew what had been done, was seized and gave information about these things. "* Therefore, a great part of this enormous treasure was immediately found and unearthed by the Romans and Trajan used it for accomplishing his imperial policy (cf. Carcopino 1924, 30-31).

Another part of the same treasure, some fourty thousand or hundred thousand or even four hundred thousand (!) gold coins of the Thracian and Macedonian king Lysimachos (305-281 B.C.) and probably also of king Koson (around 40 B.C.) were found in the same valley of the Sargetia river, near to the Dacian capital of Sarmizegethusa in 1542 (Téglás 1896-1898, 6, Tóth 1986, 46-47). This discovery was first mentioned by the famous mapmaker and historian Wolfgang Lazius (1514-1565) in the first edition of his Rei Publicae Romanae:

"Regios vero thesauros, quos Decebalus subter vada Sargetiae amnis haud procul a regia occultaverat, invenit. Fluviu forte rex captivoru dutaxat manibus et opera de proprio cursu averterat, atque effossis subinde vadis, in specu magnam vim auri et argenti occultavit, preciosissima quaeque, et eos liquores qui recondi et servari poterant, eodem congerens. Quibus confectis, ne quisqua que gessisset prologui posset, omnes qui facti conscii erant occidi iussit. At Biculus captivus, cui res cognita erat, abditos thesauros indicavit. Haec ille. .... Huius thesauri reliquum ante annos circiter octo (i.e. eight years before the first edition of his work in 1550), *in eodem fluvio Sargetia, quem Walachi Istriga appellant, inventu est hoc eventu. Navigabat ex Marisio per ostiu Walachi piscatores in Istrigam, et cu forte ad truncu arboris cimbas admovissent, conspicati sub aqua aliquid quod valde splenderet: cum illud essere fuissent aggressi, magnam vim aureorum extulerunt. Qua re alacriores effecti, fundum diligentius rimati, pervenerunt postremo ad aedificium quoddam parvum sub undis, instar loculi: cuius fornicem quia arbore nata, vetustate decidens, ad ruinam tracto aedificio aperuerat, omni diligentia perscrutati, ingentem vim numorum aureorum (qui magna ex parte Lysimachi Thraciae regis Grecam inscriptione ostendebant) milia (ut ex fide dignis audivimus) plusquam quadringenta, et massas insuper auri sectiones gravis ponderis. Quibus domum delatis, atque inter se divisis, cum Albam Iuliam ingressi, aurificibus ostendissent numos, et valorem sciscitarentur, res palam facta, Georgium Monachum, qui tum pupilli regii nomine Transylvaniae praesidebat, excivit, ut rei inquisitionem faceret. Fecit ille quidem, et multa adhuc milia vel inventoribus ademerat, vel de novo in aedificio memorato invenerat. Caeterum certiores ante facti, qui antesignani huius reperti erant, cum aliquot oneratis plaustris in Moldaviam procul anfugerunt. Et hac tenus de inventione Dacici thesauri."* (Lazius 1598, 926-927).

Another early writer who mentions (with some important differences) the 1542 treasure is a Transylvanian chronicler Mátyás Miles (1639-1686). His text from 1670 reads as follows (Miles 1670, 45):

"Alß Castaldus seyn Heer nach Hause ließ zu wintern, kam ihm unterwege diese erfrewlige Post zu: Nahe bey Deva, da vormahls Ulpia Traiana gestanden, an dem Fluß Strigh (genant) haben die Pawren unter einem alten Bawm, welches Wurzeln daß Wasser ganz unterwaschen, etwa gleisendes gesehen, wie sie zu Mittag ihr Vieh wollen tränckèn. Derowegen sich in Fluß begeben und etwa fleissiger nach gegraben, biß sie einen über alle maß reichen Schatz überkommen: Oben war eine güldinne Schlange, gleichsam wie ein Hütter daraufgesetzt (welche nach Georgy, (i.e. Georgius Martinuzzi, Cardinal of Hungary) Todt Ferdinandus überkommen) sonst güldinne Müntzen waren unzählig vill, auff einer Seitten hatten Sie Lysimachi, auff der andern der Göttin Victoriae Büldniß gepräget, und machten im Gewicht unser gutten Duckaten 3. Die Pawren hatten schon vill davon vertuscht, biß es richtbar worden, und waren sehr reich davon worden: Jedoch waß noch überblieben, und aus ihren Händen genom-

men, wurde auff 20000 Duckaten geschätzet, und Ferdinando durch Joh. Baptistam Castaldum überschicket, nebenst zweyen güldinnen Büldnissen Nini und Semiramidis, so nachmahls Carolo V. zu einem Anreitz und Anleittung Ferdinandum auch weitter in Siebenbürgen mit seiner Hilffe zu stärcken, wurden verehret: Daß also dieser Vorrath in allem mit dem Teihl, so Castaldus für die Kriegs-Knecht behalten, auch die Pawren verschaffet, auf die 100000 Duckaten auffs genawste gerechnet wurde: Diesen Schatz hatte vormahls der Thracier, und Dacier oder Siebenbürger Könige Décébalus (wovon droben) aus Furcht des Römischen Keysers Trajani, damit er nicht den Römern zu theill wurde, vor seinem Tode in diesen Fluß vergraben."

The fantastic hoard weighed ca. 370 kg of gold at least (i.e. forty thousand coins: 40.000 x 3 x 3.5 g), and came into the possession of the Hungarian cardinal Georgius Martinuzzi, prince of Transylvania before his death in 1551. After he was crudely assassinated on the order of the Austrian king, Ferdinand, by hired killers of the Italian mercenary Giovanni Battista Castaldo on the night of the 16th of December 1551 (Szalay-Ritoók 1975), the treasure was confiscated by Castaldo, and a part of it was taken to the Cabinet des Médailles in Vienna. The raw material of the coins was in all probability derived from gold sources of the Golden Quadrangle.

Memory of these reports survived for a long time after the 16th century A.D., for instance in the verses of the 18th century poet from Transylvanyan Saxony (Georg Marienburg, 1751-1817): *"Die Szászcsorer Burg im Albenser Komitat"* i.e. The Fortress of Décébalus in Co. Fejer:

"Ich ging hinein, die Pforte war offen.
Der Wärtel (!) sprach freundlich zu mir:
Sei mutig, Freund, nicht werde betroffen,
Dein warten die Schätze allhier,

die einst Decebal, König der Daken,
hier flüchtig im vollen Galopp
noch rettet'. Sie liegen in Haken
von Eisen und Ketten darob.

Kaum sagt er dies: so sprengten die Riegel
der grausig knarrenden Tür.
Ein langer Saal - die Wände voll Spiegel,
der Boden von blauem Saphir.

Drauf stand ein Tisch von glattem Opale
mit purpurnen Streifen furniert,
auf ihm zehn große goldne Pokale
mit grünen Smaragden geziert.

Auch sah ich Manns- und Weiberfiguren,
gelagert auf Stühlen von Gold.
Ein Diamant ziert ihre Frisuren,
die Haare in Locken gerollt.

Ich staunte lang, beguckte die Schätze
und sagte: O waren sie mein!
Da sprang ein Knappe mit wilden Geschwätze
zu meinem Erstaunen herein.

Sieh, sprach er, Herr, ein feuriger Drache
besorget die Schätze von hier
und vordert Blut und schröckliche Rache
von Jedem in diesem Revier,

der nicht mit Blut mißhandelter Bürger
bespritzt ist, nicht raubt, was er kann.
Bist du das nicht, so fliehe den Würder
und rühre die Schätze nicht an.

Ich eilte fort, mein Leben zu fristen,
ein Wildes Getöse mir nach
seither besuchen nur jüdische Christen
und Mäkler und Gauner den Schatz" (Brandsch 1944, 68).

It is very probable that rich hoards of gold coins discovered in the same area in 1803-1804 (i.e. 966 gold coins of Koson and an unknown number of coins of Lysimachus) also belonged to the treasure of Decebalus hidden in the fortress in 106 (Jakó 1966, 1968, 1971, 1972).

It appears to the writer that all of the Transylvanian gold which had been used in prehistoric times, i.e. in the Late Neolithic (?) and Copper Ages was alluvial gold from stream placers which had been released by weathering and erosion of the primary gold deposits. Since the stream valleys of the Golden Quadrangle must have been very rich in these surface occurrences (i.e. visible nuggets), there was no need until at least the Middle Bronze Age for any kind of mining activity to extract primary gold, or for panning in the Küküllö, Maros and Aranyos (its name simply means "aureous") rivers. As a consequence, primary gold mining can only be proven from the time of the Roman occupation on (Tylecote 1987, 46, Téglás 1897, 9-10), but some mining activity already may have started during Dacian times, and even before (Decebalus employed Roman and Illyrian miners and by doing so, he enraged Trajan).

Pure chance and modern mining activities have produced impressive gold nuggets. Tylecote mentions such pieces of 5 kg to over 10 kg of gold (1987, 47), but it is also known of a 57.726 kg nugget found in the Muszéri valley near Brád/Brad in the Maria mine in 1891 (Franzenau 1892).

Nicolaus Oláh, cardinal of Hungary (1493-1568) mentions in his "Hungaria" (Oláh 1938) that gold was also found among stones in solid, nugget-like form (palaga or palacurna in Latin: "larger gold nugget", and obrizum/obryzum "fine and pure gold piece"), and he possessed a specimen which was as large as an egg, and weighed about 100 ducats. In 1536, bishop Nicolaus Gerendi had a piece of nugget gold weighing 350 ducats (1.225 kg), but at that time a serf had discovered a piece weighing 1600 ducats (5.6 kg) near Abrudbánya (Oláh 1938, cap. XIX, p. 33). It seems that serfs and outcasts were especially successful in finding big nuggets. Sources mention the recovery of a 37 kg nugget - called "The Great Triangular" (Bolsoi Triugol'nik) - in the Ural area, in the valley of the Taškurganka river. Here a political prisoner, N. Siutkin in 1842 had discovered this great piece during field work at a depth of 3 m and he reported it, to the great surprise of his commanders. This astonishment induced them to pay the real value of the piece (0.15 roubles for each gold ducat, i.e. 3.5 g) to Siutkin, altogether 1266.60 silver roubles. Poor Siutkin was also very much surprised by this gesture and immediately started to drink vodka. The story goes that he drank up this entire large sum to the last drops, i.e. kopeks and, after an official and public punishment on the whipping post, he died in disgraced poverty (Maksimov 1988, 92, and Fig. 43).

The whole inventory of the Varna gold, numbering over 3000 pieces, totals around 6 kg, and the weight of the gold finds of the ECA and MCA cultures of the Carpathian Basin (the Tiszapolgár, Bodrogkeresztúr and Lasinja cultures), including the reconstructed Tiszaszölös and Mojgrád hoards, can be estimated at 5 - 6 kg (Makkay 1991, 119-120). Therefore a medium-sized gold nugget discovered by early and fortunate prospectors would have been a more than sufficient supply for the entire gold inventory presently known from the cultures mentioned above. Consequently, the expenditure of social energy to supply gold by simple prospection in the Eastern and Central part of the Carpathian Basin need not have been very important, and was surely far lower in these early periods than in the case of copper. V.G. Childe was the first to recognize and emphasize the role of the earliest (southern) prospectors in the discovery and, probably, trade of Transylvanian gold (probably nuggets) as early as the local Late Neolithic, i.e. well before the second phase of the Tiszapolgár period (Makkay 1990, 90, note 76). Then there was no local demand for these exquisite luxury items, wholly useless to the natives at the technological and economic level they had reached before the advent of the "Golden Age". A genuine demand for precious metals, i.e. for gold existed only in the territories of the Aegean and Near Eastern civilizations (including Egypt) at this early date. Because of the high risk - and cost - of transportation, this long distance trade was mainly restricted to materials which were of great value or produced and/or available in limited areas. This definition can only be valid for gold, and taking the socio-economic level of the period into consideration this trade was through indirect, when gold was passed from place to place without a specific purpose and use in the source area. Such a long distance trade of Transylvanian gold as early as the Middle Neolithic was long ago suggested by the writer on the basis of the evidence of a gold object found in grave V at Abydos (probably belonging to pharaoh Khasekhemwy, who reigned as the last king of the second dynasty between ca. 2703 and 2686 B.C. (Makkay 1975, 28). The red crust of the object was a compound consisting of gold combined with antimony and some tellurium, a specific characteristic of gold of Transylvanian origin. Recent chemical analysis of fifteen samples of native gold from Verespatak clearly show that a characteristic feature is the presence of inclusions of different Au/Ag tellurides with Te levels of ca. 10 % - 40 %, sometimes with traces of antimony (Sb) (Hauptmann et al. in this volume).

Assuming even the highest possible amount of natural gold used for jewellery by the Copper Age cultures during their entire life span (which remains unknown to us, but must be a multiple of 6 kg), and considering the fact that heavy gold nuggets could have been found continuously during the last five centuries (and consequently also before), it is highly likely that similar preconditions can be presumed for prospectors/tradesmen/goldsmiths of the post-Bodrogkeresztúr period, i.e. the Baden and the contemporary Coţofeni cultures.

Curiously enough this is not the case: There are no assemblages of gold and silver from these latter, Late Copper Age cultures. The same also holds true for the copper industry: in strong contrast to the hundreds of heavy axe-adzes of the Bodrogkeresztur culture (having weights of 3.65 kg; Patay 1984, 48. no. 190) with an average weight of around 1 kg, the whole assemblage of copper jewellery and implements in the Late Copper Age (LCA) consists of a few pieces, whose weight probably totals that of a single Bodrogkeresztúr axe-adze (Banner 1956, 172-173, Kalicz 1963, 62-64).

There is no evidence whatever that the Baden and Coțofeni people collected, mined, panned or processed gold. This surprising and total lack of gold (and the paucity of copper) on the same territory which abundantly used gold and copper in the preceding period cannot be explained in terms of common sense, that, e.g. the last survivors of the Bodrogkeresztúr and related peoples rich in gold would have taken away (or hidden) all their gold and copper. Weathering had continued to reveal gold nuggets and natural copper also for - the probably non-existant - prospectors of the Baden and Coțofeni cultures. The most likely reason that no gold (and very little silver and copper) is found in the LCA assemblages is that there was no use for and no demand of gold. Consequently gold was not manufactured and there was no need for prospectors or prospecting. This is not a mere argument from silence: if was gold there, it is simply unbelievable that with all the extensive and careful excavation work little more than a handful of copper finds and a few pieces of silver (Vlassa et al. 1985-1986, 61-64, Pl. XI,1-4, Ciugudean 1986, 67-82) should have been brought to light in central Transylvania, and in the big cemeteries of the Baden culture.

As a result, there is no evidence for a substantial metal industry or for the use of gold in the LCA of the Carpathian Basin and immediate by to east, in Moldavia and Ukrainie. A similar phenomenon has been observed over the territory of the former Varna culture, where gold and copper seems to be entirely lacking in the EBA (Ivanov 1989, 64). At the same time one cannot attribute this scantiness to the lack of local metal sources. There is no evidence to suggest a conflict between the given cultural phase (the LCA) and the actual geographical setting (rich sources of gold in Transylvania and of copper in Bulgaria). One point is suggested by common sense and the few existing metal finds: the knowledge and use of metal did not fall into oblivion in the LCA. The lack of gold and the decline of metal industry had probably more general causes.

The general history of metallurgy in SE Europe and the Aegean offers a convincing answer to this question. The EB I saw the very beginning of silver and gold metallurgy in Troy (and, to a lesser extent, also on Crete), but at the same time the copper industry flourished (including even a few early pieces of tin bronze). From these two primary centres (i.e. Troy and Crete) *"we witness what we might fairly describe as a "metallurgy explosion" in EB 2, in which the arts of metallurgy become widely practised throughout the Aegean"* (Branigan 1974, 106). The general picture of the Carpathian area can be related to this situation but with some important distinctions. Assuming that the ECA Tiszapolgár culture, MCA Bodrogkeresztúr culture and LCA Baden culture sequence was contemporary with the EB I, II and III sequence in the Northern Aegean (Makkay 1976), the start of the use of gold in the Tiszapolgar culture and its explosive expansion in the MCA Bodrogkeresztúr (and Lasinja) cultures is very comparable to the situation in the EB I and II phases. The distinctions are that this Carpathian Copper Age gold (and copper) industry does not seem to be so advanced technologically as the contemporary industry of the Aegean and it does not show a marked increase in the range of artifacts produced: there is no trace of the melting of gold, but the most important difference is the lack of metal vessels and composite jewels, such as the Euboea vessels and the diadem-pendants from Troy II and Poliochni. The complete lack of human and animal figurines and of arsenic bronze in the Carpathian ECA and MCA is another marked difference between the South and the North. The first appearance of arsenic bronze in the Carpathian Basin can probably be dated to the Baden culture (unfortunately the sporadic "copper" finds of this culture, including the curious diadem from Vörs, have not been investigated yet: Banner 1956, Pl, LXXXVII, 1-2, 4, 8). A further and decisive difference is that while there is a pronounced continuity in the Aegean metal industry of the EB 3 - MB 2 (Branigan 1974, 114, Makkay 1989 101-102), the Carpathian industry came to a nearly total halt after the Bodrogkeresztúr culture, and this decline apparently began in the late phase of the same culture when the first traces of eastern influences appear (see also the East Balkan connections of the Hunyady-halom group). This cannot be simply the result of the severance of metal trade contacts with the Balkans and the Aegean in the LCA. Carpathian metallurgy was an independent industry exploiting local resources during the Tiszapolgár and Bodrogkeresztúr periods irrespective of where the original heartland from which this metallurgy and its main types derived lay at the dawn of metallurgical invention (in the case of copper surely well before the Tiszapolgár and Varna industries; Makkay 1992).

The once prosperous metal industry of the Bodrogkeresztúr culture declined during the last third of the third millennium B.C. before the end of its life, when a wave of eastern intruders started to infiltrate the region. By the end of the period most of the eastern part of the Carpathian Basin was invaded and occupied. The gold sources and inhabitants of Transylvania came under the control of the invaders. After this conquest precious metals and copper were no longer commonly worked, gold luxuries were no longer in demand since these eastern invaders, the peoples of the Pit-grave (wrongly Kurgan) culture had only sporadically used metals in their eastern homelands in the steppes, before their migration to the west and southwest. Most of the metal finds of the Sredni Stog phase are copper daggers, a sign that the Pit-grave people was armed and ready for battle (Makkay 1993, 124, Häusler 1985, 39-40). The situation can be clearly demonstrated by referring to the scarcity of silver (or electrum) and copper finds recovered from the Pit-grave culture burials of Hungary: a few earrings, a handful of cylindrical beads made of copper plate, and nothing else (Ecsedy 1979, 43-44). The poverty of the Sredni-Stog, Pit-Grave and Tripolye-Cucuteni cultures in precious and other metals can perhaps be explained by their origin in Moldavia and the Pontic region, lying far from the metal sources of the Caucasus and the Ural mountains and, at the same time, far to the east of the main metallurgical areas and metal sources of Eastern Europe in Transylvania and the Eastern Balkans (i.e. Aibunar, Rudna Glava, etc.). The Tripolye-Cucuteni culture and the western region of the Pit-grave culture were thus dependent on the Carpathian-Balkanic metal supply (Chernykh 1991, 387). The apparent ignorance of the population groups of the Coţofeni culture and their immediate successors about the rich gold and silver sources of their Transylvanian territory remains to be explained, since it is hardly possible that such resources were forgotten if any part of the native inhabitants of the region survived the infiltrations and invasions of the Pit-grave people. One may perhaps assume that the reticence of the native inhabitants on this matter (they did not want to share their knowledge of highly valued gold sources with their new overlords) coincided with the occupants' lack of demand. One can wonder at this curious situation that the Tripolye-Cucuteni and even more, the Pit-grave culture, living between such metallurgical centres and metal sources as the Maikop culture and the Caucasus, Transylvania, and the

Eastern Balkans with the Varna cemetery, had not already mastered a fully developed gold, silver and copper metallurgy in their first homeland on the steppes and in Moldavia. The importance of the vicinity of the metal sources from this respect is clearly shown by the fact, that the earliest gold finds of the Carpathian Basin were found on the site of the western branch of the Tripolye-Cucuteni culture, i.e. in levels 4 and 7 of Erösd (Makkay 1990, 157, note 46 with further literature).

This situation, i.e. the relative isolation of the western Pit-grave territory from prosperous metallurgical centres and their consequent lack of metals, only began to change after the end of the LCA i.e. following the assimilation of the ruling élite of the Pit-grave people into the local native populations. When the new metallurgy of the EBA I, i.e. the Vučedol-Zók culture and its Transylvanian contemporaries emerged with their shaft hole axes, flat axes, chisels, daggers (and, already in the initial phase, a mould with traces of copper), this process was clearly the result of a cultural diffusion from the South-East, transmitting inventions from the Eastern Balkans; neither the artefact types, nor the technology show influences from the steppe or from the Pit-grave culture (Ecsedy 1982, 91). Metallurgical skills and workshops developed even in areas devoid of metal sources, such as Moldavia or Southern Transdanubia. New types and new technology spread northwards from the Balkans, replacing the earliest metallurgy based on the collection of gold nuggets and native copper. One of the most important developments of this period was the appearance of specialist craftsmen engaged in the mining, smelting, melting and casting of gold, copper and other metals. At the same time, the extraction of local ores began anew suggesting that, following a long period of gold-prospecting and a gap in the LCA, new techniques of gold extraction began: gold panning, and much later, probably in Pre-Roman periods Transylvania, the extraction of gold by deep mining.

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Chapter 2

GOLD AND SILVER DURING THE 3RD MILL. CAL. BC

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ABSTRACT. Gold and silver entered the archaeological record in different periods and regions. Research on the sources and technological processes connected with early silver are of considerable interest, as the results could be used to check models of interaction. Silver appeared in the Near East as well as in Europe in the 4th mill. cal. BC, but for a long time, it played only a marginal role in the real value systems of the European continent. In the Near Eastern borderlands, the relative scarcity of precious metals in the Levant contrasts with the situation in the Caucasus, where at the turn from the 4th to the 3rd mill. cal. BC sumptuary goods of gold and silver in tumulus burials are paired with settlements of an altogether unsophisticated type. At the same time, people from southeastern Europe, the Adriatic and several islands of the Aegean were participating in networks of exchange operating in two directions: the Black Sea and the Eastern Mediterranean. The rest of Europe was split into at least two areas of different social display. From Central Europe hardly any precious metal finds are known so far from contexts dated around 3000 cal. BC. This negative evidence contrasts with the gold finds of the prebellbeaker period of the Iberian peninsula and southern France. The situation changed in the middle of the 3rd mill. cal. BC, when gold metallurgy expanded into new areas, and some silver arrived in Central Europe.

1. Introduction

General agreement on material as well as spiritual values is one of the unifying bonds in human social groups. Apparent changes in this field deserve careful investigation of evident as well as hidden influential forces. The role gold and the other metals played in early civilizations is not only dependent on technological competence and strategies of resource accumulation, but also indicative of shared or non-shared rules of social and ritual behaviour. The special properties of gold have largely determined its embedding in the ritual sphere. Around 90% of the gold objects from prehistoric periods were found in graves or in depositions of a probably ritual origin. Source critique is an essential procedure for sound archaeological work everywhere, and of particular importance in connection with rare and outstanding materials. Wherever the balance between settlements and funeral sites is biased, conclusions have a provisional status. Not only incomplete sources, but also changing filters have influenced the archaeological record. When metals began to play a significant role in the real value systems of Old World societies, the recycling process became an important variable, and subsequently grave robbery left its marks.

Distinct expressions of wealth and real value are preserved in the Near East from the 3rd mill. BC onwards in texts as well as in the archaeological record. As a result of unequal sources, comparative assessments of Europe and the Near East are difficult. Gaps in the Eu-

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ropean archaeological record cannot be filled with texts. However, textual evidence from Egypt, Mesopotamia and Syria encompasses characterizations of their neighbours which have, if treated with caution, some ethnographic significance. An alternative strategy is research on technological processes. Implemented on a supraregional level, it offers the opportunity to detect independent checkpoints for or against presumed interactions (Pernicka 1990).

All chronological issues concerning Europe as well as the Near East are discussed in the following sections on the basis of calibrated radiocarbon dates, i.e. conventional ^{14}C data treated as explained in Pearson et al. (1986), Hassan and Robinson (1987) and Weninger (1987). If not stated otherwise, the calibrated age ranges from cumulative probability are expressed using the 95% level of confidence.

2. Early silver artifacts

The 4th millenium BC was the time of expanding polymetallism, as Moorey (1988) rightly stressed. In the Near East we are faced with a significant body of silver and lead objects covering the area between eastern Anatolia and Egypt (Prag 1978). An important crossroad was certainly the Levantine coast. The so-called eneolithic graves of Byblos are typical for the situation in this region, where relations of shifting intensity with eastern Anatolia, Syria and Egypt are the rule, and interactions with Mediterranean islands a possibility (Fig. 1). Metal artifacts distinctly increased in number and weight during the younger phase of the relevant period, around 3500 BC. In Byblos, 10% of the published graves contained silver rings, beads and headbands, while gold was present only exceptionally (Dunand 1973). On the object level, gold was used for beads and small jewels, silver for a variety of ornaments including mountings for maceheads. Daggers and tools were made of copper. This functional grouping may reflect technological properties as well as the availability of the metals concerned. In eastern Anatolia the rules of grave furniture were similar, but gold was of no obvious relevance. Silver ornaments were found in the graves of individuals of both sexes (van Loon 1973). In western Anatolia, a silver ring from the settlement level XXXIV at Beycesultan also belongs to this early group, according to the calibrated ^{14}C date (P-298: 4690 $\pm$ 58 bp. that is 3942-3650 cal. BC). Research on the sources of early silver is in its infancy; results would also be of considerable interest for the following periods.

In Egypt, metal artifacts and jewels are attested in graves from the second Naqada period on. However, social or personal distinction was still accentuated by traditional means, namely stone vessels, large pottery sets and ivory (Seeher 1991). Silver was used almost like copper, as two silver dagger-blades, a knife and an adze may show (Baumgartel 1960). Gold appeared in rare cases and in small amounts, essentially shaped into beads or pendants. Gale and Stos-Gale (1981) analysed three presumed silver artifacts from Predynastic Egypt (Table 1). One proved to be of lead, the second of silver with more than 30% gold, perhaps native silver from an Egyptian gold deposit. The third object, the lid of a stone jar from Naqada, contained 15% copper. This is certainly an alloy, with copper added to silver intentionally.

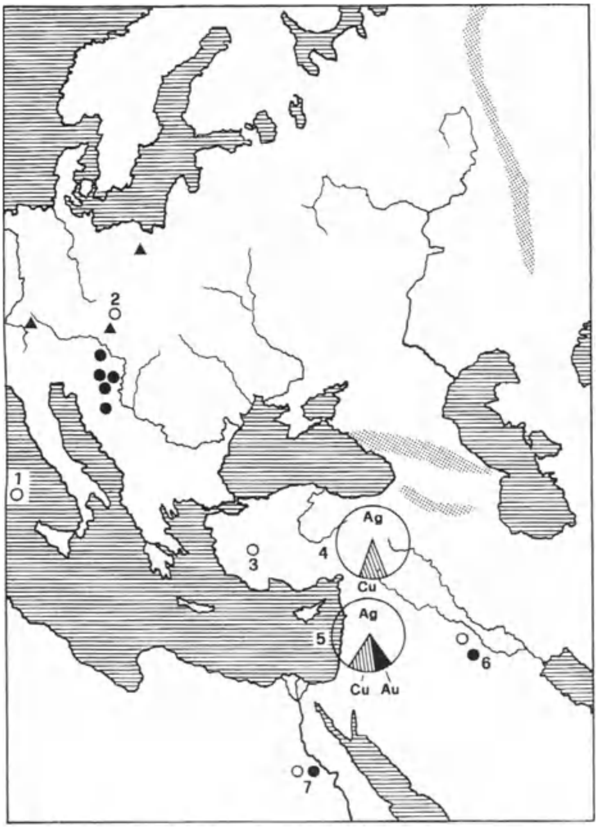

Fig. 1: Silver objects from the 4th Mill. BC. 1 Sardinia (Italy); 2 Stramberk (Moravia) (Stollhof type disc; silver = open circle; gold = full circle; copper = triangle); 3 Beycesultan (Turkey); 4 Korucutepe (Turkey); 5 Byblos (Lebanon) (the cake diagrams show the proportion of Ag, Cu and Au artifacts); 6 Uruk/Warka (Iraq); 7 Naqada area (Egypt).

Table 1. Silver in Predynastic Egypt (after Gale and Stos-Gale 1981).

	%Ag	%Au	%Cu	%Pb
1. Hawk	ppm	ppm	ppm	99.9
2. Rim of vase	61.35	33.74	4.9	0.14
3. Lid for jar	83.5	1.0	15.0	0.4

Silver appeared in Europe as early as in the Near East, but for a long time it played a marginal role in the real value systems of the continent. In Sardinia, small silver rings and spiral rings have been reported from several contexts of the Ozieri cultural group (Lo Schiavo 1988, Atzeni 1981). Radiocarbon dates put the Ozieri group in the first half of the 4th mill. cal. BC, considerably earlier than previously thought. Silver remained in use during the following period in Sardinia, while gold appeared distinctly later.

The earliest continental find is a disc of the well-known Stollhof type normally made from gold or copper (Pavelcik 1979). It came to light on the hillock Kotouc near Stramberk in Moravia and must be considered as a single find, though a copper spiral was found not far away from it (Jisl 1967). The shape and ornamentation of the silver disc corresponds so closely with the golden examples that manufacture should be located in the same area and time. The silver seems to be cupelled, which means that it was most probably derived from an Anatolian of Near Eastern source (Pernicka 1990, 57). It is reasonable to assume that an exchanged foreign silver object had been recycled somewhere in East Central Europe. Eventually, lead isotope analysis might settle the issue. Some of the copper discs of related shape and ornamentation are helpful for establishing the chronological span of the type, which has no comparison in more recent contexts (Table 2).

Table 2. Chronology of copper discs related to the Stollhof type of gold discs.

Age Range	Site	Reference
3915/3907 BC	Hornstad-Hörnle I (dendro-dates of settlement)	Dieckmann 1990/1992
3605-3363 cal. BC	Hlinsko (^{14}C dates of pits, Lab.Nr. GrN.6941/6942)	Nemejcova-Pavukova 1981

3. Gold and Silver in the 3rd Mill. BC: First Stage (ca. 3300-2600 BC)

This span of time has been chosen in view of Near Eastern evidence and according to the limitations imposed by calibrated radiocarbon data. It includes the Jamdat Nasr phase with its significant innovations (Palmieri 1981, Moorey 1985). The lower limit is set by the Fara texts, which constitute, together with other archives from subsequent centuries in Mesopotamia and Syria, a new major source of information concerning economy and society. In some areas, phases extend beyond the proposed brackets. This is the case with Early Helladic II/Early Minoan II in the Aegean (Warren and Hankey 1989). For the present discussion, however, a macro level seemed appropriate (cf. Fig. 2).

3.1 THE LEVANT AND THE NORTHERN CAUCASUS

Sophisticated ornaments and hammered vessels have been found in Egypt, the Levant, Mesopotamia and the Northern Caucasus. Regional differences are distinct. So far, golden vessels are unknown in Mesopotamia (Müller-Karpe 1990). The Royal Graves of Ur, the only exception, date to the beginnings of the following stage, after 2600 BC.

Larger amounts of gold have been found in Egypt than anywhere else, most of it in high-ranking contexts. In spite of looted graves, gold mountings of wooden construction elements and pieces of furniture have remained as distinct markers of affluent gold resources in the royal sphere. Jewellery design was characterized by a combination of different materials, precious stones as well as gold and ivory. Silver was almost absent. Copper vessels became common for washing purposes (Radwan 1983). As an exception, three golden drinking vessels were found in the unlooted grave of Hetepheres, the mother of Kheops.

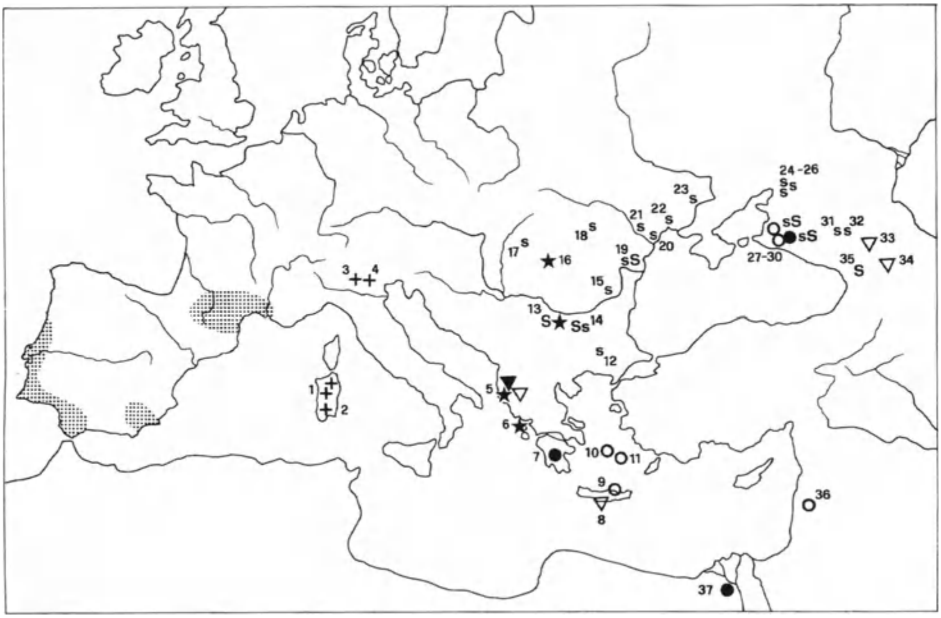

Fig. 2: Stage 1 (3300-2600 BC). Dotted areas: Gold finds in western Europe (after Pingel 1986, Eluère 1977). Crosses: silver finds of the central Mediterranean. Triangles: weapons of silver and gold. Circles: metal vessels. Full signs: gold; open signs: silver. Star sign: golden ear-rings of Leukas type. S: spirals of gold; s: spirals of silver.

List of findspots: 1 Filigosa and Corte Noa (Nuoro, Sardinia); 2 Serra Cannigas (Cagliari, Sardinia); 3 Remedello Sotto (Brescia I); 4 Villafranca (Verona I); 5 Velika Gruda/Mala Gruda (Kotor, Montenegro); 6 Leukas, Nidri Plain (Greece); 7 Arcadia (? no context); 8 Koumasa (Crete); 9 Mochlos (Crete); 10 Naxos (Greece); 11 Amorgos (Greece); 12 Trojanovo (Stara Zagora BG); 13 Tarnava (Vraca BG); 14 Goran/Slatina (Lovetch BG); 15 Zimnicea (Teleorman R); 16 Ampoita (Alba R); 17 Balmazujvaros (Hajdu-Bihar, HU); 18 Brosteni (Baia R); 19 Glubokoe (Ukrainia); 20 Odessa (Ukrainia); 21 Sukleya (Moldavia); 22 Usatovo (Odessa, Ukrainia); 23 Nikopol (Ukrainia); 24 Donskoi (S' Russia); 25 Ch. Veselyi (S' Russia) 26 Ch. Popova (Rostov/Don, S' Russia); 27 Maikop (N' Caucasus); 28 Staromyshastovskaya (N' Caucasus); 29 Novosvobodnaya (N' Caucasus); 30 Letnitskoe (N' Caucasus); 31 Ust-Dzhegutinskaya (N' Caucasus); 32 Suvorovska (N' Caucasus); 33 Nalchik (N' Caucasus); 34 Martkopi (Georgia); 35 Sachkhere (Georgia); 36 Tell Farah (Palestine); 37 Gizah (Egypt).

In the Levant, which was linked with varying intensity to both riverine civilizations, the relative scarcity of precious metals deserves attention. It contrasts with the situation in the more distant Caucasus. Exceptional pieces are a silver figurine (Tirat Zvi) and a silver cup (Farah North). Multiple burials were the rule in Palestine. Gold as well as silver ornaments, mainly beads and rings, appear among the grave offerings (Hanbury-Tenison 1986). An incipient dual value system of precious metals is a possibility, though this must remain a working hypotheses as long as sources are scarce. As a case study for limiting factors in settlement archaeology, Byblos is especially revealing. The early urban settlement (the K-levels in the revised stratigraphic order established by Saghieh 1983) ended in a conflagration. Even the walls seem to have been robbed and the stones re-used for new buildings, which were constructed under a new ruler, a governor (ensi) installed by the expanding Akkadian superpower. Moorey (1985, 75) certainly put it correctly when he stated:

"The precious metals were always carefully plundered from any accessible place when cities were sacked, and they were always sparingly placed in graves, where they were also subject to plundering."

In Georgia as well as in the northern Caucasus, between Maikop and Nalchik, at least half a dozen exceptionally prestigious tumulus burials, some of them looted in spite of their huge overburden, and a probable hoard (Staromyshastovskaya) are actually known; additional, unpublished evidence will be forthcoming (Iessen 1950, Lordkipanidse 1991, Chernych 1992). The graves were furnished with metal vessels, usually of copper or silver; further the container of the hoard was a silver flask covered by a bowl of the same material. Two golden vessels from the well-known Maikop barrow are an exception. They were associated with 14 silver vessels, some of them with elaborate decoration in repoussé (Andreeva 1979). There are thousands of gold ornaments and beads of gold and silver. In two graves of the region, weapons of silver were found; generally, several copper axes and daggers were put into the first class graves. In comparison to adjacent areas with different burial customs and a main archaeological emphasis on settlement research (Anatolia, Mesopotamia and the Levant), the evidence is biased. The presence of sumptuary goods in a society whose settlements are not sophisticated at all would be compatible with a scenario of warlords dominating a borderland with wealthy neighbours. But more investigations and dendro-data are needed.

3.2 SOUTHEASTERN EUROPE

From the North Pontic steppes to the East Central Balkans, tumulus burials sprinkled with ochre are distributed in clusters of uneven density. Metal equipment, although not regularly present, is rather uniform throughout the vast area. Small silver rings, spirals and beads are extant from the Volga steppes to Romania, where they were also found in flat graves (Häusler 1974, 1976, Petrescu 1950, Alexandrescu 1974). The repertory of shapes is consistently uniform, and so was display, normally as head ornaments (Fig. 3). Golden beads, spirals and rings are attested in more restricted areas: in the Caucasus and to the west of the Dnjepr, apparently not connected by a land route. One of the richest western findspots is the Kurgan group of Goran/Slatina in northern Bulgaria where, in a total of 34 graves under 8 mounds, five graves had silver as well as gold ornaments and three had only silver spirals (Kitov et al. 1991). This ratio of precious metals can be compared with the Round Graves excavated by Dörpfeld on the island of Leukas in the Ionian Sea (Dörpfeld 1927, Branigan 1975, cf. Table 3). The gold sources have not yet been investigated thoroughly.

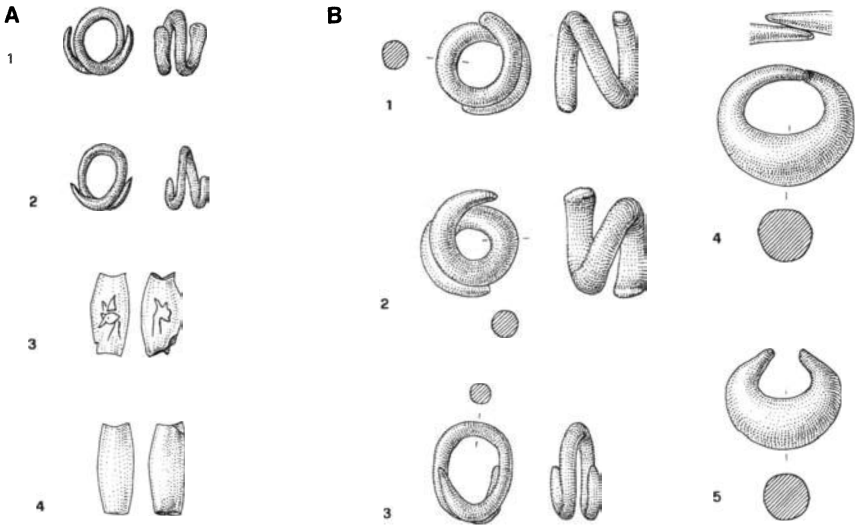

Fig. 3: Spirals, small rings and beads: A Goran/Slatina (BG), gold; B Zimnicea (R), silver (after Kitov et al. 1991; Alexandrescu 1974). Scale 1:3.5.

Table 3. Ratio of gold and silver in two well-equipped cemeteries.

Nr. of burials	Gold & Silver	Silver only	% of graves with precious metal objects
Goran/Slatina: 34	5 graves	3 graves	23% (small objects only)
Leukas, R-graves: 45	4 graves	3 graves	15% (more and bigger objects)

In the Adriatic area, two tumulus burials, also of early 3rd Mill. date but only distantly related to the eastern Kurgan groups, were investigated near the town of Kotor in Montenegro (Primas and Raub 1992, Parovic-Pesikan and Trbuhovic 1971). The associated pottery belongs to a regional group with Vucedol affinity. The deceased individuals were not sprinkled with ochre. The metal finds consisted of golden rings worn at the occipit and, in one of the graves (Mala Gruda), weapons of gold and silver, while the other (Velika Gruda) had equipment made of arsenical and tin bronzes. Analyses using X-ray fluorescence (cf. Table 4) showed that the dagger was cast of a hardened alloy with 5% copper. With its short tongue and the arrangement of the rivets (Fig. 4, 1) it belongs to a Levantine group (cf. Philip 1989, 110-130). For the moment it is the only golden specimen known. However, the archaeological record of this period is biased in important places like Byblos, as noted before. Textual evidence from a somewhat later context at Ebla can fill the gap to a certain extent: Several daggers of gold and silver, were registered there and changed hands in a way that is not yet clear (Amadasi Guzzo 1988).

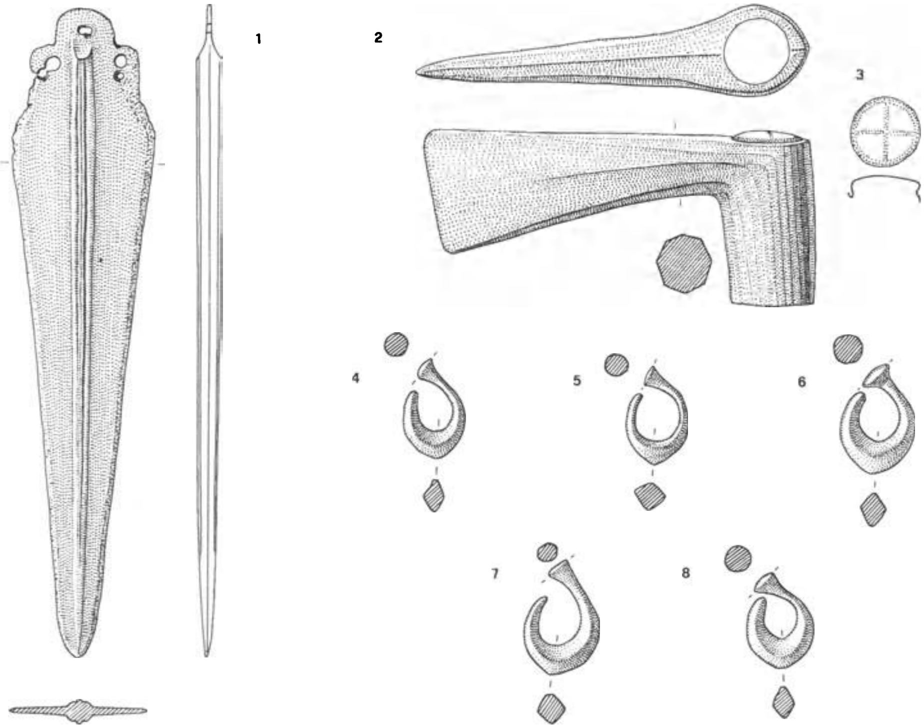

Fig. 4: Dagger, axe, ornament and rings from Mala Gruda (Kotor, Montenegro) 1, 3 - 8 gold; 2 silver/copper-alloy. Scale approx. 1:4.

The golden rings of the Montenegrin tumuli are most probably sintered, not cast. Their section is distinctly rhombic in the thickened middle part, where the surface shows extensive traces of filing. They consist of a gold that is rich in silver; copper was not detected. Inspection under the microscope revealed that two of the rings had inclusions of osmium and iridium, which were subsequently analyzed using energy dispersive X-ray equipment in a scanning electron microscope (Primas and Raub 1992). The debate on platinum group inclusions in gold has been closed provisionally by the well-founded statements of Meeks and Tite (1980). They concluded that compositions of this type of inclusion do not necessarily provide a basis for characterizing the gold source. In general, the presence of platinum group inclusions is indicative of provenience from placer deposits.

Golden rings of the variety with tapering ends (Fig. 5), which were named Leukas type by Primas (1992), are known from one of the already mentioned Early Helladic round graves of Leukas (R 15b). Two related pieces, which are somewhat larger, were found in tumulus graves in northern Bulgaria and Transsylvania (Panaïotov 1989, 88, Ciugudean 1991, 93).

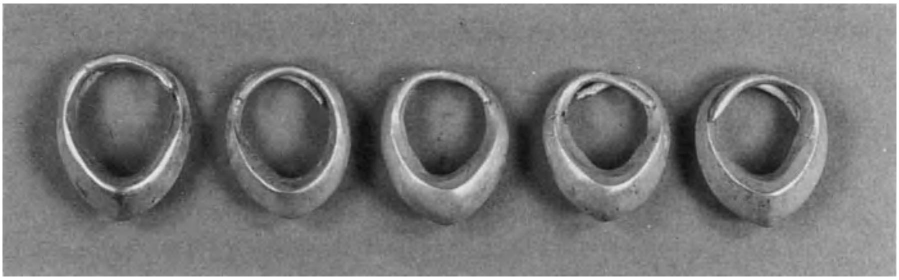

Fig. 5: Golden rings of Leukas type from the Velika Gruda head ornament (Kotor, Montenegro). Scale approx. 2:1.

Table 4. XRF analyses of Montenegrin gold objects (by the Forschungsinstitut für Edelmetalle und Metallchemie, Schwäbisch Gmünd).

Type	% Au (± 1)	% Ag (± 1)	% Cu (± 1)
Dagger	60	35	5
Disc	90	10	n.d.
Ring 1	77.5	22.5	n.d.
Ring 2	77.1	22.9	n.d.
Ring 3	68.7	31.3	n.d.
Ring 4	68.3	31.7	n.d.
Ring 5*	81.9	18.1	n.d.
Ring 6	68.7	31.3	n.d.
Ring 7*	83.9	16.1	n.d.
Ring 8	73.8	26.2	n.d.

Dagger and disc: Mala Gruda; Rings: Velika Gruda. *Inclusions of Os/Ir.

The silver axe from the Mala Gruda tumulus (Fig. 4, 2) belongs to the vast group of transverselly socketed axes distributed in considerable typological and chronological variety from Iran, Mesopotamia and the Caucasus to the Balkans and East Central Europe. A less elaborate replica in copper comes from the Central Dalmatian hoard of Topolje. Local manufacture with recycled silver from a foreign source seems probable for the Mala Gruda specimen and could be verified or discarded by comparative analyses.

In conclusion, the Bay of Kotor, with its excellent harbor facilities, was linked at the start of the 3rd Mill. BC with the island of Leukas, not by burial customs or pottery style, but by the mutual presence of silver and of almost identical golden rings. Both places, Leukas and the Bay of Kotor, were interconnected with other areas, too. Seafaring activities seem very probable indeed; primarily, interactions with the Black Sea region and the Levant deserve further studies.

3.3 THE AEGEAN

In the Aegean, the gradation of grave furniture continued to be made by traditional means like figurines and marble vessels well into the 3rd Mill. BC (Doumas 1977). During the second quarter of the millenium, however, metal offerings made a regular appearance in up to one third of the burials, for instance at Manika on Euboea (Sampson 1988). Two areas can be distinguished by their choice of precious metals: Crete and Leukas introduced a dual gradation, using gold as well as silver, while in the Cyclades, on Euboea and at Poliochni on Lemnos gold was virtually absent at this time. Only a small proportion, 2-3% of the cycladic graves contained silver objects. But the trend, at least in some of the islands, was clearly a rising one, with greater abundance in silver during the second half of the 3rd Mill. BC (Renfrew 1972).

In settlements, polymetallism is attested by traces rather than products. Thermi on Lesbos is ranking among the earliest in the region, where the spectrum of metal objects, though small in number, embraces gold, silver, lead and tin, together with copper and copper alloys (Lamb 1936, Begemann et al. 1992). The scarcity of metal finds in the so-called first settlement of Troy, uncovered by Schliemann and revised by Blegen, is not an exception (Blegen et al. 1950, Schmidt 1902, chronology: Korfmann 1986). The situation on mainland Greece is similar. The well-known golden sauceboat housed in the Louvre, which is alleged to come from Arcadia, has no context (Branigan 1974).

The local availability of gold in western Anatolia and Macedonia and of silver and copper ores in several spots along the Aegean are certainly not a sufficient explanation for the change of preexisting value systems. Especially revealing is the situation of Leukas, where no metal ores are existant, but the grave equipment can compete with contemporary evidence on Crete. On this island, early gold finds as well as a silver bowl (Branigan 1968) come from a few graves at Mochlos on the northeastern coast. The majority of goldwork in Crete belongs to the following periods (Branigan 1974), which brought significant advances in metallurgy and changes in lifestyle. The communal tombs of the Mesara plain conform to this trend, though checking their chronology is not an easy task (Warren and Hankey 1989). The three silver daggers from Koumasa (cf. Primas 1988, 174) most probably belong to the early group of precious metal finds.

The resulting scenario would be that people from several islands of the Aegean and the Ionian Sea were able to participate in the developing networks of exchange, which were rising in the Black Sea and in the Levant. The virtual absence of precious metal in contemporary Cyprus tends to invalidate eventual hypotheses of a preference for nearest neighbour interactions in the Mediterranean.

3.4 WESTERN AND CENTRAL EUROPE

The map shown in Fig. 2 indicates that the continent was split into at least three areas of different social display. In Central Europe hardly any precious metal finds are so far known from contexts dating from around 3000 cal. BC. This situation contrasts with the gold finds of the so-called pre-bellbeaker period of the Iberian peninsula and southern France. They have been studied by Eluère (1977) and Pingel (1986) respectively. Sheet gold as well as beads were present in both areas. If the absence of silver and lead is not caused by the current state of research, then the early Iberian metallurgy would seem to have evolved without relevant interactions with the central and eastern Mediterranean.

In Sardinia, silver remained in use during this phase, but even Corsica apparently did not get anything of it (Camps 1988). From continental Italy we have no gold at all, but two silver objects found in the eastern Po valley: a pin from Remedello (Cornaggia Castiglioni 1971) and a crescent-shaped sheet ornament from Villafranca Veronese (Ghislanzoni 1932). The pin has good but not identical counterparts in copper or bronze rather far away in the Sachkhere group of Georgia (Lordkipanidse 1991, Plate 6). The chronology of the Remedello group and of related chalcolithic cemeteries has changed since ^{14}C data became available (Barfield 1983, Bagolini 1981). Calibrated age ranges are distinctly earlier than those of bellbeaker contexts, which corresponds well with recent work in southern France and with transalpine connections.

In addition to copper and gold, some beads of lead were found in southern France (Arnal et al. 1978, Guilaine and Vaquer 1978). Their exact date is not clear in every case; lead remained in use during the following phases. The same problem arises for several of the gold objects, too. A single silver bead is known from Soyons, but unfortunately again without a context. The role of beads in general deserves more thorough studies. They possibly functioned as a medium of exchange in societies where metal was accepted as such.

4. Second stage: Gold and silver from ca. 2600-2100 cal. BC

From the Fara texts, which were written around 2600 BC, we know that copper and silver were then used as a means of payment in Mesopotamia; at this time copper was more important in economic transactions than silver (Müller 1982). During the Akkad period, after 2400 cal. BC, the silver standard of value became firmly established in vast parts of the Near East (Foster 1977, Snell 1982). Though silver was most important as a unit of account and did not have to be physically present in every transaction, a regular supply of relatively cheap silver was a precondition of the system. The steadily developing silver metallurgy in adjacent areas like Iran, eastern Anatolia, the Caucasus and the Aegean are indicators of involvement. The Mesopotamian sphere of influence had now reached the important coastal town of Byblos, where a dependent governor was ruling. One of the concomitants of the silver standard of value is hoards containing scrap silver as a constituent part. This economic signal can be followed from Mesopotamia to Byblos, where a small silver vessel filled with silver fragments and a few pieces of gold foil was found in the levels of this period (Moorey 1985, 117, Dunand 1958, Nr. 17512).

In the Near Eastern economy, gold was now exchanged in two ways: as a commodity of high value and as a special-purpose gift, including tributes. In Ebla, for instance, gold had five times the value of silver per weight unit (Pettinato 1979). The surrounding regions became embedded in these networks directly or through intermittent powers. Progress in the manufacture of jewels is just as evident as the technique of producing gold and silver vessels in large areas now including Anatolia. The presence of silver ingots of graded weight in Troy indicates knowledge of the silver currency system (Schmidt 1902, 236).

A silver cylinder seal from Mochlos shows, that Crete was involved, too. According to Aruz (1984) the seal is of Levantine provenience and mid 3rd millennium date. It was found in grave 1 together with stone vessels, a copper dagger and beads of gold and other precious materials and may well be a lonely sign of otherwise hidden interactions between Crete and the Levantine coast.

On the European scene, gold metallurgy expanded meanwhile into new areas, to the Atlantic coast of France (Eluère 1977), the British Isles (Taylor 1980) and Central Europe (Hartmann 1970, 1982). Gold ornaments in bellbeaker contexts show a rather small variety of applied techniques, which contrasts with the growing skills of the goldsmiths in Crete as well as in Troy and Poliochni on Lemnos. However, two distinct, new ornament groups appeared on the continent: a) headbands, some of them of a silver-rich gold (electrum); b) asymmetric spirals with an enlarged, leaf-shaped or basket-shaped ending (Fig. 6). These spiral rings became fashionable in different variants from Portugal and the British Isles to Central Europe, where items of silver have been found, too (Hajek 1968, Schubert 1973, Bocksberger 1976). Remarkable is a distant golden replica from Lapithos in Cyprus (Karageorghis 1968, plate 50).

In southwestern Spain, Portugal and Brittany silver appeared only at the end of the 3rd mill. BC, but then in quite considerable amounts (Pingel 1991, Harrison 1974, Briard 1978). The silver rings and headbands in graves of the Argar group and the silver cup of St-Adrien are part of a wave of innovations, which was of economic as well as ritual significance and linked a rising European nobility.

In conclusion, it can be stated that cupelled silver, the product of an advanced technology, has much to tell about networks of interaction. More analytical work is necessary to differentiate between cupelled material and the use of native silver, silver minerals or natural gold-silver alloys with low gold content.

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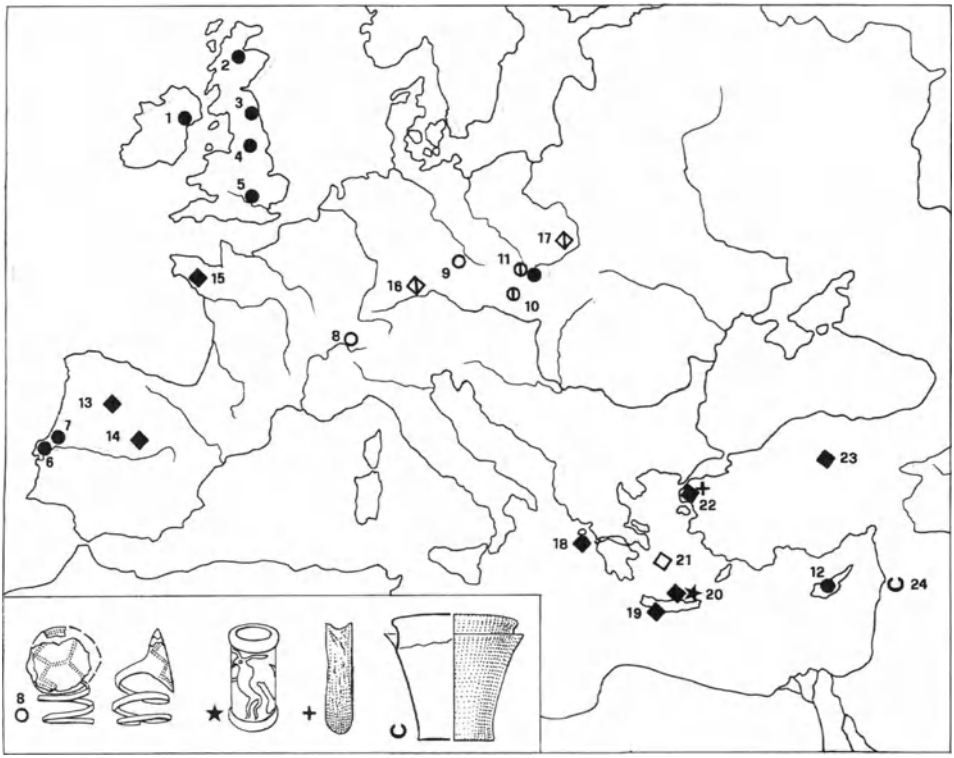

Fig. 6. Stage 2 (2600-2100 BC). Circles: small (spiral) rings with a disc- or basket-shaped ending. Squares: headbands. Full signs: gold; open signs: silver; divided signs: electrum. Additional signs: cf. findspots.

List of findspots: 1 Dacomet (IR); 2 Orbliston (Morayshire GB); 3 Kirkhaugh (Northumberland GB); 4 Boltsby Scar (York GB); 5 Barrow Hill, Radley (Berkshire GB); 6 Ermigueira (Lisboa P); 7 Cova da Moura (Lisboa P); 8 Sion (Valais CH); 9 Praha-Bubenec (CR); 10 Borkovany (Breclav, CR); 11 Predmosti (Prerov, CR); 12 Lapithos (Cyprus); 13 Aldeiavieja (E); 14 Entretérminos (E); 15 Plouhinec (Morbihan, F); 16 Grossmehring near Ingolstadt (Bavaria D); 17 Samborzec (Tarnobrzeg PL); 18 Pelikata (Ithaca, GR); 19 Pyrgos (Crete) 20 Mochlos (Crete), star sign: cylinder seal, silver; 21 Chalandriani (Syros, GR); 22 Troy (GR), cross sign: ingots of silver; 23 Alaca Hüyük; 24 Byblos: small silver vessel containing scrap silver.

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CHAPTER 3

Sources of Precious Metals in Europe

Chapter 3

MINERAL ECONOMICS, MINERALOGY, GEOCHEMISTRY AND STRUCTURE OF GOLD DEPOSITS: AN OVERVIEW

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ABSTRACT. The desire for gold has dramatically influenced the history of man. Its price is clearly related to its reputation as a safe store of wealth, the fear of inflation and war increasing it markedly. Because gold is usually alloyed with silver and copper, not only in jewellery, but also in coins, these three elements are collectively known as "coinage metals" and were almost certainly three of the first metals known to man. In the upper crustal rocks of the earth the gold to silver ratio is about 1:17. Copper and silver react easily with sulphur but gold does not. Gold and silver are therefore found in different types of deposits; silver as a sulphide and associated with other suphides, gold in elementary form. Gold deposits were formed throughout the whole history of earth, the size and structure of gold deposits depends on the local geological situation.

1. Introduction and fundamentals of mineral economics

Due to its great natural beauty and resistance to decay gold has retained its fascination for more than 5,000 years. The desire for gold has dramatically influenced the history of man. It has lured men across the oceans and continents, over the highest mountain ranges, through nearly impenetrable jungles and into glowing hot deserts, sometimes with deep political and social changes across whole continents. One can take as examples of this both the Spanish "conquistadores", destroying the cultures of the Indios in south America in the search of the "Eldorado" and the settling of the whole American West essentially started by the "gold rush" of 1849 in California. One should consider also the gold rush in New South Wales in Australia in 1851 as a result of which the population of Australia doubled in the next seven following years, reaching one million.

The gold digger or prospector of those times in America and Australia was a very popular and very typical person (Fig. 1).

Today the greatest hoard of gold in the world is the 30,000 tons of bullion lying in the vaults of the US Federal Reserve Bank and belonging to about eighty different nations (Greenwood and Earnshaw 1984).

In nearly all cultures the term "gold mine" is not only used to indicate a place where gold is mined, but much more generally as a metaphor for a source of safe and abundant income. Any mining geologist is immediately aware that in using this metaphor one stands on very shaky ground. Peters (1978) characterizes the situation as follows: "A mine, even the ghost of a mine in a remote desert canyon, is evidence that the minerals in that specific location

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were valuable to someone at some time. The ghost may be brought to life if the minerals in that location have sufficient value now".

Fig. 1: Gold prospector, California around 1850.

Time and the price of the mineral commodity, dictated usually by demand, are the key to understanding the difference between a deposit and an occurrence. A deposit is an accumulation of a mineral commodity, in the present case gold, that can be mined with profit at any given time. If this is not the case the deposit has to be called an occurrence. From the above, it also follows that with rising prices an occurrence may be transformed suddenly into a deposit, whereas with falling prices the opposite will happen. The profit of a mining operation is given by the difference between the cost of the production of the commodity (including the costs of mining, concentration, extractive metallurgy, refining and transport) and the price paid by the customer.

Reserves are also, in the light of the above, not a fixed entity. With rising prices for a given mineral commodity an increasing number of occurrences of that commodity are transformed into deposits, often dramatically increasing the reserves. The cry of alarm of the Club of Rome in 1972 (Meadows et al. 1972) that some raw materials might be exhausted very rapidly resulted from incomplete consideration of this close relationship between price and availability of mineral commodities.

The history of gold mining is an excellent example of the interrelationships of price, mining activity and availability. In prehistoric times until the discovery of the Americas gold had a much higher value relative to the labour costs and the price of ordinary goods. The consequence of that was that gold was intensively mined by a low cost work force in large areas of Europe from occurrences that nowadays nobody would consider to be of any economic interest. A close look at the traces of early gold mining in fact reveals that large areas of central Europe are scattered with signs and relics of prehistoric to early medieval mining.

The increasing interest in gold exploration and mining in recent decades is not only due to the rise in the price of gold (see below), but also to the improvement in the last ten to fifteen years in mining and processing machinery and methods, enabling the treatment of large tonnages of low grade (down to 0.7 ppm) gold ore.

The price influences not only the search for minerals, but also the scientific interest in specific mineral commodities. As a result of the fixed gold price from 1935 until 1971 both scientific research and exploration of gold deposits ceased; this decrease in interest is reflected in the lapse in time between the appearance of Emmons' classical textbook on gold deposits, which was published in 1937, and those of Boyle and Bache which were published in 1979, 1984 and 1982, 1991 respectively. The gold price increase from 1971 onwards is shown in Fig. 2 by the monthly average London gold price from 1968 to 1992 (Murray et al. 1993). This high gold price prompted a large increase in exploration and mining activity.

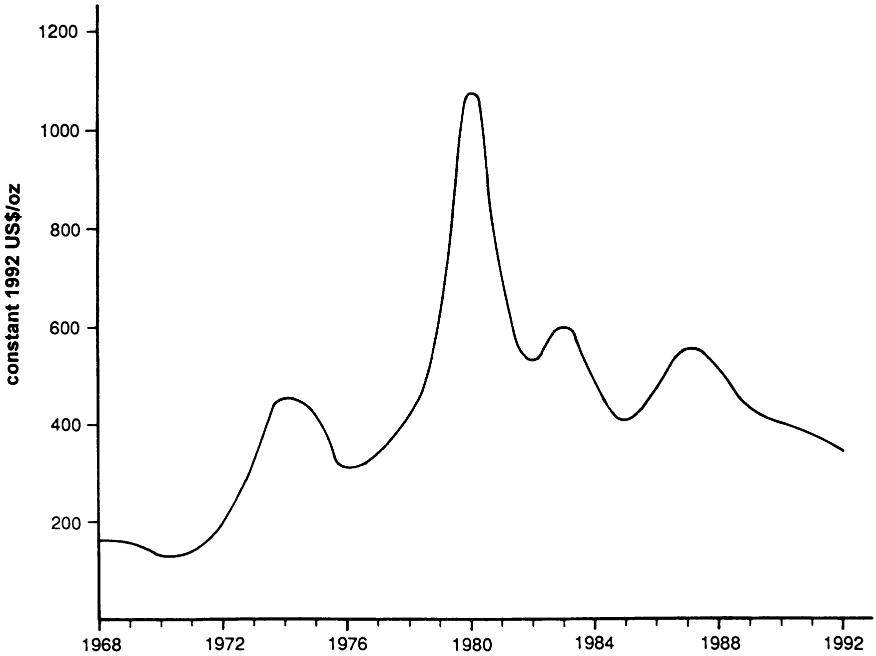

Fig. 2: The monthly average London gold price in US $ per troy ounce from 1968 to 1992 (Murray et al. 1993).

The price of gold is, and always was, clearly related to its reputation as a safe hoard of wealth. As an example of this it can be seen in Fig. 2 that in the recession periods around 1974 and 1980 the gold price increased markedly. The enormous price increase around 1980 was due not only to inflationary tendencies, but by the combination of these with the additional fears produced by the invasion of Aghanistan by the USSR, the second oil shock, the Iranian revolution and the Iran/Iraq war. The decrease in gold price in the last few years is the consequence of the erosion of the fears that pushed investors into gold in the late 1970s. Additionally, severe inflation is still regarded - for how long is an open question - as a thing of the past.

2. Geochemistry of gold

Gold, together with silver and copper, are transition metals that are found in the IB subgroup of the 4th to 6th periods of the periodic table of the elements (Fig. 3).

IA	IIA	H	He									IIIB	IVB	VB	VIB	VIIB	0
Li	Be											B	C	N	O	F	Ne
Na	Mg	IIIA	IVA	VA	IVA	VIIA	←	VIII	→	IB	IIB	Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	**Cu**	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	**Ag**	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	**Au**	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Fig. 3: Periodic table of the elements. The "coinage metals" including gold are found in the IB subgroup of the 4th to 6th period.

Cu, Ag and Au are collectively known as "coinage metals" because of their former usage. These elements were almost certainly three of the first metals known to man. The reactivity of Cu, Ag and Au decreases down the group, and in its inertness gold resembles the platinum metals. Copper and silver react easily with sulphur. In contrast to this the affinity of gold for sulphur is very low. Sulphur is generally present in ore-forming processes. This explains the fact that in most primary deposits the gold and silver ratios are very different from the crustal one (Fig. 4). Silver is typically associated with sulphides, commonly with lead sulphide, galena.

The relative abundances of the three coinage metals in the earth's crust are: Cu = 68 ppm, Ag = 0.08 ppm and Au = 0.004 ppm. Gold belongs to the group of 23 trace elements forming together only 0.0003 % of the total elements present in the earth's crust (Fig. 5). In sea water gold is present to the extent of approximately 1×10^{-3} ppm, but no economic means of recovery has yet been devised.

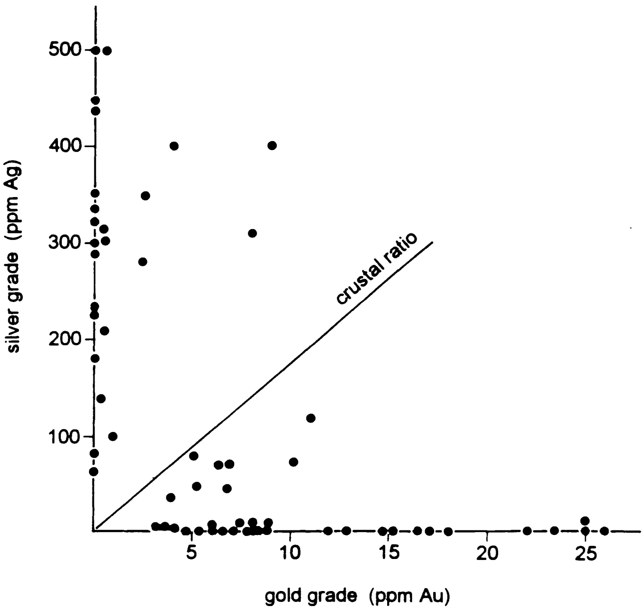

Fig. 4: Graph of gold grade vs. silver grade in 63 Au-Ag deposits according to Ivosevic (1984). It can be seen that gold and silver form separate deposits and that mixed gold/silver deposits are rather rare. This is due to the affinity of silver for sulphur (see text).

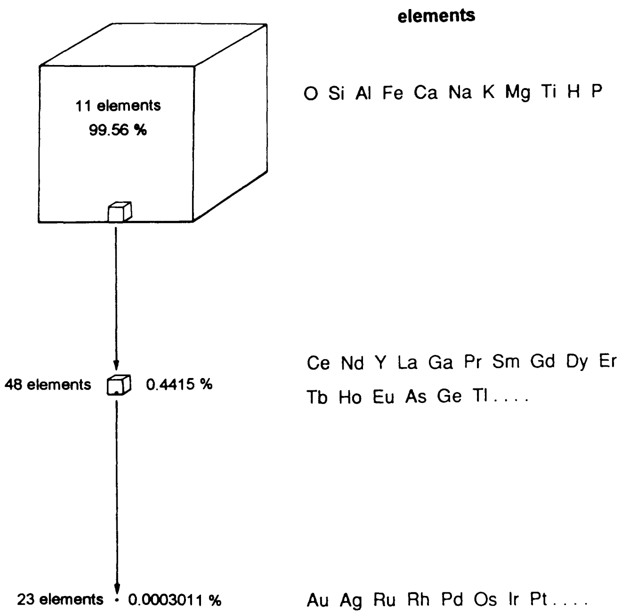

Fig. 5: Graphical representation of the abundance of the main, minor and trace elements of the earth crust. Gold and other precious metals with 15 other elements form only 0.0003 % of the total earths crust.

Experiments have shown that copper, silver and gold may form not only ternary Cu-Ag-Au alloys but also extensive series of alloys with many other metals like magnesium, zinc, indium, cadmium, aluminium and tin, including many intermetallic compounds. Some examples of gold intermetallics are: AuMg, AuZn, Au_3In, Au_5Zn_8, $AuZn_3$, AuCd, Au_5Cd_8, Au_3Al, Au_3Sn. Most of these compounds are not found in nature.

Gold and silver do form a solid solution series; the mineral electrum represents such a silver-rich gold-silver alloy. In primary deposits gold is often chemically associated with tellurium, bismuth, and silver, less frequently with antimony, selenium and copper. Typical minerals are, for example, $AuTe_2$ (calaverite), $Pb_5Au(Te,Sb)_4S_{5-8}$ (nagyagite), Ag_3AuTe_2 (petzite), $(Au,Ag)_2Te_4$ (sylvanite), $CuAuTe_4$ (kostovite).

In primary deposits elementary gold is mainly found with pyrite and arsenopyrite. This seems to be due to the electrochemical precipitation of elementary gold from hydrothermal solutions carrying gold as chlorides, sulphide and polysulphide complexes (see Möller, this volume: "Accumulation of gold by electrochemical processes"). In secondary deposits, i.e. fluviatile or marine sediments, gold is found enriched in elementary form as grains in so called *placer* deposits. The chemical composition of the gold grains and their shape reflects the distance of such secondary deposits from the primary deposits from which they derive. Gold grains in placers found at a great distance from the primary occurrences are usually flattened and/or bent and folded, and often formed of rather pure gold. The original silver and gold contents found in the gold grains of the primary deposits have been lost.

3. Classification of ore deposits

Ore deposits, like gold occurrences, are basically nothing more than places where elements have been accumulated in a restricted area by one or more geological processes, producing a concentration well above the crustal average of those elements.

The deposition of gold in primary deposits usually takes place via metal-rich hydrothermal fluids circulating in open spaces and depositing the gold as a result of cooling and/or boiling of the metal-rich fluids. Where such hydrothermal fluids reach the surface the precipitation of the metal contents by cooling and boiling can be directly observed, as in some of the thermal springs in the Altiplano of Bolivia or those, like the Champagne Pool, in New Zealand (Fig. 6).

The concentration rate needed to produce a deposit varies depending on the elements. Primary gold deposits with values less than 4 grams per ton are currently uneconomic. The average gold content of the crust (Clarke value) is 0.004 ppm i.e. 0.004 grams per ton. Gold must therefore be concentrated by natural processes by a factor of 1000 in order to give a deposit that can be mined under current conditions. For comparison the Clarke value of iron is 62,000 ppm, i.e. 6.2 %. Big mining operations like those in Australia, North America and Brazil produce concentrates of about 70 % Fe. The concentration factor in this case is only about 10.

Fig. 6: Precipitation of reddish gold-rich metal slimes (at the border of the lake) in a thermal spring (Champagne Pool) of northern New Zealand.

Even now there is still a debate about the primary sources, the chemical composition of the gold-carrying hydrothermal fluids and the mechanism of gold precipitation that finally forms the gold deposits. These uncertainties are also reflected in the classification of gold deposits. This may be based on structural, mineralogical or genetic aspects, but usually derives from a combination of all three. The first two are the most interesting to the exploration geologist, whereas the genetic aspects are often considered to be more of academic interest, in spite of the fact that there are classic cases in which they have led to the development of successful large scale exploration strategies. A classification combining grade and tonnage is also used, mainly for academic purposes.

In the following, a brief summary of the basic concepts incorporated into classical theories of ore deposits, from the 16th century to the present day will be presented first, followed by the classification used for gold deposits, and, finally, examples of the most relevant types of deposits are given.

A comprehensive treatment of current trends in the theories and classification criteria of ore deposits in general, and of gold mineralization types and processes in particular, with a complete discussion of the connected problems, is beyond the scope of the paper.

4. The non-genetic classification

The classification of ore deposits began with the book "De Re Metallica" by Agricola (1556), a German by the name of Georg Bauer (Fig. 7).

Fig. 7: Portrait of Agricola (by permission of the Heimatland Sachsen Chemnitz GmbH).

He developed his ideas by studying the deposits of the Erzgebirge, also called the Ore Mountains. His classification, as well as those proposed later on by the internationally pre-eminent German school, represented by e.g. Werner (1791), Breithaupt (1849), von Cotta (1859), von Groddeck (1879), Müller (1901), Beck (1909), Stelzner and Bergeat (1904-1906), Beyschlag et al. (1914), was based mainly on structural features such as mineralization in beds, veins, stockworks and impregnations. De Launay (1913) emphasized both host rocks and structural types to produce a typological classification; this was also achieved by Bateman in 1950, who differentiated between segregation, pyrometasomatic substitution and cavity-filling ore deposits. Since then Raguin (1961) and Routhier (1963) distinguished thirty types of ore deposits, based on host rock types, structural features and mineralogical associations. All these classifications are deliberately founded on combinations of mineralogical and structural characteristics which are easy to observe, and avoid genetic criteria as much as possible, in order to facilitate application in the field.

5. The genetic classifications

Genetic processes as classification criteria have been used, for example, by Lindgren (1933, first edition 1913), Niggli (1925) and Schneiderhöhn (1941, 1949). These authors based their classifications to a great extent on the evaluation of the stability data of ore and gangue minerals, crystallization and substitution histories deduced from an extensive use of ore microscopy and on physicochemical consideration of ore-forming processes and magma crystallization.

Niggli (1925) subdivided the magma-related deposits into volcanogenic and plutogenic types, further subdividing the latter into orthomagmatic, pegmatitic-pneumatolytic and hydrothermal deposits. Subgroups are then distinguished according to their associations of predominant elements. Schneiderhöhn (1941, 1949) used physico-chemical conditions of deposition and the influence of P-T-gradients on zonal distribution of mineralizations around magma chambers to define the classes of ore deposits. Further, Schneiderhöhn (1949) stresses the distinction between deep and shallow deposits i.e. between plutogenic deposits, found in deeply eroded terrains, and volcanogenic deposits.

Within hydrothermal deposits Lindgren (1913, 1933) distinguished between hypothermal ones formed at great depth and at high temperature (300 to 500°C), mesothermal ones formed at intermediate depths and temperatures (150 to 300°C), and epithermal deposits formed at shallow depths and relatively low temperatures (50 to 100°C). Graton (1933) recognized the telethermal deposits formed at shallow depth from "nearly spent" solutions. The most widely accepted classification nowadays is a modification of Lindgren's (1933) and Graton's (1933) scheme, the best examples are reproduced in Raguin's (1961) and Guilbert and Park's (1986) textbooks, the latter including also plate tectonic concepts.

6. Influence of the plate-tectonic theory on classification

Since 1968 the plate tectonic theory has provided an exciting new view of global geological processes. Plate tectonic models have influenced theories of metallogenesis, shedding new light on the chronological and spatial distribution and genetic relationships of the various deposit groups to different tectonic settings. These relationships are discussed in the following textbooks: Strong (1976), Walker (1976), Wright (1977), Mitchell and Garson (1981) and Sawkins (1984).

7. Classification of gold deposits

The ultimate aim of the classification of ores - to find rules leading to new discoveries - is particularly relevant for gold. This is the reason why exclusive classifications have been developed for gold deposits. The first well-known textbook devoted entirely to gold deposits is Emmons' (1937). Emmons (1937) based his classification firmly on the principle that most gold deposits formed from fluids ascending from deep granitic bodies to the earths' surface. Boyle's (1979, summarized in Boyle 1984) textbook on gold deposits offers a treatment of the history, chemistry, economics and geological description of gold deposits worldwide. The textbook of Ivosevic (1984) deals with Au-Ag deposits from a predominantly genetic point of view. No less than 29 different gold deposit groups are distinguished, with a further nine containing silver only. Saager (1986) adopts the typologic classification of Boyle (1979) but attempts further simplification. In criticizing the old magmatogenic-hydrothermal theory of ore deposition, processes of regional metamorphism are stressed, forming epigenetic gold veins within narrow intervals of temperature (320°-380°C) and pressure (0.8 - 3kb). Bache (1981, 1982, 1987) and Bache and Sunarya (1987) take into account not only structural but also genetic characteristics.

8. Examples of gold mineralizations

Fig. 8 gives a simplified profile of the Kalgoorlie gold field in Western Australia. It is an example of discordant vein deposits in volcano-sedimentary country rocks. The minerals associated with free gold and gold tellurides are: quartz, ankerite, calcite, pyrite, fluorite, tourmaline, with minor amounts of chalcopyrite, galena, sphalerite, tetrahaedrite, stibnite, enargite, pyrargyrite, loellingite, specularite and magnetite. The gold to silver ratio is about 8:1.

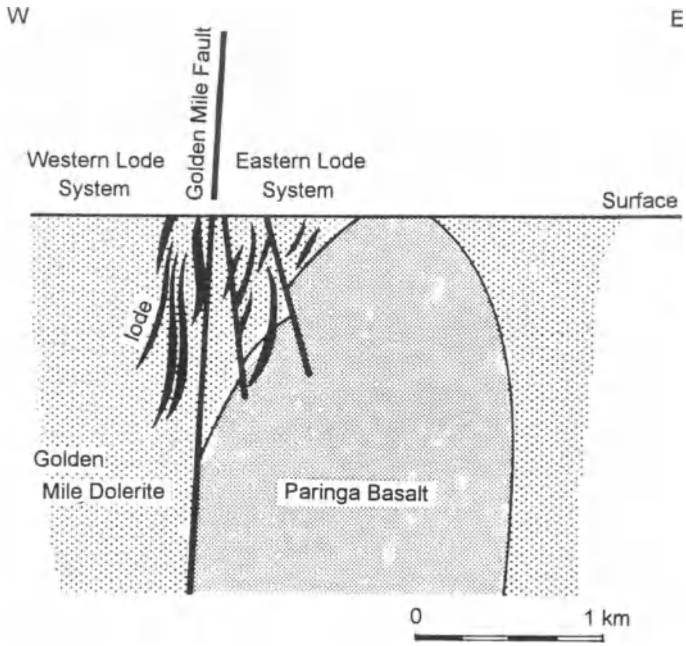

Fig. 8: Profile of the Kalgoorlie gold production area, Western Australia.

Fig. 9 gives a section through the auriferous deposit of Bendigo in Australia. Typical are the very well developed and mineralized saddle reef structures concordant with the bedding at the top of the anticlines. The minerals associated with gold are quartz, albite, ankerite, calcite, chlorite, pyrite and arsenopyrite, with smaller quantities of pyrrhotite, galena, chalcopyrite, sphalerite, stibnite and bismuth.

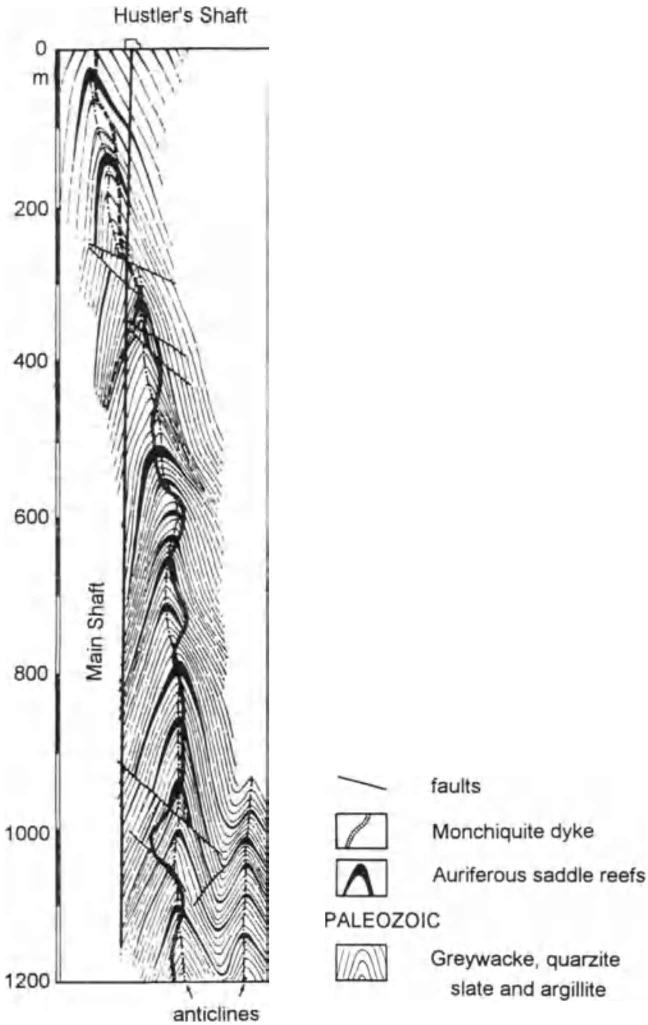

Fig. 9: Stacked saddle reefs, Bendigo goldfield, State of Victoria, Australia (after Petraschek and Pohl 1982).

The porphyry-type deposits are by far the most important copper and very important gold mineralizations on a world scale. They are formed by brecciation and subsequent low grade disseminated mineralization of shallow intrusive bodies of generally monzonitic to granodioritic composition. Porphyry-type deposits are typical bulk open-cast mineable deposits that gained importance in the last decades only through the availability of heavy mining equipment and advanced mineral preparation techniques.

Gold mineralization in carbonate rocks, like that of Carlin in Nevada (USA), has generated enormous interest in the last two decades. In Fig. 10 a schematic geological profile through the Carlin deposit with the possible flow paths of the mineralizing fluids according to Radke et al. (1980) is given.

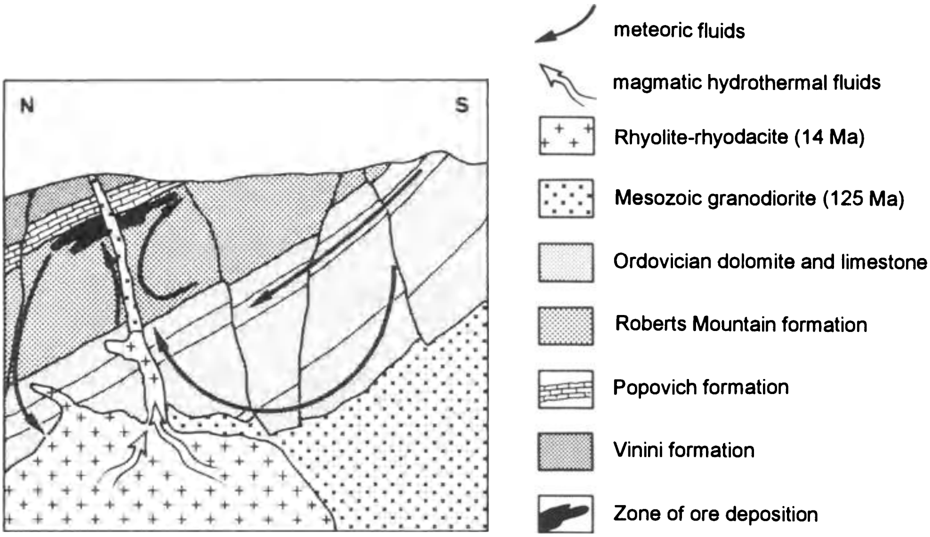

Fig. 10: Schematic section through the Carlin deposit (Nevada/USA) showing the geology and the flow paths of the mineralizing fluids (after Radkte et al. 1980).

The gold mines of the borderlands between Hungary and Romania have been important from prehistory to the present day. In Fig. 11 a schematic profile through the partially eroded volcanic edifice of the Sacarimb (Romania) gold mining area is given. The gold mineralizations are found below the deeply eroded volcanoes of Saracau, Haitau and Sacarimbu. This type of sub-volcanic deposit is usually characterized by very silver-rich native gold.

The formation of such deposits is very typically produced in rocks below volcanoes by the interaction between the magmatic fluids emanating from deep seated magma chambers and upheated meteoric fluids. The processes are given schematically in Fig. 12. This figure shows also that in such a geological setting the silver-rich base metal mineralizations are found in deeper levels than the gold-rich precious metal ones.

Massive sulphide ore bodies are formed by submarine hydrothermal activity. The process is shown schematically in Fig. 13. The gold-rich ores are deposited on the sea floor, according to Plimer (1978), at a certain distance from the hydrothermal spring in between the sulphide-rich ore body and the wolframite-rich ($CaWO_4$) one.

All the gold deposits described above have been formed by hydrothermal fluids derived from magmatic bodies or produced by the heat emanated from such melts. Detrital deposits, or placer deposits, are secondary deposits produced by the erosion of primary gold deposits and therefore not connected at all with hydrothermal fluids.

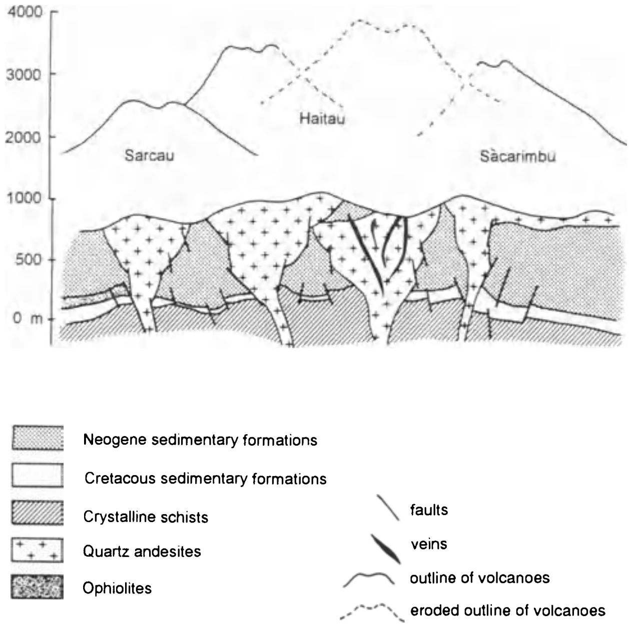

Fig. 11: Sacarimb (Nagyag) volcanic edifice and auriferous veins, Apuseni Mountains, Romania (after Boyle 1979).

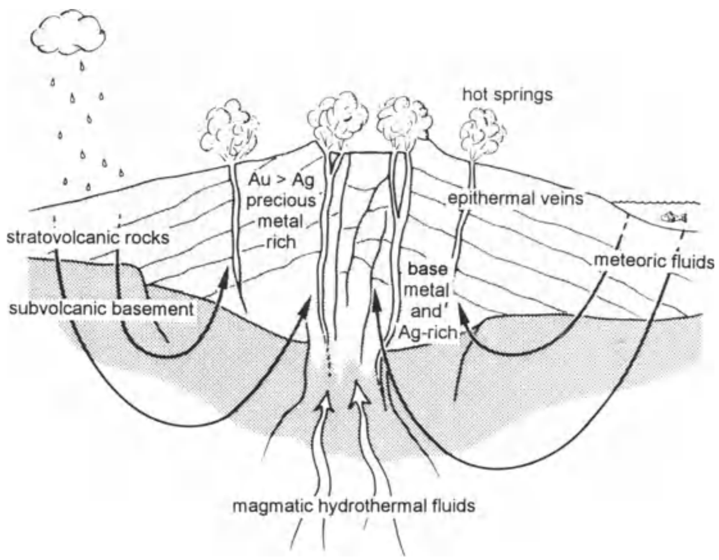

Fig. 12: Schematic representation of the formation of subvolcanic to epithermal gold deposits. The silver-rich base metal mineralizations form at deeper levels than those of gold (after Guilbert and Park 1986).

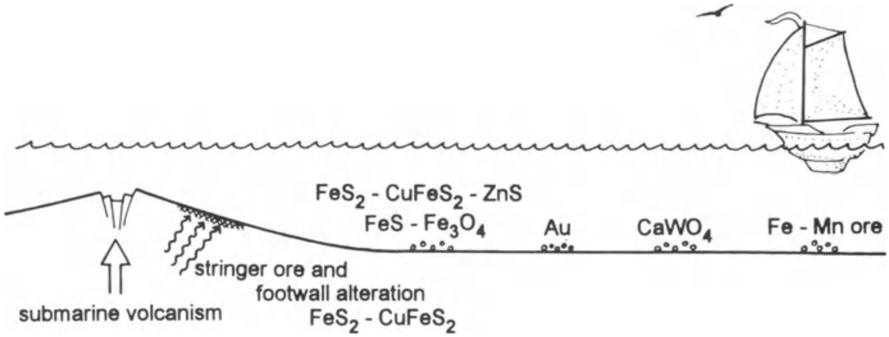

Fig. 13: Formation of gold ores on the sea floor by submarine hydrothermal springs (after Guilbert and Park 1986).

It is possible to distinguish between old placers and recent ones. Old placers are characterized by several conglomerate layers with sulphides, gold and uranium. Typical old placers are those of the Witwatersrand in South Africa or in the Serra de Jacobina in Brazil. The conglomerate layers of the Witwatersrand still form the most important gold deposit in the world. There is some debate about the formation of these old placers. The most widely accepted theory of the formation of such gold-bearing conglomerates is shown schematically in Fig. 14. It is supposed that a stream, carrying gold from the erosion of primary gold bearing rocks, deposited the conglomerates in a large fan along a shore line. The interaction of the fluviatile transport with the action of the waves of the sea produced the accumulation of the gold in specific areas of the Witwatersrand conglomerates.

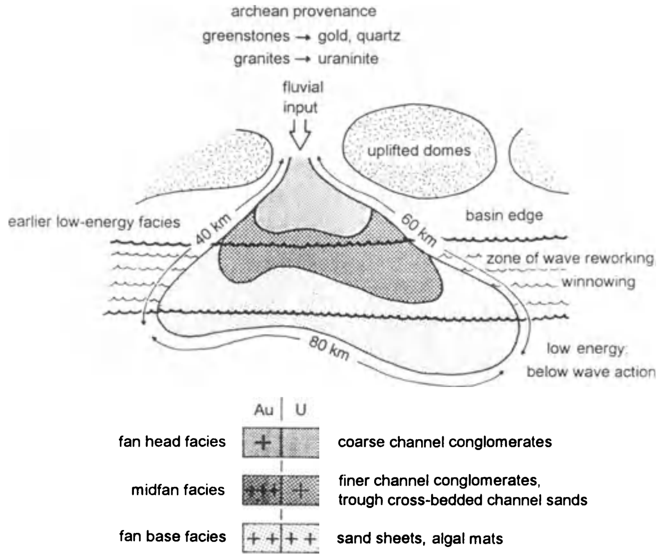

Fig. 14: Formation of the Witwatersrand conglomerates by interaction of fluviatile and marine sedimentation processes (after Guilbert and Park 1986).

Young placers are of Tertiary or Quaternary age. These placers, like old ones, were formed by erosion of preceding gold deposit types. The mechanism of young fluviatile placer formation is shown in Fig. 15. Due to the very high specific gravity of gold the gold grains are accumulated preferentially in areas where the flow velocity of the stream is low. In rarer cases gold placers can be also be found along a coastline. A typical case is that of Nome in Alaska.

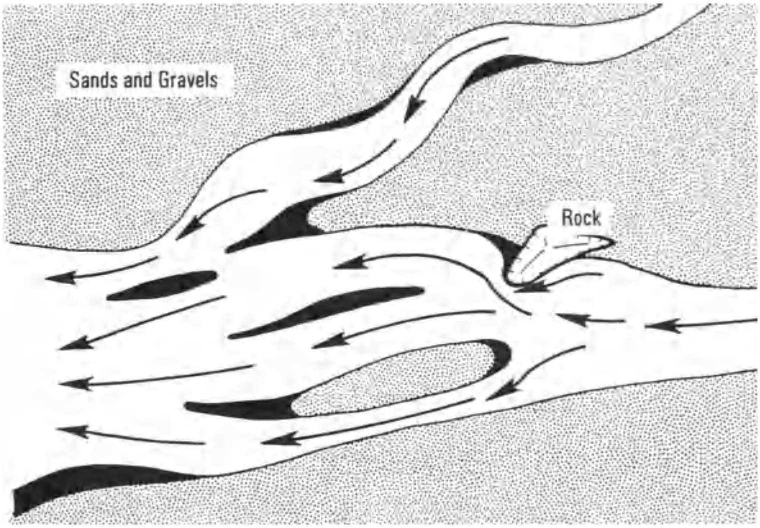

Fig. 15: Schematical representation of the placer gold accumulation in a river bed.

9. The economic importance of different mineralization types

The actual percentages of the world's recorded gold production are: volcano-sedimentary deposits about 19.5%, plutono-volcanic deposits about 13%, and 67.5 % from sedimentary secondary placer deposits, of which Witwatersrand alone delivers 58% of the world's total gold output. But it must be stressed that these figures may change dramatically due to the sharply increasing production from new volcanic deposits of epithermal type and from greenstone terrains.

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Chapter 3

THE GOLD DEPOSITS OF EUROPE:
An Overview of the Possible Metal Sources for Prehistoric Gold Objects

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ABSTRACT. The more than thousand gold mineralizations in Europe indicate, that gold had been potentially available to the prehistoric societies of Europe from many different mining districts scattered over whole Europe. Gold mining in Europe started in the Neolithic times and reached a first maximum of production during the Roman empire, mainly on the Iberian peninsula. From the findings of gold objects it can be deduced that most of the gold occurrences have been mined during the middle ages, but gold workings reliably defined as prehistoric are very few.
Geologically, most of the primary gold deposits are located within the pre-Hercynian basement areas, mainly consisting of highly metamorphic or magmatic rocks.
Placer gold deposits are known from paleo-fluviatile sediments of upper Paleozoic age, Cretaceous age and quite frequently in Tertiary rocks, mainly in the foreland of the Alps. Quaternary terraces and actual river sediments are also important gold sources.
The geological evaluation shows that Europe can be regarded under an actual economic point of view "rich in poor gold deposits and occurrences", which nevertheless could have easily supplied the gold known from archeological gold finds under completely different economic conditions in prehistoric times.

1. Introduction

The aim of this paper is to give an overview of gold mineralizations in order to provide information on potential sources for the prehistoric gold. Since in most countries mining archeological investigations are in a very early stage, many of the known gold showings could be in future defined as prehistoric mining sites.

Only recently in some European countries (Italy, Germany, Czech Republic) the relationship between natural gold occurrences and finds of archeological gold objects has been studied, too.

The first gold occurrences were discovered in Europe probably by prospectors looking for cassiterite in stream sediments as a source for tin-copper-bronze in Spain or northern Portugal (Quiring 1948).

The decay of the several thousand years old European gold production was started by the discovery of the Americas in 1492, that opened the way to enormous imports of the "metal of the sun" from the abundant and rich oversea deposits.

The overall historic gold production prior to the discovery of the Americas is estimated not to exceed 2.000 t.

The area covered by the present investigation excludes Scandinavian countries and the states of the former Soviet Union.

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The quality and quantity of information on gold occurrences is very different for the European countries. This article thus reflects obviously the present state of knowledge as available by the evaluation of international and only partly regional literature. As a typical example, an article on German gold deposits a few years ago would have mentioned only about ten to twenty deposits, while today, after much exploration many more than 100 old gold workings are known.

The gold mineralizations mentioned in this paper are not at all of equal importance. One must be aware that many mineralizations are single veins of a few tens of meters length, and many mining sites do not exceed a few hundreds of square meters extent, whereas others are big deposits still nowadays in operation. Furthermore, the chemical analyses of the ores and particularly of individual gold grains may be not at all representative for the gold content and composition of an occurrence. The inhomogeneities within and between deposits can be enormously high, so that numerous grains of gold have to be analysed to document the full range of composition present in one deposit or mining district. Samples of the upper and near surface parts of deposits are usually quite different from those from deeper zones and it should be kept in mind that such surficial parts of the deposits delivered the ores of the (pre)historic miners.

The wish of the archeologists for a determination of provenance of the gold by a geochemical fingerprint cannot be fullfilled until now because of the above described problems of sampling but also because the mineralogical and geochemical investigations almost have been concentrated on the few bigger deposits. The small and now uneconomic deposits remained undescribed but they may have been of importance under the different prehistoric economic conditions.

Comprehensive compilations of data on European gold deposits are few: Quiring (1948) was the first to present an enormous number of detailed observations. After more than 45 years the publication of Quiring is still one of the main sources of information on the history of European gold. Neuninger et al. (1971) contributed no new ideas giving only rough information on European deposits, mainly on Romania. As a catalogue accompanying a small exhibition in Dortmund the booklet: "Gold - occurrences and mining in Europe" was published by Homann (1985). This publication is a short guide written in German to the major European gold sites. Much information was gathered through the conference "Gold '89 in Europe" which was held in Toulouse in May 1989. Many articles concerning European gold deposits appeared in the abstracts and proceedings volume.

In what follows the gold mineralizations and mining districts in Europe are listed and briefly commented on a geographic basis, roughly going from west to east. An overview is given in the map in Fig. 1. The individual localities are found on the maps for individual countries.

2. Spain and Portugal

According to Quiring (1948), Domergue (1970) and Emmons (1974) two of the main gold mining regions in ancient times were Spain and northern Portugal. The deposits of this region also attracted great attention from Roman miners. With regard to their gold deposits Spain and Portugal cannot be treated separately and are therefore described together. The locations of gold mineralizations and mining are shown in Fig. 2 according to Porter et al.

(1989) and Pingel (1992). Many contributions on gold deposits of the Iberian peninsula have been presented at the "Gold 89 in Europe" meeting in Toulouse.

Fig. 1: Gold districts of Europe (for detail see maps for each country).

Fig. 2: Gold mineralizations of Spain and Portugal (dark pattern); light pattern: basement rocks (after Pingel 1992).

Spain:
1. Carballo-Cabana
2. Zas-Brandomil
3. Santiago de Compostela
4. Moncelos
5. Pol
6. Río Eo
7. Salabe
8. Las Furadas
9. District of Cangas de Nárcea
10. Río Orio
11. District of Salas
12. Río Pigueña
13. Sierra Aramos
14. Ortiguera
15. Río Omañas
16. Río Sil, upper part
17. Río Boeza
18. Sierra del Teleno
19. Río Sil, central part
20. Río Lor
21. Montefurado
22. Río Bibey
23. Río Arnoya
24. Río Miño, central part
25. Carballino
26. Río Miño, lower part
38. Villar de Ciervos
39. Sierra de Gata
40. Cavenes del Cabaco
41. Río Tormes
42. Río Alagón
43. Coria
44. Río Erjas
55. Río Salor
56. Alluviones de Cáceres
57. Montes de Toledo
58. Oliva de Frontera
59. Cala
60. Aracena
61. Almonaster
62. Tharsis-Alosno
63. Riotinto
64. Hornachuelos
65. Pozoblanco
66. Sierra Bermeja - Río Guadiaro
67. Granada, e.g. Río Darro, Río Genil
68. Cabo de Gata, Rodalquilar
69. Río Almanzora
70. Puebla de Don Fadrique,
71. Murcia and surroundings
72. Río Segura
73. Navas de Jadraque, Prov. Guadalajara
74. Río Jalón
75. Río Ebro
76. Benasque, Prov. Huesca

Portugal:
27. Sierra de Arga
28. Río Limia
29. Chaves, Distr. Vila Real
30. França, Distr. Bragança
31. Río Sabor, Distr. Bragança
32. Vila Flor, Distr. Bragança
33. Urros, Distr. Bragança
34. Río Douro, Distr. Bragança
35. Vila Pouca de Aguilar, Distr. Vila Real
36. Valongo, Distr. Porto
37. Sierra das Banjas, Distr. Porto
45. Rosmarinhal
46. Río Alva, Distr. Coimbra
47. Río Mondego, Distr. Coimbra
48. Sierra da Lousa, Distr. Coimbra
49. Río Zezere
50. Vila Velha de Rodao
51. Maçao, Distr. Santarém
52. Rio Tejo - lower part, Distr. Santarém and Lisbon
53. Adiça, Distr. Lisbon
54. Río Sver, Distr. Portalegre

The recent major gold producing area of Portugal is found around Jales in the north of the country, north-east of Porto. Cotela Neiva and Neiva (1990) presented a paper, which describes the main features of the mineralizations. Jales is located 13 km south-east from Vila Ponca de Aguira. The veins cut through Ordovician and Pre-Ordovician metasediments and Hercynian granitoids. Gold is present in quartz veins with associated sulphides, sulphosalts, and silver-minerals. The veins fill structures of late Hercynian age. Quaternary eluvial deposits (about 2.4 million m^3) formed by weathering and 1.7 million m^3 of alluvial sediments are mineralized with 0.2-0.5 g/m^3.

In Spain numerous deposits occur in the NW districts. The deposits of the Extremadura province are regarded of importance for historic gold production (Gumiel et al. 1989).

One of the biggest gold deposits in Spain is located at Rodalquilar in the Sierra Cabo de Gata east of Almeria (Arribas et al. 1989). The mineralization is bound to dacitic and andesitic rocks of Tertiary age and resembles a typical epithermal precious metal deposit (Friedrich et al. 1984). The production of up to 1 ton per year ceased in 1966, but the deposit has been under exploration again in the recent years.

The Pyrenee mountains host some minor gold deposits associated mainly with arsenic in Spain as well as in France (Ayora and Casas 1986, Tollon et al. 1989). The main localities are Val de Ribes on Spanish side and Glorianne on French side. All deposits are found on the southern side of the Hercynian age Canigou gneiss massif and consist mainly of stratiform Au-As mineralizations. Underground mining and working of placer deposits is reported from the early 20th century.

3. France

The French gold deposits produced a lot of gold in Gallo-Roman times and, during the second major mining phase at the beginning of the 20th century.

The main gold districts are a) eastern Bretagne, in the Armorican Massif, b) the Central Limousin and Marche in the northwest part of the Central Massif, the Montagne Noire in the southern part of the Central Massif, and c) the Canigou Massif in the Eastern Pyrenees (Fig. 3).

In eastern Bretagne a major gold producer was the La Lucette Au-Sb-deposit, which was mined from 1903 to 1913 for gold (Geffroy 1980). 90 km south at La Lucette a gold-bearing arsenopyrite mineralization occurs in the La Bellière deposit (Emmons 1974).

The gold-bearing mineralizations of the Marche district occur mainly in volcano-sedimentary rocks found in tectonic depressions within the migmatites and granites of the Central Massif (Bouchot et al. 1989). At Villeranges pyrite and gold-bearing arsenopyrite are disseminated in tuffs. At Le Châtelet, where arsenopyrite is found in veins hosted by migmatites, gold is known to be hidden in the crystal lattice of arsenopyrite and thus invisible (Wu et al. 1990).

In the Central Limousin the main gold deposits are found in the Saint-Yrieix district (Braux et al. 1989). This district has the greatest number of gold mineralizations of the French Hercynian basement. Only Le Bourneix and Laurieras are in operation at present. Gold is associated with galena and sulphosalts and postdates pyrite and arsenopyrite. Impregnations in brecciated quartz lenses are typical (Touray et al. 1989).

In the Montagne Noire, the Salsigne mine, whose gossan was mined for iron in Roman times, has been mined for arsenic from 1873 onwards and is still today one of the biggest European gold mines (Fig. 4). The deposit consists of quartz veins and stockworks in quartzites and black shales of Cambrian age (Tollon et al. 1989, Lepine et al. 1989). Further stratiform mineralization is known in the upper part of the sequence.

The gold mineralizations of the Eastern Pyrenees have been mentioned in the section about Spain. Historic mining sites are the Glorianne and Serrabonne mines with gold-arsenopyrite veins of up to 60 g/t gold (Polizzi et al. 1989).

Fig. 3: Gold localities in France (filled circles); pattern: basement rocks.

Fig. 4: Open pit mine of Salsigne (Foto 1989)

4. British Islands

A very useful short compilation of the British gold deposits was published by the British Museum of Natural History (1973). All data are based largely on this publication. The map of the gold locations is given in Fig. 5.

Even though some indications date gold workings back to Roman time, most activity has been reported from the 16th century onwards. British gold production flourished during the second half of the 19th and the early 20th century. Wales was the main producer having yielded twice as much as the other parts of the country combined.

In Cornwall the basement rocks of the Variscan massif are not only famous for tin mineralizations, but have also yielded minor amounts of gold. Most of the Cornish streams have been worked for their placer deposits, Carnon stream is among the most famous of these. The gold is regarded as hosted in sulphide ores, which have been mined in the past. Rich specimens of gold-quartz veins were recorded in the Treore mine, near Port Isaac, and gold placers are known from Treore Creek.

In Devonshire spectacular dendritic gold is known at the Hope's Nose deposit near Torquay (Harrison and Fuller 1987). Remarkable gold specimens also came from old Prince Regent (Britannia) and Bampfylde copper mines.

Some 25 km SW of Torquay gold-stibnite veins with sulphosalts were mined in Loddiswell, Devon (Stanley et al. 1990).

In Cumberland gold and silver were obtained from the Cu-Pb mine of Goldscope in the Vale of Newlands. Several smaller gold occurrences of no commercial relevance are also known from Cumberland.

Fig. 5: Gold localities in the British Islands

1. Levant mine, Pendeen, Cornwall
2. Wheal Sparnon, Redruth, Cornwall
3. Carnon stream, near Falmouth, Cornwall
4. Hope's Nose, Torquay, Devonshire
5. Treore mine, near Port Isaac, Cornwall
6. North Molton Area, Devonshire
7. Dolaucothi (Ogofau) mine, Pumpsaint, Carmathenshire
8. Mawddach river area, Merionethshire
9. Castel-carn-dochan mine, Dolaucothi, Bala, Merionethshire
10. Robin Hood mine, Bassenthwaite, Cumberland
11. Embleton, near Cockermouth, Cumberland
12. Caldbeck Fells area, Cumberland
13. Leadhills - Wanlockhead area, Lanarkshire/Dumfriesshire, Scotland
14. River Tay headwaters, Perthshire, Scotland
15. Tyndrum mine, Perthshire, Scotland.
16. Brora, Sutherland, Scotland
17. Helmsdale (Kildonan), Sutherland, Scotland
18. Suisgill, Sutherland, Scotland
19. Goldmine River (= Ballinvalley stream), County Wicklow, Eire
20. Lodiswell

In Wales the by far richest gold-mining area on the British Islands lies in the Mawddach valley northeast of Bontddu, in the region of Gwynedd, formerly Merionethshire. Several mines were worked, mainly in the second half of the 19th century, the most productive being Clogau (or St. David's). Gold is associated with pyrite and sphalerite and hosted by quartz veins. The Castel-carn-dochan mine near Bala and the Mawddach river placers also had some importance. The overall production of the Merionethshire mines from 1861 to 1906 exceeded 35 tons. The Ogofau mine near Pumpsaint in Carmarthenshire was the second biggest gold producer in Wales and has probably been worked since Roman times. Recently the old pit of Ogofau, now called Dolaucothi mine was explored (Annels and Roberts 1989).

In Scotland most gold is in placer deposits in a small area around Leadhills and Wanlockhead, on the borders of Lanarkshire an Dumfriesshire, and in Sutherland. Interesting specimens were produced by minor occurrences near Loch Tay and the head-waters of the Tay, in Perthshire. The alluvial deposits of Crawford Moor, a few miles to the north-east appear to have been among the richest. The largest nugget found there weighed over 90g. Workings are reported from the 16th century onwards. In Sutherland the main areas of gold workings are the stream valleys inland from Brora and Helmsdale, particularly Suisgill.

In Ireland only the gold deposits of County Wicklow are of economic interest. They are mainly confined to the alluvia transported by the Ballinvalley stream from the area of Croghan Kinshelagh. The primary source of the gold is not yet known. Deposits in the Spewin Mountains in Ulster are currently being tested for their commercial potential.

5. Belgium

Belgium is rather poor in gold occurrences. These are found only in the eastern part, where the lower Paleozoic sediments of the Rhenish Schist Mountains extend into Belgium, forming the massifs of Rocroi, Stavelot, and Serpont. Dunning and Evans (1986) report several workings in the surroundings of these areas obviously dating back to Celtic and Roman times. Along the Amblève River gold workings probably operated until the 19th century.

The Belgian gold occurrences consist of alluvial sediments in terraces or actual river beds. There is evidence, that the primary sources of the gold could have been quartz veins, but most of the gold seems to be contained in paleoplacers of Siegenian or Gedinnien age, so that there must have been a multiphase placer formation.

6. Germany

The "Rhinegold" is famous all over the world through the opera by Richard Wagner, but many other sites with historic gold mining or at least mineralization are known and were catalogued in the last few years mainly by Homann (1989 and 1993), Spycher (1983), von Wichdorff (1914), Arnold and Quellmalz (1978), and Lehrberger et al. (1988). The gold localities are shown in Fig. 6.

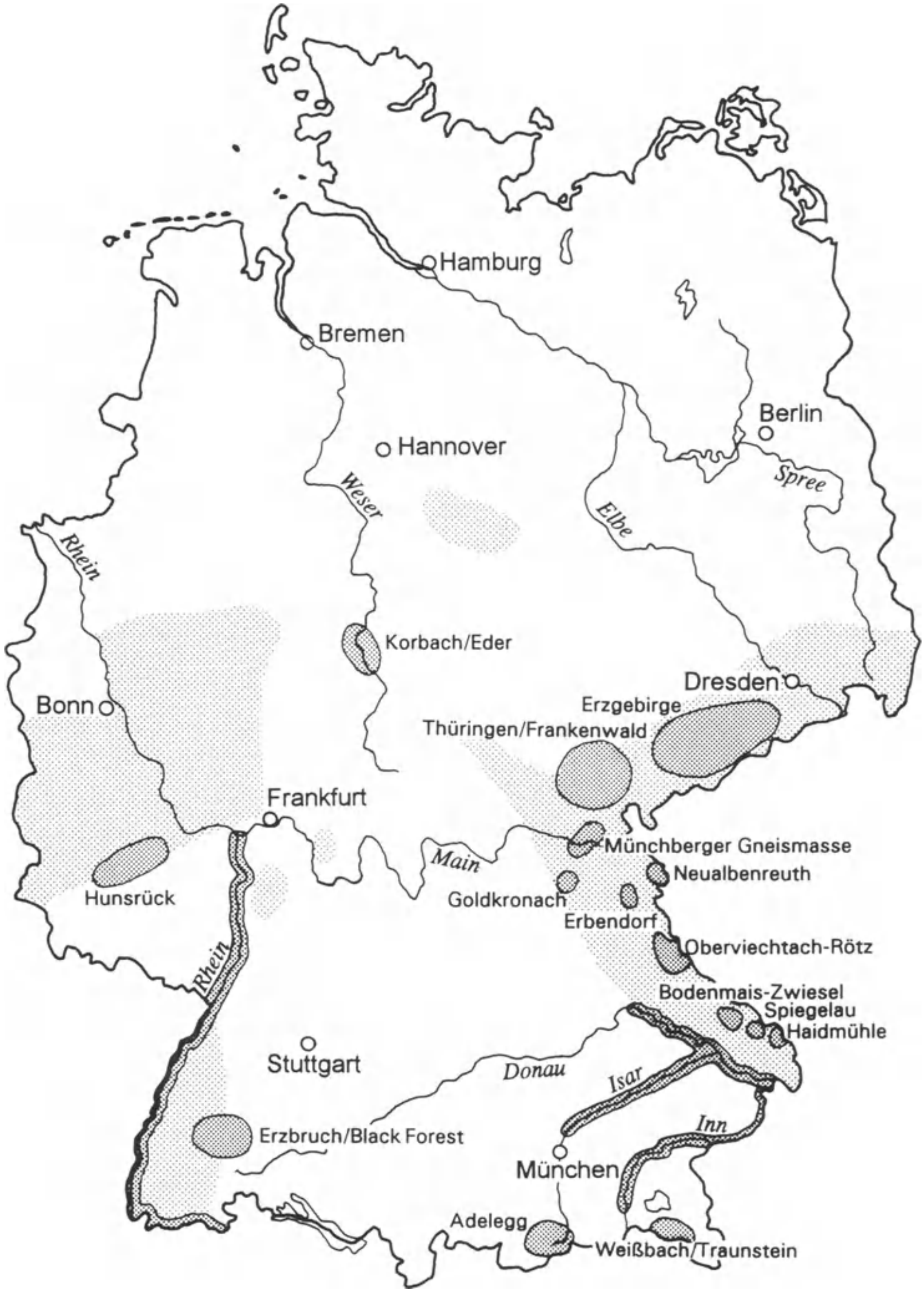

Fig. 6: Gold localities of Germany (dark pattern); bright pattern: basement rocks.

In the Harz (Hercynian Mountains) Homann (1993) found several gold showings, but large amounts were only produced by the Rammelsberg polymetallic sulphide deposit near Goslar. This massive sphalerite-galena-chalcopyrite deposit hosts gold in grades of 0.2 to 2 ppm. As a by-product it ranged around 500 - 1000g (!) per year until the 1860s, when an increase of production and better recovery lead to an annual gold production of 12-14 kg. The main problem until the 20th century was the separation of gold and silver, only solved by electrolysis. The raw "Güldischsilber" was electrolytically refined. In the years 1960, 1961 and 1962 the annual production of Rammelsberg gold in the Oker refinery amounted to between 103 and 123 kg. Since 1962 gold was not directly refined at Oker but by the DEGUSSA company. Figures of production are not available for this period. (Spier 1992, 20-22).

Even in the Rheinisches Schiefergebirge (Rhenisch Schist Mountains) Homann (1989) showed, that gold is present in mineralogically interesting amounts, but so far no traces of former gold mining have been identified. The famous Korbach/Eisenberg gold deposit is located in the Eastern part of the Rhenish Schist mountains. This deposit was mineralogically described by Ramdohr (1932), and in recent times prospection and some scientific investigations were carried out on this mineralization. In the Hunsrück Mountains, which are a small unit of basement rocks south of the Rhenish Schist Mountains, several nuggets of some grams weight were found at the end of the last century, but the related primary gold mineralizations have never been located (Zöller 1919).

Along the whole upper Rhine valley from Basel to Mainz the fluvial gravels and terrace sediments have been worked, probably since prehistoric times. The primary gold sources for the "Rhinegold" are located in the Swiss Alps. Some contribution to the gold content also comes from Tertiary sediments in the so-called Molasse zone along the northern Alps, also mainly in Switzerland. The gold of the Rhine valley was mineralogically described by Ramdohr (1965), Lepper (1980), Spycher (1983) and others.

In Saxony Arnold and Quellmalz (1978) compiled several placer gold deposits located in the Sächsisches Erzgebirge (Saxon Metalliferous Mountains) and in the Lausitz Mountains north of Dresden. Both areas consist of basement rocks. The primary gold deposits in this area have never been investigated in detail. In the Franconian and Thuringian Forests several gold mineralizations and related old workings are reported by v. Humboldt (1792), v. Wichdorff (1914), and Pfeiffer (1994). The deposits often occur in close association with Paleozoic volcanics of basaltic composition ("Diabase") (Ebert and Kern 1985). Placer deposits have been worked as well, mainly in Thuringia along the major rivers.

In the Fichtelgebirge in Northern Bavaria the greatest gold deposit of Bavaria is located in the area of Goldkronach and Brandholz (Buschendorf 1931, Arnold and Lehrberger 1990, Irber and Lehrberger 1993). Quartz veins hosted by Paleozoic metasediments and volcanics carry a mineralization of arsenopyrite, stibnite, sulphosalts and gold.

In the socalled Münchberg Gneiss Massif gold deposits were explored and mineralizations were found in metamorphosed quartz veins in amphibolites (Grüner 1990).

In the surroundings of Neualbenreuth near Tirschenreuth several old workings mark the outcrop of a stratabound gold-arsenopyrite mineralization which seems to be hosted by Cambrian quartzites (Seitz and Wolf 1971).

Cretaceous gravel deposits are enriched in gold south of Erbendorf near the German continental deep drilling site (KTB). Placer workings are found along several small creeks in this area and the mining is dated by documents to at least the 18th century.

In the Moldanubian unit of the Bohemian massif numerous gold mineralizations and even mining sites were investigated by the research team of the Technische Universität München

(Lehrberger et al. 1989, 1990, Martinek and Lehrberger 1993). The main areas are found near Oberviechtach in the Oberpfalz district, and near Zwiesel, Bodenmais and Spiegelau in the Bavarian Forest. All deposits in this area are located relatively close to the border with the Czech Republic and are genetically of similar types to deposits described there.

In the alpine foreland of southern Bavaria gold has been mined along the major rivers Isar, Inn, and Danube. Gold coins minted from this gold testify to this activity, which had its greatest extent in the 18th and 19th century, but could reach back to prehistoric times. Recently, some smaller fluvioglacial sediments with interesting contents of coarse-grained gold were found along the Northern Alps near Traunstein (Lehrberger et al. 1989).

7. Switzerland

The Swiss gold deposits are not economic at present, but in the past numerous placers and a few major primary deposits in the Alps were exploited (Rütimeyer 1927). The gold occurrences and deposits are compiled in Fig. 7 after Hofmann (1991) and Jaffé (1986).

The Calanda deposit in the Grisons district is hosted by a limestone of the Helvetic unit in the upper Rhine valley. The deposit consists of quartz veins with gold-bearing pyrite which led to an insignificant production of gold in the early 19th century (Bächtiger 1967).

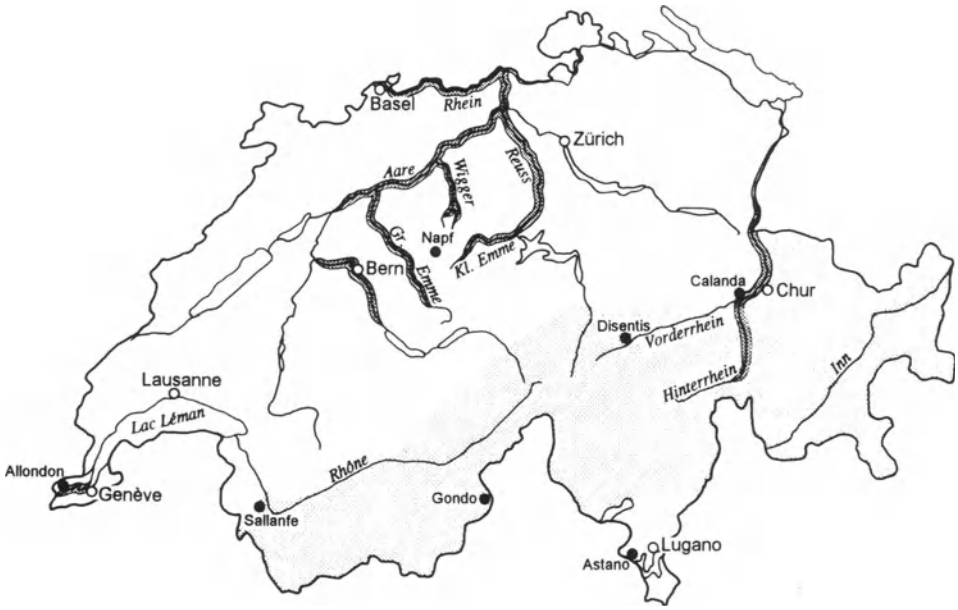

Fig. 7: Primary (filled circles) and secondary gold deposits (dark pattern) of Switzerland (after Jaffé 1986, Hofmann 1991); bright pattern: basement rocks.

Gold ores related to skarns, marbles and graphitic schists are found at Sallanfe in metamorphic basement rocks of the Arguille Rouge Massif approximately 2100 m high. Gold grades of up to 20 ppm are associated with arsenopyrite, loellingite, pyrite, and minor scheelite.

The deposit of Disentis in the metamorphic rocks of the Tarvetscher Zwischenmassiv was only recently discovered (Knopf et al. 1989). In the irregularly banded and disseminated sulphide horizons gold is in paragenesis with pyrite, pyrrhotite, arsenopyrite, and accessorial stibnite, sphalerite, galena, and chalcopyrite. Gold contents in the ore do not exceed 7 ppm.

South of the Simplon pass, near Gondo in the Canton of Wallis, pyrite-bearing quartz veins host gold, silver and bismuth. This deposit belongs to the Piedmont mining area, which is described in detail by Piana Agostinetti et al. (this volume) and in the section on Italy in this paper.

A similar deposit is that of Astano, near the Ticino river, in the Malcantone district. The mine was called "Costa" and worked until the second world war. Veins hosted by alkali feldspar gneisses of Hercynian or older age contain arsenopyrite, some antimony minerals and gold.

Many publications on Swiss placer gold deposits appeared in the last few years. The following compilation is mainly based on Hofmann's article in the catalogue of the "Helvetii" exhibition (Furger and Müller 1991).

The main placer gold occurrence of Switzerland is located in the Napf area, between Luzern in the east and Bern in the west, where Tertiary alluvial sediments (conglomerates) of the alpine Molasse basin contain gold (Schmid 1973). From these placer deposits gold is washed out by creeks and small rivers and deposited in their sediments or further transported to the bigger rivers of the Große Emme, Kleine Emme, Reuss and Aare, and finally into the upper Rhine river (see also Felix Müller, this volume).

Historic gold workings of placer deposits are known from the upper Rhine valley inside the Alpine mountain chain and in the vicinity of Basel (Spycher 1983).

In southwestern Switzerland gold occurs in the Arve, Allondon, and Rhone rivers near Geneve, but without considerable economic importance, even in the past.

Numerous gold occurrences have been found by hobby prospectors in alluvial sediments derived from the Quaternary sediments of the former Rhine glacier.

In the Tessin canton placer gold occurs downstreams the primary deposit of Malcantone in the Magliasana river and further in the Vedeggio, Breggia, Ticino, and Melezza rivers.

8. Austria

Austria is famous for the socalled "Tauerngold" which is named after the Hohe Tauern mountains in the central Alps (Posepny 1880, Niedermayr and Seemann 1975). There, gold mining began probably already in Neolithic times and developed greatest activity in the 18th and 19th century (Ertl 1975, Zirkl 1982, Dunning and Evans 1986). There are many other gold mineralizations in all parts of the country, which have been compiled by Zirkl (1982). The following text is mainly based on this comprehensive publication. The map (Fig. 8) is drawn after Niedermayr and Seemann (1975).

In the lower Austrian district only very few primary gold occurrences are known. Near Hirschwang gold-bearing shale covers the siderite deposit of Edlach. Auriferous chalcopyrite has been mined at Trattenbach since the 16th century. More gold has been produced from alluvial deposits along the Enns and Danube rivers.

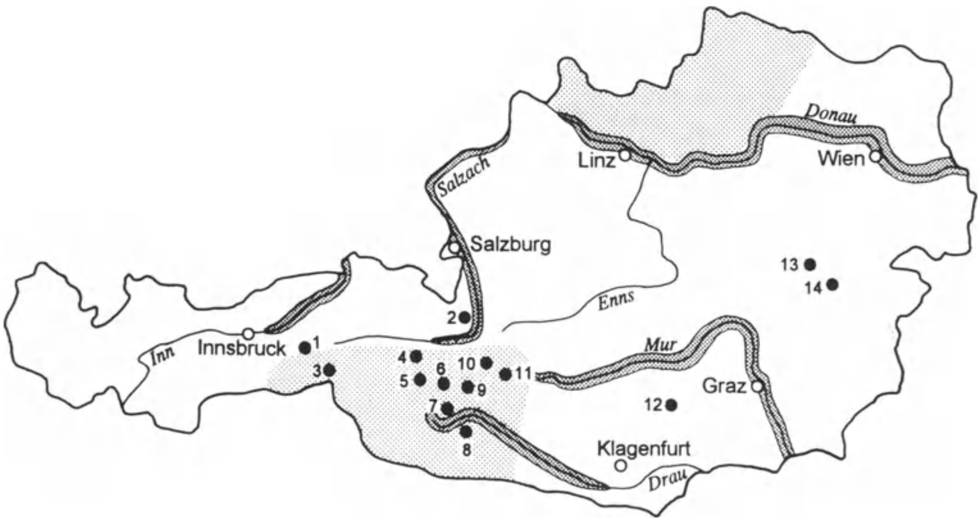

Fig. 8: Primary (filled circles) and secondary gold deposits (dark pattern) of Austria (after Niedermayr and Seemann 1975); bright pattern: basement rocks.

1. Zell am Ziller	4. Fusch	8. Kreuzeckgruppe	12. Kliening
2. Mühlbach am Hochkönig	5. Heiligenblut	9. Gastein	13. Edlach
	6. Rauris	10. Großarl	14. Trattenbach
3. Venedigergruppe	7. Döllach,	11. Murwinkel	

Styria has many different types of small gold deposits (Seebacher-Mesaritsch 1974, Weninger 1981). Gold almost occurs in sulphide-bearing veins with prevailent As- and polymetallic mineralization. But even in geological environments like gypsum and siderite deposits gold has been found. Upper Austria lacks primary gold deposits at all, but shows major placer workings along the Danube, which date back to at least the 12th century.

Most of Austrian gold comes from the federal states of Salzburg and Carinthia (Paar 1991). The deposits of this area in the Central Alps yielded gold since prehistoric times till the 20th century. The deposits are geographically confined to the Goldberggruppe of the Central Tauern area and the Kreuzberggruppe in the east.

Numerous small deposits are found mainly in the border zone of the gneiss core of the Tauern window to its schistose cover rocks. Recent investigations on these deposits have been conducted by Feitzinger (1992), Paar (1991) and other scientists from the University of Salzburg. The wellknown Tauerngold occurs in quartz veins with sulphides. The most famous deposits are located in and between the Rauris and Gastein valley. At Schellgaden-Rotgülden auriferous arsenopyrite has been mined (Friedrich 1934, Dunning and Evans 1986).

In the copper deposits of Mitterberg and Mühlbach, which lie in the geological unit of the socalled "Grauwackenzone" gold is found together with uranium oxides (Paar 1981).

Carinthian gold deposits are the continuation of the veins of the Goldberggruppe on the southern slope of the Alps (Lahusen 1969). A further gold mining area is located in the Kreuzeckgruppe, where gold is mainly bound to sulphide veins in metasediments around tonalitic intrusions. In the Hüttenberg siderite deposit rich gold zones were found.

The Hainzenberg near Zell am Ziller is the greatest gold mineralization of the Tyrol state (Schulz and Wenger 1980). Quartz lenses in black phyllites host gold together with arsenopyrite and other sulphides. Similar deposits are also known from other places in the Ziller valley.

Placer gold occurs nearly in all rivers which drain the valleys with primary gold mineralizations and transport the gold into the sediments of the Salzach river, where gold has been panned in the past at many sites (Wolfskron 1895, Zirkl 1982).

In Carinthia the Lavant, Lieser, and Drau rivers are known to be considerably gold-bearing.

Placer gold in Tyrol has been worked along the upper Inn river and its tributaries, mainly the Sill river.

9. Italy

In Italy gold is found only in the northern part of the country, in the Alpine and Appennine mountains. Since a detailed compilation of gold deposits in the Italian Alps is presented in this volume by Piana Agostinetti et al. (this volume), only the main occurrences and their features will be described. The locations of the gold mining areas are given in Fig. 9.

The major gold mineralizations of northern Italy are found in the "western Alpine gold province" (Omenetto and Brigo 1974), which covers the Graie and Pennine Alps in the Northern Piedmont province. The main mining sites are the Pestarena mine in the Monte Rosa district, Val Toppa, Alagna Val Sesia, Val d'Ayas, and Antrona-Val Bianca mines in the Piedmont area with a total production of more than 150 t in the last 150 years.

A second important area for primary gold deposits is found in the Ligurian Appennine west of Genova in the socalled "Voltri Group". The host rocks of the gold-bearing quartz veins are mainly ultramafic rocks such as serpentinites found in metamorphosed ophiolite sequences. Following Piana Agostinetti et al. (this volume) the two gold mines of Tiglieto and Laghi di Lavagnina were major producers. East of Genova the Bracco Pass area contains gold mineralizations. Gold is associated with Cu in an ophiolithic rock series.

According to Leonardelli and Suardi (1988), the gold deposits of the Alps and Appenines largely are tabular or lentiform veins or stockworks with predominant quartz as gangue. Gold mostly is associated with sulphides such as pyrite and arsenopyrite. These structures are related to the Alpine tectonism during the Tertiary. The transport of metals was mainly by metamorphic fluids. Gold itself can rarely been found in macroscopic grains, it is mostly finely dispersed in sulphides.

The placer deposits of Italy can be devided into alluvial and fluvioglacial or glacial deposits. The main workings are known from the Aosta valley, the Po valley, and many smaller rivers in Piedmont and Liguria such as Ticino, Agogna, Sesia, Dora Baltea, Orco, Malone, Tanaro and their tributarial rivers.

An important alluvial deposit is that of "La Bessa" in the Ivrea area, since a production of 50 t gold by the Romans is reported (Leonardelli and Suardi 1988). Other placer deposits are known from several rivers in Piedmont and Liguria draining the areas with primary mineralization.

In the 1980s the worldwide boom in the exploration of epithermal gold mineralizations also made Italian prospectors look for this type of deposit in the vicinity of the volcanic areas of Tuscany, Latium, Sicily, Eolian Islands, Western Sardinia and the Euganei hills. Although

Fig. 9: Gold mining areas (dark pattern) of the Western Alps and the Ligurian Appenines in Italy (after Leonardelli and Suardi 1988).
1: Aosta, 2: Monte Rosa, 3: Adda/Serio, 4: Ticino, 5: Sesia, 6: Po, 7: Voltri Group.

Tuscany had the best potential, since there are many other deposits of Hg, Sb, Pb, Zn and other metals promising for gold, only small mineralizations of no economic relevance could be found. Bencini et al. (1989) show that the gold contents of the volcanic rocks of Tuscany are relatively low.

Ogniben et al. (1988) published some data on the gold contents of sulphide deposits in the Trentino province east of the city of Trento. In these deposits gold occurs in minor amounts in a) pyrite deposits in the metamorphic basement, b) polymetallic veins related to late Hercynian magmatism of the Cima d'Asta batholith and the comagmatic Athesine prophyric Plateau and finally c) in synsedimentary Pb-Ag mineralizations in the socalled "Bellerophon" limestone of Upper Permian age. Gold was only a byproduct of mining in the past; the contents in the ores were almost lower than 1 ppm.

10. Czech Republic

In 1992 a compilation of the results of many years, campaigns of gold prospection and exploration by state owned companies in the Czech Republic was published by Morávek et al. (1992). This book gives a classification and description of the gold deposits in the basement rocks of the Bohemian Massif. Fig. 10 shows the main gold districts in the Czech Republic.

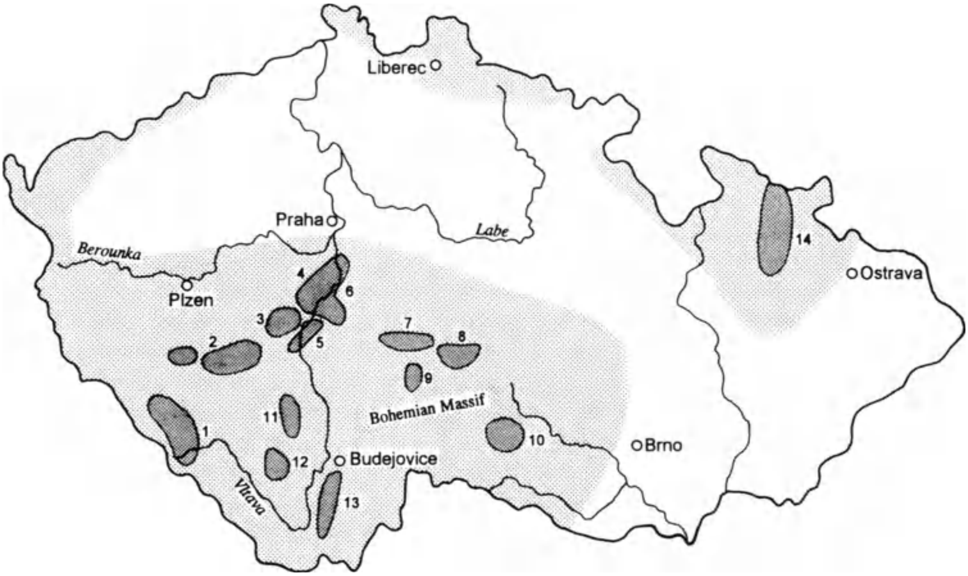

Fig. 10: Major gold districts (dark pattern) of the Czech Republic (bright pattern: basement rocks of the Bohemian Massif).

1. Hartmanice-Kašperské Hory
2. Kasejovice
3. Nový Knín
4. Jílové
5. Krásná Hora
6. Jílové-Belt, Mokrsko
7. Roudný
8. Humpolec
9. Zlátenka
10. Předin
11. Písek
12. Křepice
13. Dobrá Voda
14. Zlaté Hory/Opava

Recently, a further compilation of data on gold mineralization, related mining activities, and gold findings has been prepared by scientists of the Technical University of Munich in a project sponsored by the Volkswagen Foundation. While the book of Morávek et al. (1992) emphasized more the primary gold mineralizations, Kudrnac (1977) and others found in the western part of the Bohemian massif in the Czech Republic but also on German territory (Lehrberger et al. 1988) more than 700 (!) sites of gold mining and/or treatment.

The gold deposit, which supplied the gold for the "golden roofs" of many public buildings in Prague is Jílové some 30 km south of the city. Quartz veins and disseminated mineralizations occur in Proterozoic metavolcanic rocks of the Jílové belt, which has some similarity to the greenstone belts of many regions in the world. Gold contents of many kg per ton made Jílové famous. The mining ceased in the 1960s.

For some years Roudný southeast Prague was the greatest gold mine in Europe (Susta 1922). Discovered only at the end of the last century, much gold was produced from a pipe-shaped ore body in gneisses of the Moldanubian geotectonic unit.

The last operating gold mine of the Czech Republic was Zlaté Hory (Gold Mountain) in the Jesenicky Mountains in the Sudetenland along the Polish border (Jedlicka and Hauk 1989). Gold there occurred in a stratabound sulphide deposit. In the vicinity other deposits are known, with placers formed mainly along the Opava river.

In the area of Krásná Hora and Milešov in southern Bohemia gold-bearing stibnite veins were mined (Posepny 1895). The mineralization is accompanied by mafic dykes. A typical mineral of these deposits is the gold-antimony alloy aurostibite. The production at the Krásná Hora mine ended only in 1992 due to economic reasons.

Kašperské Hory in the Bohemian Forest near the German border is an old mining town, where gold has probably been produced since the early Middle Ages or even earlier. Numerous old workings and remains of gold mills are found near the town. An adit driven in the late 1980s gives acces to the mineralizations east of the old town and shows that gold is closely related to an arsenopyrite mineralization (Morávek and Puncochar 1983). An overlapping scheelite mineralization is also present and of economic interest. The mineralized bodies are lentiform quartz veins which are subparallel to the foliation of the highly metamorphic gneisses and calcsilicate rocks. Several smaller mineralizations are known around Kašperské Hory.

In the context of the exploration campaigns of the GEOINDUSTRIA state-owned mining company near the village of Čelina on the banks of the Vltava (Moldau) river the biggest gold deposit known so far in the Bohemian massif was discovered (Morávek et al. 1989). More than 15 tons of gold are contained in the deposit called "Čelina-Mokrsko" which is situated at the contact between the volcano-sedimentary sequence of the Jílové belt and the central Bohemian pluton. A stockwork shaped mineralization hosts gold intergrown with arsenic-bismuth and tellurium minerals. Scheelite is also frequently found. An open pit operation is planned to mine the complete deposit, which, centuries ago, was mined in small adits near the surface. Similar to the Čelina-Mokrsko deposit is the newly discoverd and explored Petráčkova deposit south of the famous mining town of Příbram. Other old mines are found in the vicinity of the town of Písek in southern Bohemia.

The placer deposits of Bohemia are fairly well-known. Along major parts of the Otava river many placer workings are still preserved, some of which are thought to date back to Celtic times (Kurdnac 1971, Waldhauser 1991).

11. Poland

According to Homann (1985) and Solecki (1989) the gold deposits of Poland are almost restricted to the Sudetenland along the border with the Czech Republic. In the Bobr river area, Tertiary and Quaternary gold placers were probably mined since Celtic times or even earlier. In the eastern Sudetenland gold mineralization is related to Variscan magmatism and metamorphism.

In the central Sudetenland gold is associated with loellingite and arsenopyrite in the contact zones of granitic intrusions mainly in the Zloty Stok deposit (formerly named Reichenstein) (Welter 1923, Niczyporuk and Speczik 1993). In the western Sudetenland Au-Ag-bearing veins are hosted by Silurian schists and Permian rhyolites at Wielislaw and Stara Góra. The elemental association is mainly with As and Pb.

Placer deposits of Tertiary or Quaternary age have been mined in the eastern and western Sudetenland (Rutkowski 1989). Some of these deposits seem to be related to transport processes by the Scandinavian ice shield, particularly in the Oldza basin (Wojciechowski 1989).

12. Hungary

According to Dunning et al. (1982) and Homann (1985) the placer deposits of the Danube valley, mainly downstream of Budapest, were probably already known to Bronze Age gold miners. The former Hungarian primary gold deposits in the Carpathian mountains today belong partly to the Slovak Republic and partly to Romania. Only the gold deposits of Matrabánya near Recsk in the Matra mountains are still within the Hungarian border.

13. Slovakia

Slovak gold deposits are amongst the most famous in Europe due to many nice museum specimen, mainly from the Kremnica area (Huber and Huber 1981). Banská Stiavnica, the former Schemnitz, is the center of the gold, lead, copper, and zinc mining district, and hosts the oldest "mining academy" of Europe. The gold deposits of Slovakia are shown in Fig. 11.

In western Slovakia the metallogenic provinces of Kremnica-Banská Hodruša and Banská Stiavnica are related to Tertiary volcanic rocks, mainly pyroxene andesites (Helke 1938). In graben structures strato-volcanoes and caldera type collapse structures developed and made a path for ore forming solutions (Knesl et al. 1989). Mining has been active since the fourteenth century. In Kremnica gold mineralization is hosted by epithermal quartz-pyrite veins, partly accompanied by stibnite.

In Banská Stiavnica gold was mainly a byproduct of polymetallic and silver mining. Recently, a rich gold mineralization has been discovered in the Hodruša polymetallic deposit and the deposit is now worked only for its gold-bearing ores (Duda et al. 1993).

In augengneisses and granodioritic intrusions of the Carpathian mountains an Au-W mineralization had been discovered near Jasenie. In this primary deposit gold is intergrown with arsenopyrite and scheelite; in the valleys gold placers were exploited in the past.

In eastern Slovakia polymetallic ore veins occur again in Tertiary to Quaternary volcanic rocks of the Slanske mountains (Prešov-Tokaj moutains). The main mine is Zlatá Bana, where mining started in the Middle Ages.

Fig. 11: Gold deposits of Slovakia (filled circles).

14. Former Yugoslavia

Since the borders of the new states forming on the former Yugoslavian territory are not yet defined, the gold deposits of this area are described in one chapter. The locations are given in Fig. 12.

According to Friedensburg (1953) and Jankovic (1982), the main gold production of Yugoslavia comes from porphyry type copper deposits such as Bor or Majdan Pek. The host rocks are andesites affected by strong hydrothermal alteration.

The polymetallic deposits of the southern Serbian Trepča mining district are known to host gold as a byproduct in grades of up to a few ppm.

According to Friedensburg (1953) and Jankovic (1982) the main exclusive gold deposits are found in the northeast of former Yugoslavia on the banks of the Pek river. The deposit of Neresnica near Kucevo hosts gold in quartz veins, which occur in chlorite schists along the contact with a granite intrusion. Gold mineralization is accompanied by a minor polymetallic mineralization with W, Pb, Zn, and Cu. Emmons (1974) reports a gold deposit of Deli Jovan, 35 miles SW' Kucevo hosted by serpentinites.

The Fojeica mine near Bacovici in Bosnia, west of Sarajevo, produced gold from antimoniferous quartz veins.

Placer gold mining in modern times has been active only along the Pek river between Neresnica and the Danube river, but in antiquity probably many rivers have been exploited for gold.

Fig. 12: Gold localities in former Yugoslavia (filled circles); bright pattern: crystalline basement.

15. Romania

Romania has some of the most important gold mineralizations in Europe and mining dates back at least to Roman times (Udubasa 1993). The gold deposits are found in three major districts, a) the Baia Mare area in the north, b) the so-called "Golden Quadrangle" in the Apuseni metalliferous mountains, and c) in the south central Carpathians (Fig. 13). The deposits were compiled after Helke (1977), Friedensburg (1953), Ianovici and Borcos (1982), Udubasa and Anastase (1989) and Udubasa et al. (1992). In particular the publication of Ianovici and Borcos (1982) shows many details of the deposits including numerous maps and cross sections.

One problem with the literature about Romanian gold deposits is that normally there are three names for each deposit, one German, one Hungarian and one Romanian, causing some confusion to the reader.

Baia Mare district:
The Baia Mare district is famous for its mineral wealth and for first class mineralogical samples. Baia Mare, Baia Sprie and Cavnik are the major ore deposits, which consist mainly of gold-bearing argentiferous galena and fahlore mineralization. In some deposits gold is known in paragenesis with stibnite.

Apuseni Metalliferous Mountains: "Golden Quadrangle"
This area of the former "Siebenbürgen" has been the main producer of gold in Romania and in Europe. Epithermal veins and disseminations are hosted by volcanic rocks such as andesites, dacites and rhyodacites of Tertiary age. Breccia pipes and subvolcanic intrusions are typical host rocks and display strong hydrothermal alteration and hydraulic fracturing. Porphyry copper type deposits are widespread and known to bear considerable amounts of gold. Mineralogically this area is best known for the Au-Ag-Te minerals, which are found in outstanding samples in some of the mines (Huber and Huber 1983).

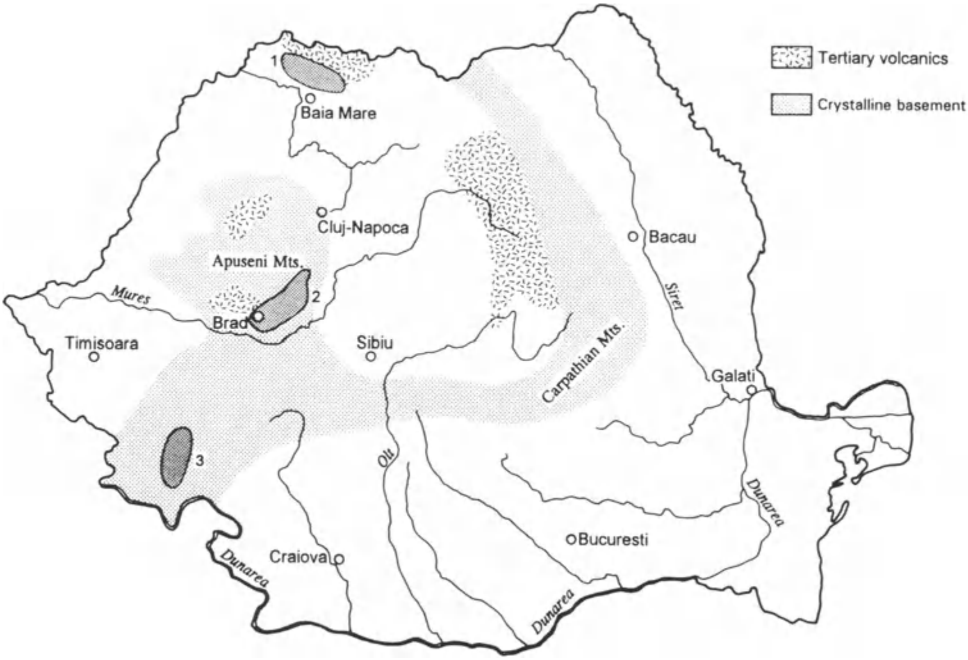

Fig. 13: Major gold mining districts (dark pattern) of Romania;
1: Baia-Mare and Baia Sprie, 2: "Golden Quadrangle", Apuseni Mountains,
3: South Carpathian metamorphic zone.

South Carpathian Zone:
In the south Carpathians shear zone related gold ores in Precambrian metamorphic rocks were described by Udubasa et al. (1992). The area consists of a greenstone belt type rock series. The primary deposits are located near Valea Lui Stan and in the Costesti Valley in the Capatina Mountains. Placers formed along the Olt and Lotru valleys.

16. Bulgaria

Due to the restrictive information policy of the Bulgarian government, even after the opening of the country to the West, only limited information is available on Bulgarian gold deposits. The published information reflects predominantly the situation before the second world war. According to the official map (Bogdanov 1982), only a few primary gold deposits are known in the mountains northwest of Sofia. According to historic information many rivers are gold-bearing and placer working is still active among the poor people, even in the eastern part of the country. According to Homann (1985) the copper mineralizations of Arcar, Bucovec, Trembes, and Panagjuriste had been a gold source even in ancient times. Placers have been worked since early times on the rivers Isker, Arda, Strymon, Nestos and Maritza.

The only gold mine worked until the 20th century is Zlatá near Trn in western Bulgaria (Homann 1985). From the geological point of view one would expect some gold mineralizations associated with arsenopyrite in the south of Bulgaria along the Greek border in the Angistron mountains (see chapter about Greece).

17. Greece

According to Dunning et al. (1982) gold is found in the whole country in many different types of deposits because of the geological complexity of the area. The locations of the gold mineralizations are compiled in Fig. 14. The major gold deposits occur in the Rhodope massif in the Macedonian province in northeast Greece. The following information was mainly compiled on the basis of the publications by Dunning et al. (1982) and Pernicka (1987).

The ancient gold production of Greece was mainly confined to Macedonia, where an estimated 300 tons of gold were produced. According to Pernicka (1987) numerous gold occurrences were already known in prehistoric times in central and eastern Macedonia. The geological types are quartz veins in the Serbo-Macedonian basement rocks, disseminated porphyry copper ores with gold mineralization, and palaeoplacers in Tertiary sediments and river sediments. The localities given by Pernicka in his map of gold mineralizations are included in Fig. 14. The areas with old mines and dumps are Macedonia, Thrace and Laurium, in southern Euboea, and in the Cyclades islands in the Aegean (Wagner 1984). According to Emmons (1974) Thasos has been an important supplier of gold in ancient times.

In Macedonia gold-arsenopyrite-bearing quartz veins have been mined and massive sulphide deposits, particularly copper deposits, mainly contain gold in their gossans. The deposits are located in the Pangaeon and Angistron mountains.

Placer deposits are known along most rivers in the northern part of Greece. The most prospective rivers are the Axios and Gallikos and their tributaries. Near Thessaloniki gold was exploited even recently in smaller amounts from sediments of the Gallikos river. Reworked placers are also known, particularly in western Greece in the Mesolongi coastal area.

Recently gold deposits with relatively low grade ores of epithermal origin have been discovered on some islands, e.g. Milos. These deposits are hosted by younger volcanic rocks and associated with strong hydrothermal rock alteration.

Fig. 14: Gold localities of Greece (filled circles); dotted pattern: basement rocks (after Dunning et al. 1982 and Pernicka 1987).

18. Summary

The listing of individual gold mining districts in Europe has the handicap, that the information from different countries is available in different "densities". While from some areas, like Bavaria in Germany and Bohemia in the Czech Republic, very detailed catalogues even of very small workings are available, in much more important gold producing areas information is only available on the main deposits. Thus the standard of information cannot be correlated with the quantity of gold produced.

The surprising fact is that gold is an abundant mineral in Europe. Several thousand old gold workings are scattered over all European countries recording the enormous efforts people made to get gold.

The main associated metals in gold deposits in Europe are As, which occurs in nearly all districts, Sb, Bi, Te and Fe. These metals are usually bound in sulphide minerals, but natural alloys are frequent. A typical feature of most European gold deposits is the relatively small grain size of the gold particles, which is usually less than 0.2 mm.

Concluding, it can be stated, that Europe is very rich in poor gold deposits. Most of them were worked at different times. This may be surprising, but one must remember that the relative value of gold in respect to that of the work force was much higher than today for a period of several thousand years. The end of Europe's small scale gold production was the discovery of the Americas at the end of the 15th century, where enormous quantities of "cheap" gold entered Europe.

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Chapter 3

ACCUMULATION OF GOLD BY ELECTROCHEMICAL PROCESSES

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ABSTRACT. Natural sulphides are semiconductors. Combined n- and p-type sulphides (pn-junctions) in contact with an electrolyte form a Galvanic cell with potentials up to 140 mV. This is sufficient to accumulate visible gold at p-type conductivity sulphides (cathode). Experimentally, a little gold is also observed to be deposited at anodes (n-type conductivity sulphides). This may be caused either by n-type arrays at the surface of the anodes or decomposition of anionic Au-species coupled with deposition of some gold. Most effective in determining the type of conductivity is arsenic. This is assumed to be the main reason why gold is intimately associated with arsenic. Gold accumulation is explained as largely electrochemically controlled.

1. Introduction

Gold in its metal state must have inspired mankind at a very early time. With gaining increasing importance the demand grew and concepts had to be developed where to find it. Besides placer deposits quartz-sulphide veins, massive sulphide bodies or their gossans may have been the first dominant sources. All placer gold, however, had its origin in weathering of rocks hosting sulphides enriched in native gold.

Visible gold is intimately associated with sulphides in particular with those containing arsenic. But why? Although sulphides are well-known semiconductors, little attention has been paid so far to the fact that combinations of semiconductors in contact with electrolytes form self-driving electrochemical cells with potentials sufficient for deposition of noble metals from fluids. Mironov et al. (1981) already mentioned differences in thermoelectric properties of pyrite causing adsorption of gold. Following this line, Starling et al. (1989) and Knipe et al. (1991 1992) proposed that mixed np- and p-type conductivity of sulphides leads to greatest "adsorption" of Au.

2. Electric conductivity

Silicate rocks are electric insulators. They only gain some ionic conductivity because of the electrolytes hosted in open pores. Various sulphides and some oxides are semiconducting compounds (Tab. 1). Among the sulphides arsenopyrite and pyrite play an important role in that they are semiconductors with low energy gaps. The energy gap characterizes the energy needed to transfer an electron from the "valence band" to the "conduction band" (Fig. 1). All semiconductors are sensitive to impurities that substitute for main components in the crystal lattice. These substitutes act either as electron acceptors or donors, i.e. they enable electrons

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to pass the energy gap (Fig. 1). Of special interest is the substitution of As by S in arsenopyrite leading to As/S atomic ratios less than unity which results in n-type conductivity (1). "Doping" of arsenopyrite and pyrite with As leads to p-type conductivity (2) with electron flow managed by defect electrons, usually termed "holes". Both substitutions are shown schematically in Fig. 2.

e-donor:	$S \Rightarrow S^{+} + e$	(1)
e-acceptor:	$As + e \Rightarrow As^{-}$	(2)

Table 1. Examples of natural semiconductors after Shuey (1975).

Mineral	Formula	Gap	Type of Conductivity	
pyrite	FeS_2	0.9	Cu, Ni ⇨ Fe	n
			As ⇨ S	p
arsenopyrite	FeAsS	0.2	As > S	p
			S > As	n
chalcopyrite	$CuFeS_2$	0.6	As ⇨ S	p
			S ⇨ As	n
sphalerite	ZnS	> 3	Cu ⇨ Zn	p
			Ga, In, Tl ⇨ Zn	n
galena	PbS	0.4	Ag ⇨ Pb	p
			Bi, Sb ⇨ Zn	n
hematite	α-Fe_2O_3	2	Cu, Mg, Ni ⇨ Fe	p
			Sn, Ti, Zr, Ta, Nb ⇨ Fe	n
magnetite	Fe_3O_4	0.1		

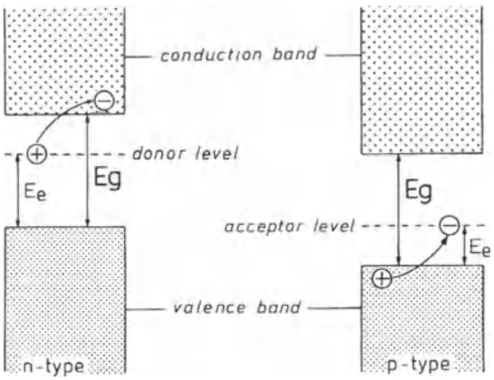

Fig. 1: Comparison of the electronic band model of n-type and p-type semiconductors. E_g = energy gap; E_e = electron energy in donor- or acceptor atoms. "Doping" of intrinsic minerals leads to considerable decrease of the resulting energy gap which is given by E_g - E_e.

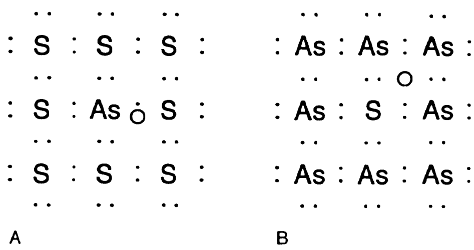

*Fig. 2: Schematic substitution of S and As in a sulphide and arsenide anion sublattice, respectively. **A**: Substitution of S (providing 6 electrons) by As with only five electrons leads to a missing electron, an electron hole. **B**: Substitution of As (providing 5 electrons) by S with six electrons leads to an additional electron in the interstitial lattice.*

If only "doped" at low levels, inhomogeneous distribution might occur leading to arrays with sulphides of different types of conductivity (mixed-type, m-type). Partial or total dissolution of exposed anodically reacting domains might explain the observed changes of the sign of the potential difference of m-type sulphides which were observed in some experiments (Kersten 1990).

In systems with linked n- and p-type semiconductors (pn-junctions) free electron flow is only possible if holes move into the n-type material, compensated by electrons moving into the p-type component (Fig. 3a), resulting in compensation of holes by electrons at the np-interface. This reaction leads to equal positive and negative charge densities respectively along the contact in the n-type and the p-type semiconductor. The substitution of Fe in arsenopyrite and pyrite by Co and Ni which act as electron donors result in n-type conductivity. Almost all natural chalcopyrites are n-type conductors (Shuey 1975).

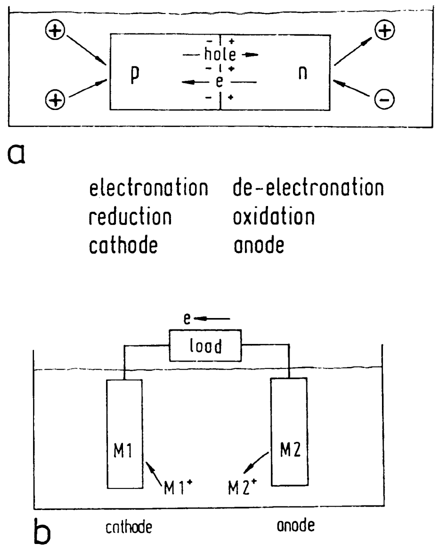

Fig. 3: Comparison of a galvanic cell consisting of (a) np-junction of semiconductors and (b) two different electrodes, both immersed in a common electrolyte. In both cases, electrons move from the anode to the cathode. This electron flux is counterbalanced by de-electronation processes at the anode and electronation at the cathode.

3. Natural self-driving cells

Any Galvanic cell, i.e. any energy-producing device or battery is a self-driving cell consisting of two half cells. The energy of the cell results from chemical reactions in the two half-cells. Self-driving cells are all either internally or externally controlled depending on reactions of components contained in the half-cells or with one component supplied by the electrolyte.

If an *internally* controlled combination of semiconductors is immersed in an electrolyte fixed charges will build up along the sulphide-solution interface as shown schematically in Fig. 3b. At the sulphide-solution interface specific reactions occur depending on whether the sulphides are electron sources (cathode) or electron sinks (anode). At the cathode, electrons are supplied to dissolved ionic species (electronation or chemical reduction of dissolved species), whereas at the anode electrons are collected from dissolved species (de-electronation or oxidation of dissolved species). The anode and cathode of such self-driving cells are defined by the free flow of electrons from the anode to the cathode, i.e., from n-type to p-type semiconductors. The potential difference is exclusively caused by diffusion of electrons and holes across the np-boundary. Such assemblages in electrolytes are comparable to standard galvanic cell arrangements (Fig. 3b) where the flow of defect electrons (holes) is substituted by that of positive ions.

In agreement with thermopotential determinations (Seeger 1982) the chemical analyses reveal that arsenopyrites with As/S < 1.0 and As/S > 1.0 show respectively n-and p-type behaviour (Möller and Kersten, in press). Other than As-S substitutions may also contribute to the conductivity, but are obviously negligible if the As/S ratio deviates by more than a few percent from stoichiometry (Fig. 4).

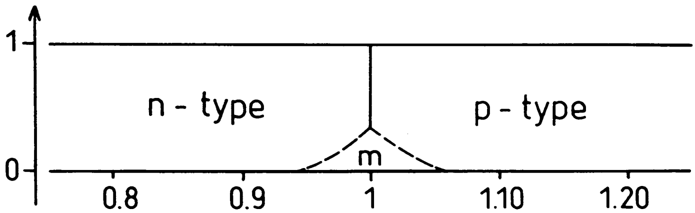

Fig. 4: Schematic correlation of As/S molar ratios of arsenopyrite with the type of conductivity (data are given in Möller and Kersten, in press); m: "mixed" type conductivity.

Externally controlled self-driving cells result if the electron conductor faces different environments at the top and bottom such as massive sulphide ore bodies with their top near the surface (high oxygen fugacity) and the bottom under reducing conditions (Fig. 5).

It is convenient to express all redox systems in terms of oxygen fugacity. The gradient of the oxygen fugacity corresponds to a gradient of Fe^{2+}/Fe^{3+} or Mn^{2+}/Mn^{4+} activity ratio. It is convenient to use the oxygen fugacity but it can be replaced by any other redox system. This is necessary if the chemical conversion is considered. Metal species concentrations are always much higher than dissolved oxygen. They of course are the reductants or oxidants in the system and manage mass oxidation or reduction. But instead of defining them the corresponding oxygen fugacity in equilibrium is more handy. It allows easy comparisons of systems which would not be possible if specific element ratios are used. fO_2 is dependent on pH, the ratio of oxidized to reduced species and temperature (ΔE_o, pK_W).

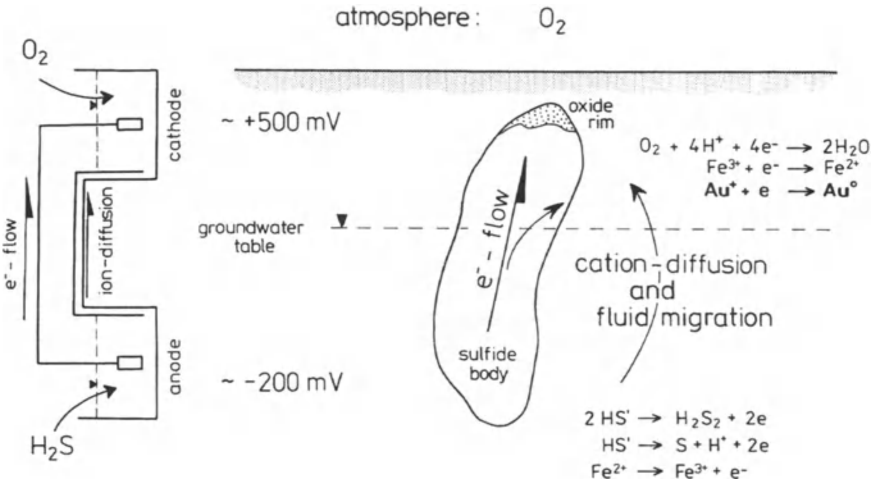

Fig. 5: Comparison of electrochemical reactions along a massive sulphide-ore body and a schematic setup of a Galvanic cell. The indicated potentials (relative to standard hydrogen electrode) have been determined for sulphides in aerated 1 M KCl solution (cathode) and H_2 S-saturated 1 M KCl solution (anode). Potentials of about 700 mV are reported as self-potentials of massive sulphide-ore bodies (Sato and Mooney 1960).

Sulphide crystals of n- and p-type conductivity were mounted as electrodes that were used in two different setups for studying the deposition of gold at sulphide surfaces:

- Linked sulphide crystals of different conducting types in the same environment as a model for different sulphide minerals in close contact or as np-junctions along fractures of sulphide crystals. This "configuration" is very common in sulphide mineralization and simulates processes in fractured crystals with chemical zonation and resembles in situ internally controlled galvanic cells, and
- Linked sulphide crystals under different externally controlled redox conditions modelling a sulphide ore body with its top and bottom under oxidizing and reducing conditions, respectively.

4. Accumulation of visible gold by internally controlled self-driving cells

In H_2S-saturated solutions each combination of sulphide electrodes shows slightly different cell potentials, probably due to varied contents of impurities in the fluids from which the sulphides formed. For example, syngenetic arsenopyrite and pyrite in contact leads to n-type arsenopyrite (anode) and p-type pyrite (cathode). In such an arrangement the noble metal ions are predominantly reduced at the pyrite surface. A different behaviour should be observed in sulphidization of löllingite ($FeAs_2$) and other arsenides where the remaining arsenic-rich component could easily become p-type conducting. Sulphides of varying conductivity types are formed if the minerals are precipitated from chemically different fluids or are metasomatically overprinted.

Potential differences between cogenetic arsenopyrite and pyrite, both under strongly reducing conditions (H_2S-saturated at room temperature), could be as high as 120 mV at the beginning, but decrease with time to about 40 mV (Möller and Kersten, in press). Figs. 6 and 7 show typical cathodic Au accumulation on arsenopyrite. Chacteristic is that Au is not evenly distributed but deposited at distinct places. In some experiments dendritic growth is observed (Fig. 6). Even when platy Au deposition (Fig. 6a) prevails it occurs only at some preferred areas. This clearly shows that nucleation is not "homogeneously" distributed all over the surface. To explain this just by assuming that only places of highest charge densities (Knipe et al. 1991, 1992) are responsible for initializing nucleation is refuted by the observation that Au is predominantly accumulated at cathodes. Much less Au is found on anodes (Möller and Kersten, in press).

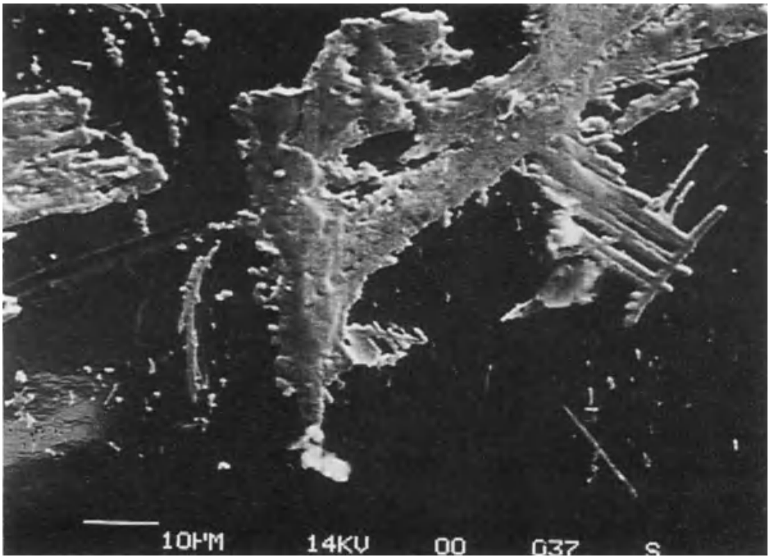

Fig. 6: Cathodic gold deposition on m-type arsenopyrite (Tangier mine, Canada) from H_2 S-saturated 1 M KCl solution. Dendritic growth of platy gold is observed.

Visible gold is preferentially accumulated at the cathode (p-type sulphide), a process which is compensated by partial dissolution of anodic sulphides. Linked sulphide minerals in contact with a common fluid are employed in studies of gold deposition at combinations of p- and n-type sulphides in nature (pn-junctions). The small electrochemical cells exert high field

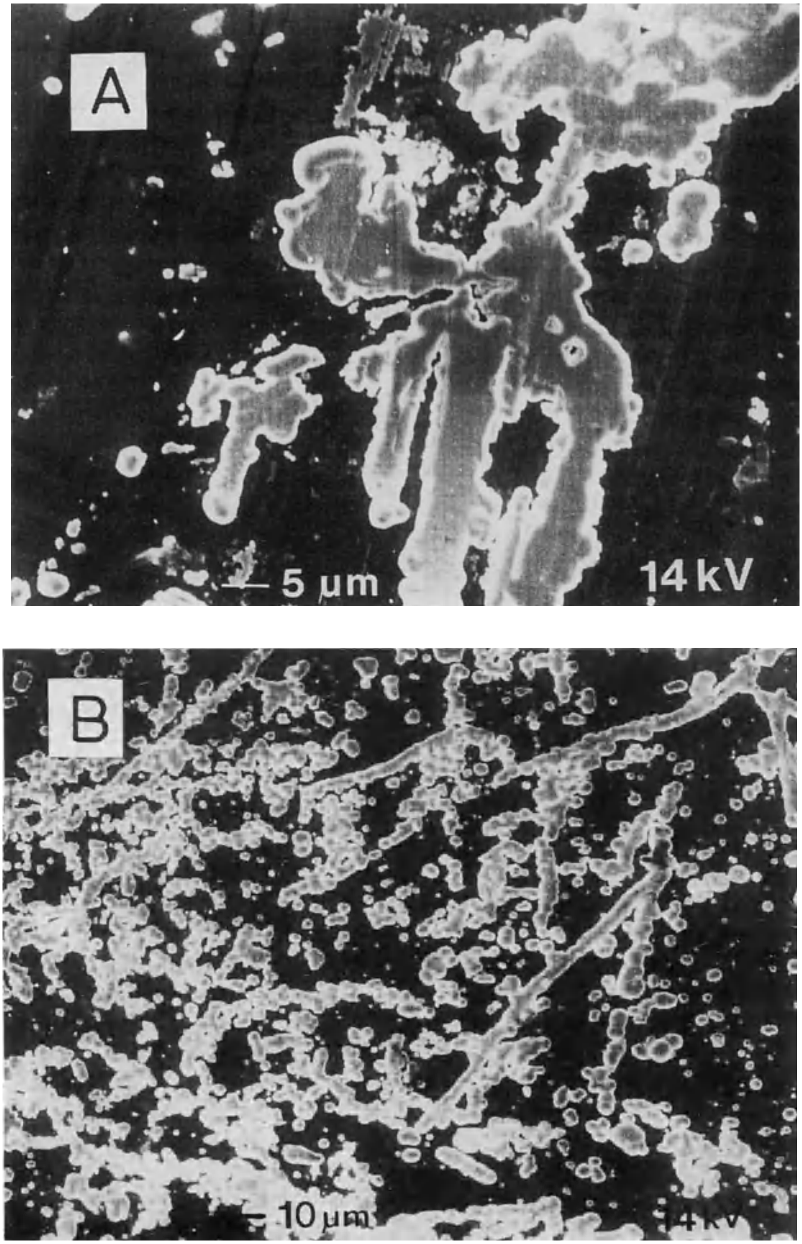

Fig. 7: Gold deposition on arsenopyrite (Freiberg, Germany) acting as cathode in these experiments coupled with chalcopyrite (A) and pyrite (B) from other localities. This assembly of electrodes was immersed in H_2S-saturated 1 M KCl solution. Gold is deposited at distinct areas. The long term potentials were in (A) 130 and in (B) 100 mV. Note the different type of gold deposition.

strengths due to which ionic Au species are moving to distinct places (Fig. 8). As long as the potential difference is maintained accumulation continues. New cells start working by fracturing zoned crystals (Fig. 9). Because the most effective element causing zonation of pyrite and arsenopyrite is As itself, it becomes obvious why gold is so tightly associated with As. Zonation of sulphide crystals, e.g. by variation of arsenic contents, is without doubt (Marion et al. 1991) an excellent base for np-junctions which become accessible to fluids after fracturing of the crystals. The observation that gold frequently heals microfractures in pyrite and arsenopyrite or precipitates at distinct places of surfaces (Knipe et al. 1991, 1992) is consistent with the necessary pre-conditions of electrochemical precipitation.

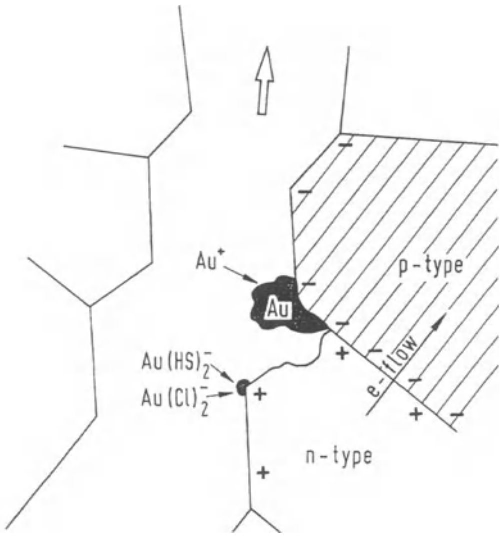

Fig. 8: Electrochemical reactions at the surface of n-type and p-type sulphides when a gold-bearing fluid moves along a pore. Gold is preferably accumulated at p-type conductivity material (cathode), whereas the n-type component is partially dissolved (anode).

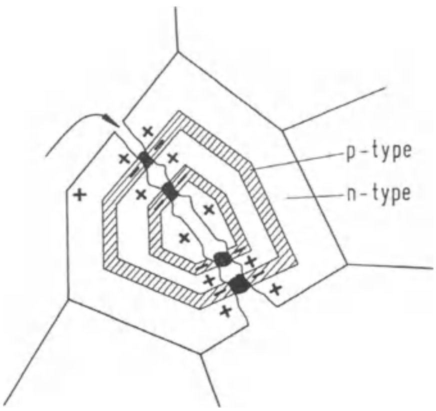

Fig. 9: Gold deposition in fractured zoned arsenopyrite. p-type conductivity zones (hatched; As/S < 1), n-type conductivity zones (white; As/S > 1) act as cathodes and anodes, respectively. Gold accumulation is shown in black. Fractured zoned crystals provide numerous np-junctions.

Pyrite and arsenopyrite with dispersed gold accumulations are described by Marcoux et al. (1989) and Wu et al. (1990) in samples from the Le Chatelet gold deposit (Creuse, France) where gold is positively correlated with excess of arsenic (p-type). Experimental examinations by Wu et al. (1990) showed that As-rich zones of arsenopyrite crystals are indeed enriched in Au. Mössbauer spectra of synthetic gold-bearing arsenopyrite proves trapping of native gold particles within the arsenopyrite apart from "combined" Au.

Electron flow is not only possible at np-junctions, but is also established where sulphide minerals are hosted in an electron conducting matrix such as graphite-bearing carbonaceous shear bands (Xavier and Forster 1991).

The deposition of gold is accompanied by oxidative dissolution of the anodic material, i.e. the n-type conductor. Thin sections reveal that gold grains are often bordered by a crystal face of the p-type sulphide at one side whereas the other side faces the n-type material showing dissolution features. This corrosion is probably due to oxidation of S^{2-} to native sulphur.

5. Accumulation of gold in externally controlled self-driving cells

Galvanic cells with one sulphide electrode under oxidizing and the other under reducing conditions show cell potentials (Fig. 3) that are in good agreement with "self potentials" observed in natural systems (Sato and Mooney 1961). Natural analogues of such Galvanic cells are massive sulphide-ore bodies or quartz-sulphide veins acting as conductors between oxidizing electrolytes at the top (above the ground water table) and reducing ones at the bottom (Fig. 5). As a result of the redox reaction at the sulphide ore body electrons flow from the reducing (bottom) to the oxidizing (top) environment. The experimental setup shown at the left side of Fig. 5 simulates the natural conditions.

In the aerated environment (cathode) the Eh conditions are controlled by the reduction of free oxygen whereas the Eh condition at the anode is largely established by oxidation reactions involving Fe^{2+}, HS^-, and H_2S. In a few experiments precipitation of elemental sulphur was observed on the anodes (Kersten 1990). The observed initial increase of potentials probably indicates chemical conditioning of the "fresh" electrode surfaces. The time needed for this process is about 100 min. and 2000 min. for arsenopyrite/pyrite and chalcopyrite, respectively (Kersten 1990).

Besides cathodic gold deposition (3) in nearly all experiments some gold was also deposited on anodic sulphide surfaces. The negatively charged Au-complexes are concentrated by adsorption processes at the anode surface particularly at places with high field strength such as at corners and along edges of the sulphide crystal. At these places decomposition of the gold complexes could takes place (4). However, it cannot be excluded that this minor gold is accumulated on domains with p-type conductivity due to chemically inhomogeneous crystals. In any case, the higher amounts of native gold were always observed at the cathode.

$$Au^+ + e \Leftrightarrow Au^\circ \qquad (3)$$

$$Au(HS)_2^- \Leftrightarrow Au^\circ + 2\,S + 2\,H^+ + 3\,e^- \qquad (4)$$

6. Electrochemistry vs. chemical precipitation

Although adsorption of Au species at sulphide surfaces (Jean and Bancroft 1985, Hyland and Bancroft 1989, Knipe et al. 1991, 1992) plays a fundamental role in any kind of concentration process, it cannot be the only reason for distinct Au accumulation because (i) in linked sulphide assemblages gold is essentially collected at the cathode and (ii) other sulphides with enhanced energy gaps (e.g. ZnS and PbS) are of minor importance in accumulating Au in nature.

Electrochemical nucleation of native gold (involving physical adsorption) is bound to potential differences at surfaces along which Au, once reduced to the metal state, clusters to form nuclei for further electrochemical deposition even with gold concentrations in the fluids being extremely low. This is in agreement with observations that pyrite is about three orders of magnitude more effective in sorbing gold from solutions than goethite (Schoonen et al. 1992). Combinations of n- and p-type sulphides are common in nature. The uneven distribution of gold deposited on sulphides and its prefered accumulation at cathodes (see also Starling et al. 1989) indicates that the electrochemical processes must dominate physical and/or chemical adsorption although the latter might occur. In contrast, chemical precipitation depends on supersaturation of the species that are involved in Au deposition. Since the complexing agents that transport Au are still present in excess in the fluid, chemical precipitation processes are very unlikely to be very efficient, excepting decrease of sulphur activity due to sulphidization processes.

The experiments discussed in this contribution demonstrate that externally and internally controlled electrochemical processes lead to Au accumulation on sulphides. The necessary conditions are common to all sulphide deposits. Typical examples selected from recent literature can show that the observations are consistent with the result of this experimental study.

Gold grains often occur close to grain boundaries of sulphides, i.e. between pyrite and chalcopyrite (Melling et al. 1990, Phillips 1987), within fractured pyrite (Starling et al. 1989, Schreiber at al. 1990, Piekarz et al. 1991) or as coatings and along cracks of arsenopyrite (Marion et al. 1991). Therefore, gold accumulation was later than the formation of the sulphides. Primary inclusions of Au grains could form provided that growth of sulphide minerals was slow enough to allow sufficient amounts of gold to be reduced. Pyrite often displays chemical zoning in Ni, Co or As-contents (Marion et al. 1991). If such crystals are fractured the sample might expose a great number of np-junctions to infiltrating fluids.

Gold accumulation associated with massive sulphide and continuous sulphide veins is abundant. Often the sulphide mineralizations are steeply dipping lodes or veins, as for example, in Archeaen and Proterozoic greenstone belts (Boyle 1979) with cell potential of about 600 mV between top (cathode) and bottom (anode). Under such conditions Au is mobilized as dibisulphido- and dichloro-gold complexes at depth and re-deposited at higher levels.

The small self-driving Galvanic cells between and within sulphide minerals with their tendency to electrochemical deposition of gold might be a great barrier in gold migration. Since these sulphides are ubiquitous, they could "filter" gold even from highly undersaturated Au solutions. This behaviour might explain why gold accumulation is abundant in the crust and particularly bound to the presence of arsenic, an element which is very efficient in controlling the p-type conductivity of sulphide minerals. The omnipresence of pyrite might explain the distribution of primary as well as secondary gold. It might even be argued that gold on quartz is due to sulphides that have been dissolved only leaving behind gold plates covering quartz.

In this contribution only natural sulphides have been considered. However it should be kept in mind that, besides sulphides, also oxides could be targets for studying deposition of gold.

7. Conclusions

Gold and probably other noble metals can be electrochemically deposited at any place where the electromotive force is high enough. Therefore, it may be of particular interest to look for such conditions in nature. If such a mechanism is really important, gold accumulation should be favoured at all mineral surfaces along the pathways of fluids where electrons are supplied (e-sources act as cathodes).

Although the phenomenon of self-driving cells in nature is just emerging it appears to be a promising way to explain accumulation of noble metals by electrochemical processes. A different approach to the problem of gold accumulation is forwarded by electrochemistry with its kinetic interpretation of equilibria. The latter is defined by charge transfer across the sulphide-electrolyte interface at the same rate in both directions but at different sites. Why should there be established local chemical equilibria between precipitated gold and dissolved Au-species provided the matrix, on which gold is deposited, shows a sufficient electronic conductivity?

Pyrite and chalcopyrite are predominantly n-type conducting, whereas arsenopyrites occur as n- and p-type semiconductors that are largely controlled by the As/S ratio. In general, the type of conductivity depends on the concentrations of specific elements that substitute for the main elements and act either as electron donors or acceptors. "Doping" leads to a decrease of the energy gap and thereby an increase in the electron conductivity:

(i) Combination of p- and n-type sulphides, either separated but electrically connected or as np-junctions, build up self-driving galvanic cells with cell potentials of >20 mV. np-junctions easily result from chemical zonation which becomes electrochemically active after fracturing of the zoned crystals.

(ii) Sulphide assemblages with one electrode in an oxidizing (cathodic) and the other in a reducing (anodic) environment yield cell potentials as high as 600 mV, similar to the well known "self-potential" of sulphidic bodies.

Gold is preferentially accumulated at the cathode. Electrochemical enrichment of gold at sulphide minerals might occur as a primary or secondary event. Au inclusions in the p-type zones are formed during growth of sulphides whereas native gold at grain boundaries precipitated from either late hydrothermal or supergene gold-bearing solutions. It might further be concluded that massive sulphides as well as dispersed sulphides in sediments or veins act as a barrier for gold migration. Even from extremely low concentrated solutions it is possible that Au is accumulated electrochemically from these fluids.

For electrochemical reasons gold is strongly associated with sulphides. This matrix, however, is extremely unstable with respect to weathering due to which gold grains become accessable to physical enrichment in placer deposits from which it can be easiliy extracted.

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Chapter 3

ORE MINING IN PREHISTORIC EUROPE: AN OVERVIEW

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1. Introduction

In the most general sense mining can be regarded as extension of the search for natural materials that could be used for the fabrication of tools and weapons or as ornaments. Thus the origins of mining go back to the Palaeolithic, even if it may often prove difficult to find any remains of such activities of this period. Nevertheless, archaeological evidence shows that in the Olduvai gorge *australopithecus*-men selected not only stone material for tool manufacture but also hematite rocks for use as pigments more than a million years ago (Wreschner 1980). *Homo erectus* used a variety of red ochre pieces to apply paint either to objects or himself at Terra Amata near Nice (de Lumley 1966). About 100,000 years ago *homo neanderthalensis* selected various red pigments (red chalk, red ochre, hematite, cinnabar) from the range of materials hitherto used only for tools to express certain ideas in painting. Neanderthal man was the first to celebrate burials and therefore obviously had already developed ideas of life after death. The use of red dyes is thought to represent the colour of blood and thus the colour of life. In Hungary there is the earliest evidence that Neanderthal man not only collected red stones but also dug into the ground to obtain the "blood stone" (Mészáros and Vértes 1955), and in South Africa Neanderthal man even dug underground for the same purpose some 40,000 years ago (Dart and Beaumont 1969). The use of pigments markedly increased with the advent of *homo sapiens sapiens* about 35,000 years ago (Mousterian). Presently, a 15,000 years old (Magdalenian) underground mine, which was exploited for hematite, is being excavated on the Aegean island of Thasos (Koukouli-Chrysanthaki et al. 1988).

Although the earliest mines most probably came into existence for reasons of religion or ideology, the extraction of raw materials for subsistence or trade did not lag far behind. Chert, or flint, was by far the most important mineral in this respect. Research carried out over the last decades has increasingly shown that flint mining also goes back as far as the late Palaeolithic period (Vermeersch et al. 1991). However, flint mining really flourished in the Neolithic from around 5000 B.C. when agriculture was introduced into Europe from the southeast. More than 200 flint mines were in operation in Europe, mainly during the fourth

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and third millennium B.C. (Weisgerber et al. 1981). Many of them were investigated, some of them very intensively. As a matter of fact, it is known more about the localities, mining techniques and organization, artefact production and trade of flint than about similar activities related to metals of comparative age.

Although workable stones were the principal material prospected in the Neolithic, other materials that could be used for symbolic and decorative purposes were also valued as indicated by a copper mineral pendant from Shanidar dated to ca. 10,000 B.C. (Solecki 1969) and the frequent use of various coloured stones, especially malachite, for the production of beads in the pre-pottery Neolithic of the Near East and the southeast European Neolithic cultures. This has nothing to do with ore mining in the modern sense but stands in the tradition of rock mining (Villalba et al. 1986). Nowadays, ore minerals are generally considered to be naturally occurring compounds valued for their metal content, so that further processing - generally including concentration, smelting and refining - is implied.

2. Copper

The first evidence for extractive metallurgy of all anciently used metals (copper, lead, silver, gold, tin, iron) comes from the Near East (see Pernicka 1990 for a recent review). Yet it has been held for some time that the earliest mines for ore minerals, namely Rudna Glava in Eastern Serbia and Ai Bunar in Bulgaria, are located on the Balkan peninsula. This has led considerable support to the hypothesis of an independent invention of metallurgy on the Balkans (e.g. Renfrew 1969). However, new radiocarbon data suggest that the copper mine at Kozlu (Kaptan 1986) in north-eastern Anatolia is at least contemporary with Rudna Glava and evidence is accumulating that smelting began already in the late Obed period (Hauptmann et al. 1993). Moreover, the failure to find any contemporary copper artefacts that geochemically match the ores of Rudna Glava or Ai Bunar (Pernicka et al. 1993, Gale et al. 1991) casts some doubt that these mines were actually exploited for their metal contents.

Nevertheless, the use of copper - most probably native copper - began in Europe in the early Neolithic on a very small scale as indicated by a few sporadic finds. Already in the late Neolithic Lengyel and Tisza cultures of Hungary copper in the form of small beads was quite frequent. Its sources are unknown but preliminary results suggest that at least part of it may have derived from Recsk in Hungary (Kalicz and Pernicka, in preparation), which is nowadays known as a large porphyry copper deposit. However, no traces of ancient mining have been reported from this district.

3. Evidence for prehistoric ore mining in Europe

Although remains of early mining activities are usually difficult to detect in the field, there is now a number of ore mines and/or smelting places known that data before the second millennium B.C. (Fig. 1). By the second millennium B.C. most mineralized areas in Europe seem to have been already discovered and exploited although, again, this is difficult to prove in the field. The best investigated area in this respect is certainly the Alpine region, with Mitterberg as the most prominent example. Well documented prehistoric mining areas of this period include Cornwall, Wales and Mount Gabriel in Ireland (Fig. 1). A noteable exception, so far at least, is the area of the Saxon ore mountains (Erzgebirge) where hard evidence for prehistoric mining is still lacking, although claims have sometimes been made that this area was an early source for tin in Europe and even for the Near East. Indirect evidence from both the remarkable distribution of archaeological features (Simon 1982) and the analyses of Early Bronze Age metal artefacts has so far been inconclusive as to the problem of locating ore sources but a new evaluation of the data using multivariate statistical methods shows encouraging results (Rau and Willing 1991).

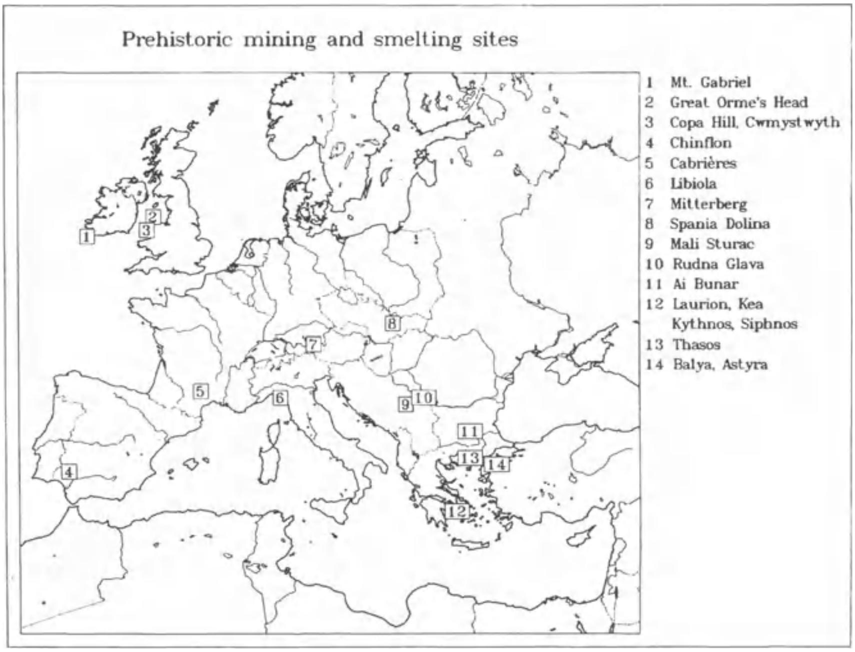

Fig. 1: Map of prehistoric copper mines that are mentioned in the text.

In the following a short description - approximately in chronological order - of several important early mining districts is given.

3.1 RUDNA GLAVA

The mines of Rudna Glava (Fig. 2) were discovered by modern open pit mining cutting the old workings. The archaeologist Borislav Jovanović from the Archaeological Institute of the Serbian Academy of Sciences recognized the importance of the site and together with the Mining Museum of Bor started a detailed investigation (Jovanović 1976, 1982) which has yet to be completed. A total of eleven mines could be studied after excavation and cleaning. The largest reached a depth of about 10 m. As Rudna Glava was the only known prehistoric mine for copper ores in southeast Europe for more than twenty years, many archaeologists were convinced that all copper came from there. This seems to be quite a naive view regarding the enormous number of copper deposits in the Balkans and considering the difficulties of recognizing and dating prehistoric mining activities.

Fig. 2: The prehistoric mining area of Rudna Glava was exposed by modern iron ore open pit mining. The row of mines follows the inclination of bedrock and veins.

It is safe to assume that in antiquity the copper mineralization at Rudna Glava was detected from bright coloured outcrops on a rather steep slope consisting of white limestone. At the beginning of the mining operations a working platform had to be cut in the slope. Mainly with big grooved hammerstones and antler picks and bars the miners followed the more or less vertically extending ore veins. For crushing, hafted grooved hammers were used, similar to the tools used for excavating flint nodules from hard rocks in the Neolithic. The hammers were made out of irregular pebbles. Presumably, many of the hammerstones were also used by hand but it was advantageous to avoid the shock in the hands by applying a groove or notches around the pebble. Frequent occurrences of flaked ends prove the intense use of these heavy duty hammers. Attacking the rock with such tools resulted in wide holes at the surface from which different narrower galleries went down irregularly until the watertable was reached.

Where larger amounts of minerals occurred the cavity tended to be larger. Where no ore minerals could be found and where only prospection took place, the galleries are as narrow as possible. This method of winning the ore is called "Tummelbau" or "coyoting". Correctly speaking, in miners' terms, such an inclined irregular mine in no way should be called a shaft. Such shallow mines had no problems of ventilation but the water table obviously represented an insurmountable barrier for the workings. New mines had to be opened from the surface after new platforms were cut. On some of the platforms large pots, ibex altars, and unused hammerstones were found, well-preserved and carefully hidden under stone built cases. They may be interpreted as offerings presented to the earth goddess. Obviously, the early miners tried to come to peace with the higher powers after they had intruded into the earth and removed some of her riches. Probably for the same reason the mines were filled after the end of the exploitation to hide the "wound" under a scar.

Unfortunately, no settlement could be discovered in the vicinity of the mines and also no slags were found despite intensive searching (Pernicka et al. 1993). It is possible that smelting was performed at village sites, but except for a few tiny pieces no slag was found in contemporary settlements of the region either. In addition, it is not at all clear whether the few small slag finds indeed indicate smelting or simply melting of native copper (Glumac and Todd 1991). The mines of Rudna Glava can be dated rather well by pottery from the offerings to the transition from the early to the later Vinča culture, i.e. to the second half of the fifth millennium B.C. in absolute terms. Such an early date of the workings is supported by ^{14}C measurements of a charcoal sample from the waste fillings near the floor of mine 2g (Pernicka et al. 1993). This sample (Hd 10820-10789) yielded a ^{14}C-age of 6220 $\pm$ 105 years b.p., which corresponds to 5320 to 5060 cal. B.C. using the calibration curve of Kromer et al. (1986). This age is higher than expected, but the charcoal is presumably from firesetting. In this case one would expect that solid dry wood was used which could be considerably older. Although one should not give too much weight to a single radiocarbon determination this high age nevertheless supports the general period of exploitation as derived from typological considerations (Jovanović 1982).

In a recent study some hundred prehistoric copper artefacts and malachite finds from archaeological sites in eastern and central Serbia as well as ores from Rudna Glava and from the major copper deposits of this region have been analyzed chemically and isotopically in an attempt to evaluate the role of the eneolithic copper mines at Rudna Glava for the early metallurgy in the central Balkans (Pernicka et al. 1993). The samples cover a long period in time ranging from the earliest Vinča-Pločnik phase to the Early Bronze Age, with the majority dating to the eneolithic period. The surprising result was that, for all the analyzed copper objects and the malachite samples, Rudna Glava can definitely be ruled out as an ore source (Fig. 3). Rather, a large fraction of the chisels and axe-adzes from the Bodrogkeresztúr period (almost half of all metal samples) may well have been derived from Majdanpek, the largest copper deposit in this region, and now lost for any mining-archaeological research because of extensive open-pit mining. No suitable ore source was found for the earliest metal objects from Selevac, Pločnik, and Gomolava, nor for the malachite samples from Selevac and Medvednjak. It is therefore obvious that there must have been other mining sites in operation besides Rudna Glava, which nevertheless continues to stand out as an example of early mining in the Vinča group.

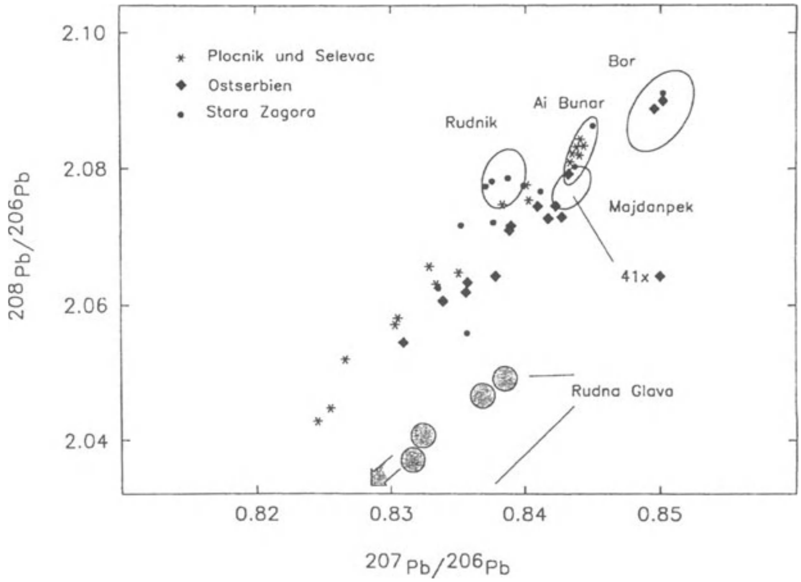

Fig. 3: Lead isotope ratios in copper ores from Serbian deposits and from the neolithic copper mines at Rudna Glava (Pernicka et al. 1993) and Ai Bunar (Gale et al. 1991) compared with lead isotope ratios in contemporary copper artefacts. The finds of Pločnik and Selevac are generally considered to be somewhat earlier than the heavy implements (mostly axe-adzes and chisels) which are summarized under the heading "Ostserbien". Copper artefacts designated "Stara Zagora" derive from various sites in the region of Ai Bunar and Stara Zagora (Gale et al. 1991) and are dated to the Karanovo VI period.

3.2 MALI ŠTURAC AND RUDNIK MOUNTAINS

Further research by the Archaeological Institute at Belgrade brought to light another Chalcolithic copper mine in Serbia. A sloping area of about 600 x 800 m without vegetation at Mali Šturac consists only of mining debris (Jovanović 1983). More than 130 of the well-known grooved hammerstones indicate the general age of the workings, which were directed towards an oxidized portion of a chalcopyrite vein. Pits indicate the places from where the galleries were driven into the ground. The investigation of this mining site is still at the beginning but it seems already established from surface finds that the exploitation must have been somewhat later than at Rudna Glava.

It is a safe guess that many more mines of this kind may be discovered in the Balkans. First observations at Jarmovac, Bor, and Mračaj seem to indicate this. On the other hand, much prehistoric mining evidence is certainly lost. At Majdanpek, for instance, most remains of the earlier mining periods have been obliterated due to the huge open-pit operation that is still going on today. Apart from the mine itself, dozens of square kilometers of the original landscape have been covered by tailings so that there is obviously no chance for any traces of ancient workings to have survived although they have frequently been reported in the earlier literature. Doelter (1916), for instance, mentions grooved stone tools made of andesite which are usually associated with prehistoric mining activities. He considered them to be Roman, as Davies (1935) did later here and in many other cases. Due to the existence of numerous adits and slag piles Doelter (1916) concluded that Majdanpek must have been a very important mining centre during the Roman period. The main activities were dated to the period between 29 B.C. and 284 A.D. according to discoveries of Roman coins, miner's lamps, fibulae, and pins. Wendeborn (1913) mentions numerous "old and very old" mines at the site Starica Kalkberg. According to Doelter (1916) mining took also place throughout the Middle Ages but came to an end with the Osmanic invasion in the 15th century. Under the Austrian administration between 1718 and 1739 the Majdanpek mine was briefly reactivated. The more recent mining period at Majdanpek started in 1850 (v. Handtken 1859, Wendeborn 1913) and continued - with several interruptions - to the present day.

3.3 AI BUNAR

In 1971 a Soviet-Bulgarian expedition visited about 50 old mining sites in south Bulgaria. Some of them could be attributed to the Copper Age by pottery finds (Karanovo VI-Gumelniţa Culture, end of the fifth millennium B.C.). The mine of Ai Bunar near Stara Zagora was the most impressive and subsequently excavated (Chernykh 1978a, Fig. 4).

Fig. 4: The great trench mining activities in Ai Bunar were only stopped by ground water seeping in.

A series of more or less vertical hydrothermal veins extends over more than a kilometre across at a width of 0.5 to 8 meters in the bedrock consisting of limestone, marl, and dolomite. The ore has been exploited wherever the mineralization showed up at the surface. Wedge-shaped trenches of 10 to 100 m length were dug. In general, they were only 2-3 m deep but at richly mineralized areas their depth extended up to 20-30 m and were stopped only by the groundwater table. The ore was crushed and concentrated by hand. The waste and the sterile country rock were backfilled so that nearly no dumps remained along the former vein. Former mining was indicated only by flat depressions that were not disturbed by later activities.

In addition to many grooved stone mauls, several copper shaft-hole-axes were obviously used, because they were found in the mines of Ai Bunar. After the mines had been backfilled miners used to live in the depressions, as is shown by abundant pottery finds. The persistent backfilling of the mine trenches can hardly be explained by any technical necessity. Therefore the reason for this practice may be sought in a religious background. As exemplified by many ethnographical examples, miners obviously considered it not unproblematic to "hurt" the earth by digging in deeply and removing her treasures. Together with Rudna Glava the evidence at Ai Bunar also demonstrates the ideological background of copper mining in Chalcolithic southeast Europe.

The total amount of rocks excavated at Ai Bunar is estimated to 20-30,000 metric tons, containing about 2-3000 tons of ore to produce some hundred tons of metal (Chernykh 1982). But, as with nearly all other Chalcolithic sites, no remains of clearly documented metal production - in the form of slags or smelting furnaces - have been discovered in the area. In fact, already Chernykh (1978b) noted that *"...numerous copper implements are known from the surrounding settlement sites, yet the chemical composition of most of these metal implements clearly fails to correspond to the geochemistry of the Ai Bunar ores"*. This statement was recently confirmed by lead isotope analyses (Gale et al. 1991) which are included in Fig. 3.

3.4 CYCLADES

In contrast to the situation on the Balkans, there is more evidence for Chalcolithic and Early Bronze Age copper smelting than for copper mining on some Cycladic islands.

On Kephala, a small promontory on the northern coast of Kea, copper slag - occasionally adhering to burnt clay - was found in an area that was inhabited by a small community of probably less than 50 individuals in the Late Chalcolithic (Coleman 1977). Although the dating of the settlement and an accompanying cemetery into the first half of the fourth millennium B.C. is well established, the contemporaneity of the copper slags is not beyond doubt, since the composition and petrography of the slags suggests a relatively advanced smelting process. On the eastern coast of the same island, at the site of Orkos, additional copper slags, similar in appearance and composition to the ones from Kephala, have been found (Pernicka 1987). Thermoluminescence (TL) data of the slags from Orkos range from 2700 to 5900 years and those from Kephala from 1200 to 3400 years (Lorenz 1988). Unfortunately, TL dating of slags is fraught with many more problems than with pottery so that these data cannot be taken at face value but merely indicate that the slags most probably are of Bronze Age date or earlier. One pottery sherd from Kephala yielded a combined fine grain and quartz inclusion TL age of 2700 ± 370 B.C. which is somewhat lower than the archaeological dating.

Copper ores and slags have also been known already before the advent of modern mining on the islands of Andros, Paros, Kythnos, and Seriphos (Fiedler 1841). This suggests that at least some of them could be ancient and, indeed, this could be confirmed at least for Kythnos. At the site of Agios Ioannis, also called Skouries, a large slag heap of more than 10,000 tons contains numerous fragments of Early Cycladic pottery. Two radiocarbon determinations on charcoal inclusions from the slags yielded calibrated data of ca. 2450 and 2830 B.C. (Stos-Gale 1989). Ancient mining is also attested on the island at Zoghaki and Milyes but not yet investigated in any detail. Similar to many other mining sites on the Cyclades the mineralization consists principally of iron ore that contains minor amounts of malachite. Most of these small occurrences of iron ore were exploited at the turn of the last century whereby many of the old workings were destroyed. Nevertheless, enough remains to warrant further investigations.

A similar situation as on Kythnos prevails on the neighbouring island of Seriphos. On its southwest coast there is a relatively rich deposit of iron ore which was worked until the 1960ies. Fiedler (1841) mentioned the occurrence of copper minerals in these iron ores and, indeed, about two kilometers north of the mine there is a very large copper slag heap of at least 100,000 tons near the bay of Avyssalos. Davies (1935) has also visited the mines and found fragments of ancient pottery. The slag heap also contains pottery that may well be dated to the Bronze Age but this has yet to be confirmed.

3.5 CHINFLON

The site is situated in the pyrite belt of southwestern Iberia, but it was not these huge orebodies that were exploited at the beginnings of metallurgy in the Iberia but rather small cupriferous quartz veins in a small area. Four mines are known with man wide trenches of about 4 m depth (Fig. 5). Sometimes sterile "rock bridges" remained in the trenches which were left over by ancient miners who followed the ore veins. Fragments of many grooved hammerstones were collected on the dumps and in remains of adjacent houses. There is evidence that the site was reworked in the Late Bronze Age but obviously only with little success (Rothenberg and Blanco-Freijeiro 1980, 1981, Pellicer and Hurtado 1980).

3.6 CABRIERES

During road construction works a Bronze Age copper mine was rediscovered in the vicinity of Cabrières in southern France, some 50 km west of Montpellier. This was already mentioned much earlier (Vasseur 1911) but was apparently later forgotten. Prospection and further archaeological investigations brought to light a whole metallurgical district with many more mines and sites with remains from ore beneficiation and roasting and/or smelting (Ambert and Barge-Mahieu 1991). Principal mining sites are Vierge, Broum (which may be a natural cave that was widened in the search for copper ore), Roussignole, and Pioch Farrus. At Roussignole an arrow head of the Palmela type has been found which indicates contacts with Iberia. A calibrated radiocarbon date from the lowest stratum in the Broum cave sets the beginning of the habitation and/or exploitation between 2300 and 2825 B.C.

Fig. 5: Cupriferous quartz veins were exploited in small trench mines at Chinflon in the Huelva district in southern Spain.

Similar radiocarbon data were obtained on charcoal samples from the most interesting ore dressing site at Roque Fenestre (Ambert 1990/91). It seems that sulphidic copper ores were roasted and/or smelted there, since the copper ores of this area contain a considerable amount of chalcopyrite and fahlore minerals besides oxidic minerals such as malachite. This is indicated by very high contents of antimony (up to 19%) and silver (up to 2.5%) in the ore. Although small amounts of slag and some copper droplets have also been found it is not clear if copper was actually smelted at Roque Fenestre. It seems rather that the ore was roasted in an oxidizing atmosphere to remove the sulphur which prevents the direct reduction of copper. In this process part of the ore would be converted to a black, stony mass called matte which consists of a mixture of copper and iron sulphides. If roasting was continued for an extended period or repeated then the matte would become enriched in copper and would eventually give off some copper metal. A similar process has been postulated for the Bronze Age smelting of the sulphidic copper ore at Mitterberg (Moesta 1986). It would at least explain the reported association of materials at Roque Fenestre.

3.7 LIBIOLA

Last century modern mining at the Libiola copper mine near Sestri Levante in the province of Genova had exposed a very narrow man-made "tunnel" (Issel 1892). Several tools such as wooden wedges, a shovel, a pick-handle made of oak and stone hammers were found in this gallery. Unfortunately, the present location of all these artefacts save for the pick-handle is unknown. Two radiocarbon determinations of the wood (GIF 7213: 4490 ± 90 b.p. and Bln 3367: 4610 ± 50 b.p.) yielded calibrated data of 3320-3100 and 3370-3350 B.C. indicating that this find and thus the exploitation of the mine may even be slightly earlier than the Rinaldone culture (Maggi and Del Lucchese 1988).

3.8 MITTERBERG

The ore deposit of Mitterberg was rediscovered in 1827 and in 1843 the Mitterberger Kupferbergbaugesellschaft reopened the mine. The miners regularly met traces of earlier mining activities and the administrator Johann Pirchl took care that observations of ancient workings and finds were carefully mapped and recorded. But only some thirty years later Matthäus Much recognized the prehistoric age of the mine (Much 1878/1879) at Mühlbach/Bischofshofen in the province of Salzburg in Austria. A comprehensive study was finally published by Zschocke and Preuschen (1932) making the Mitterberg the best documented and widest known prehistoric copper mine until today.

In the old men's workings only traces from the Middle Bronze Age onwards (ca. 1500 B.C.) were encountered. This is the time when the processes for smelting sulphidic ores were already mastered and well known in the Near East and in the Mediterranean (e.g. on Cyprus). But at the Götschenberg, a prehistoric settlement downhill from the Mitterberg, the lowest level yielded small copper artefacts, slags, crucibles and working stones from the Mondsee Culture dating to the fourth millennium B.C. (Lippert 1992). At the same site, in levels of the Early Bronze Age, smelting remains came to light. It is unlikely that at this early period the chalcopyrite ores of the Mitterberg were used, as indicated by analyses of slags. However, the main copper production at Mitterberg took place in the Late Bronze Age around 1000 B.C. and it is from this phase that copper ore was mined at many places and smelted near the mines at hundreds of sites at many parts of the Alps (Austria, Italy, Switzerland) and Lower Austria. The copper was traded in the form of flat cakes and ring and bar ingots. However, the attribution of these finds to specific mines is only rarely possible.

The large scale mining works at Mitterberg differ significantly from the older ones at Rudna Glava, Ai Bunar or Mt. Gabriel in their systematic approach and the mass production of copper ore.

The ore vein consisting mainly of chalcopyrite, pyrite and accessory nickel and arsenic minerals was attacked from the surface by galleries. At different height levels on the mountain slope several mine entrances were in operation at the same time. As the mines grew deeper it was necessary to connect galleries of different levels to provide better ventilation. Rock breaking techniques consisted mainly of firesetting and the application of big hammerstones; also many metal picks were used. Most of the mining debris remained in the mine, on the one hand to avoid unproductive transportation but also - and more important - to build platforms to support the fireplaces for heating the ore-containing rocks. Massive constructions of wood had to be placed in the mines. The inclined galleries reached a maximum length of 300 m and 60 to 105 m below surface. In the mines dams of wood and clay prevented the water flooding the working faces. The strong inflow of water nevertheless required considerable effort to carry the water out; many remains of wooden buckets were found. The earliest winch ever found so far comes from one of the Mitterberg mines and may have served to support the miners in climbing up and down with their loads of rock, mineral or water, or to lift a trough with a bag of minerals. The high standard of Mitterberg's mining techniques was only reached again and eventually surpassed by the Romans. Unfortunately, these mines cannot be visited. But different mines of smaller size in very close vicinity may give an impression. After the Brandner Gang mine recently vanished, only the Arthurstollen mine can be visited. Some of its features correspond to the Mitterberg Hauptgang.

Mining and smelting was very widespread in the Alps during the Late Bronze Age and the early Iron Age. Already Much (1878/79) mentioned several sites with old workings that he interpreted as prehistoric: Schladming, Kelchalpe near Kitzbühel, Ahrntal, Leogang, and Fieberbrunn. Preuschen discovered the mines at Vetriolo Vecchio (1968), Brun (1984, 1987) those in the Oberhalbstein/Graubünden in Switzerland. More than the mines, the great number of smelting sites indicates an enormous production volume. More than thousand slag heaps throughout the Alps and their promontories bear witness of these activities. Recent research has shown that some of the slag heaps contain up to 500 tons of slag and in two cases actual batteries of smelters were excavated (Cierny et al. 1992, Nothdurfter and Hauser 1986).

3.9 ŠPANIA DOLINA

It has long been suspected that the Slovakian ore mountains could have been a major source for copper of the central European Bronze Age (e.g. Pittioni 1957). Until recently, however, there was no evidence to be found in the field for this suggestion that was mainly based on spectrographic analyses of copper objects. From 1964 on, the old heaps of waste rock were prospected by modern geologists in an attempt to extract the remaining copper by leaching. On this occasion many examples of grooved hammers were found which prompted a more detailed archaeological investigation (Točík and Žebrák 1989).

3.10 BRITISH ISLES

Very recent archaeological research on the British Isles on mining has produced completely new results for prehistoric copper mining (for a summary see Crew and Crew 1990). Chronologically, these mines belong to the British Bronze Age, i.e. the second and early first millennium B.C. From a total of 31 sites presently known in England, Wales, and Ireland three sites are shortly described, because their Bronze Age exploitation has been confirmed beyond doubt by radiocarbon data.

Great Orme's Head is a major feature of about 225 m height on the coastline of north Wales. A valley at the flank in the southeast is filled with remains of debris from copper mining in the industrial period. Up to now no traces of the old workings could be observed on the surface, because they are buried under sub-modern waste tips. Early reports from 1849 mention bone and stone tools found in a cavernous old stope. In the recent investigations prehistoric stopes - some of them rather large - were met at considerable depth. In the backfilled debris (now strongly cemented) bone and stone mauls as well as ever-present charcoal were found. The charcoal indicates firesetting for breaking the rock. The stopes are of considerable size, with a length of at least 80 m from the valley side and a width and height of 15 m each. Producing galleries were 16 m (A) respectively 47 m (B) long. The two inclined stopes were driven from the gently sloping valley flanks so that the mines appear similar to those in the Mitterberg area in Austria. There is evidence for at least three more similar stopes. Calibrated radiocarbon data from the mines range from about 1000 to 1500 B.C. There is no doubt that these mines once produced a considerable amount of copper ore.

At Cwmystwyth, Copa Hill, quartz veins mineralized with copper ores occur within the bedrock consisting of shale. They have been worked in the Early/Middle Bronze Age and have been dated by radiocarbon around 1500 B.C. calibrated. Since the summit and the hillsides are moorland, the latest activity on the site is the exploitation of peat, but there is also some sub-recent small scale mining and prospecting. The area is divided into an opencast about 40 m long and open to the slope, and a considerable number of mining tips aligned along two long heaps of mining debris stretching more than 50 m. Their surfaces were littered with hammerstones although the area was partly overgrown with turf. An excavation at the face of the opencast provided evidence for galleries driven by firesetting, which also exhibited stone tool marks reminiscent of hammerstones. The stratified mining debris contained hammerstones, fragments thereof and charcoal from firesetting. The opencast at Copa Hill with sealed faces and layers of mining debris may offer the largest research potential of all prehistoric mines in Europe.

First reports of the copper mines of Mount Gabriel in Cork county, south-west Ireland, appeared some 25 years ago. They are situated in sedimentary copper beds (so-called red-bed sequences of the Late Devonian Castlehaven Formation), which are typically low-grade deposits with small local enrichment zones. The existence of these mines stresses the importance of oxidized mineralizations for early copper mining. It is thought that they attracted attention only after the supplies from vein sources diminished. So far 31 mines have been discovered at Mt. Gabriel. Although the flanks of the mountain are polished blank by the last glaciations, the mines at the foot of the mountain were mostly buried under a blanket of peat (Fig. 6). Radiocarbon data show that the principle mining activities concentrated between 1700 and 1500 B.C. calibrated. As in the other mining districts in Britain stone mauls and grooved hammers were the main tools (Fig. 7).

The originally horizontal bedding of the sedimentary layers has been tilted 20°-30° westwards by tectonic processes. This gives the mines their typical features and created a series of problems for the miners. Apparently, mining started with a detailed inspection of the outcrops in an effort to locate the most promising mineralizations. These were then exploited along their 200 m long strike length in 14 major workings. When the mineralization continued underground, then galleries were driven by firesetting and the use of stonehammers. Most likely, the miners soon encountered problems with drainage and lighting. This may be one of the reasons for the generally shallow extensions of such sub-horizontal mines (1-11 m).

Recent excavations around the entrance of mine 3/4 revealed dumps from ore concentration under the peat which demonstrated a highly developed spatial organization. The dumps indicate that the ore has been concentrated by crushing and hand sorting. This resulted in concentrates of oxide and carbonate minerals intermixed with disseminated sulphide mineralization of a much lower grade. Arrangements of rock slabs and fragments of stone tools at the spoil dumps together with remains of a camp installation provide an idea of the procedure.

Fig. 6: Typical opening of a gallery filled with water at Mt. Gabriel (Ireland). Foto Ganzelewski.

Fig. 7: Fragments of stone mining tools at Mt. Gabriel (Ireland). Foto Ganzelewski.

Similarly to other early mining sites on the British Isles, no traces of smelting have been detected in the vicinity of the mines. This is sometimes explained by the application of an essentially non-slagging process using rather pure copper ores (Craddock and Gale 1988). However, it is doubtful, if this could have been the basis for relatively large scale copper production.

Prehistoric gold and copper artefacts were major products of Bronze Age Ireland. They are typologically so specific (e.g. thick-butted flat axes) that in England and on the Continent they can be recognized as imports. They are also characterized by specific impurity patterns which resemble the central European fahlore metal used for ring ingots, differing mainly in generally lower bismuth contents (Junghans et al. 1968). This metal type has long been associated with the Mt. Gabriel mines and this contributed to the mistaken belief that the ore from this mountain is of the fahlerz type. Instead, the oxide ores of Mt. Gabriel may well have contributed to the relatively pure bronzes that came into use during the later stages of the Early Bronze Age on the British Isles. For the fahlerz type metal other sources have definitely to be sought. Obviously, the present knowledge of ancient mines is still far too patchy to reconstruct the procurement and distribution of copper in the early stages of its use.

4. Lead and silver

In Europe these two metals appear only in the third millennium B.C. although a very few isolated finds are claimed to date to the fourth millennium (see contributions by Makkay and Primas, this volume). Considerable quantities of lead and silver have been found in excavations of the Aegean Early Bronze Age. In the past those finds were usually interpreted as imports from Anatolia or the Near East where lead and silver came into use much earlier and are quite abundant already in the Uruk period, i.e. the late fifth and fourth millennium B.C. A comprehensive study conducted by researchers from the Max-Planck-Institut für Kernphysik in Heidelberg, the German Mining Museum in Bochum and the University of Oxford revealed that the Aegean ores were exploited already in the third millennium B.C. (Wagner and Weisgerber 1985) and that the Aegean Early Bronze Age cultures played a much more active role in lead and silver metallurgy than hitherto thought (Gale and Stos-Gale 1981, Pernicka 1987).

Small deposits of argentiferous lead ores - mainly galena (lead sulphide) - occur at various locations in the Aegean region including the islands. Several of them are recorded in the Classical literature, most noteably by the historian Herodotus (490-425 B.C.). The most famous are the argentiferous lead-zinc deposits of the Laurion area in the southern part of the Attica peninsula, which were the main source of power of the Athenian city-state in the fifth century B.C. Almost as prominent in the ancient literature is the Cycladic island of Siphnos which is reported to have been the richest in all the Cyclades. In contrast to Laurion, this mineral wealth was not confirmed by modern geological knowledge at the beginning of the study, whose partial aim it was to relocate such anciently known mining sites and to evaluate their role in the ancient economy. A surprising result was the discovery that the mines on Siphnos were already known and exploited in the Early Cycladic period (first half of the third millennium B.C. or Grotta-Pelos phase).

4.1 SIPHNOS

Geologically, Siphnos belongs to the Attic-Cycladic crystalline complex, and consists of marbles, gneisses and schists. Small ore deposits cluster along a belt in the middle of the island. Their mineralization is dominated by iron ores which contain small pockets and veins of complex silver minerals which most probably owe their existence to karst phenomena. Genetically less clear are a few iron mineralizations with slightly elevated gold contents in the southeastern part of the island. In any case, the wealth of the island in terms of gold and silver as reported in the ancient literature was now confirmed for the first time. For a detailed account of the investigations on Siphnos see Wagner and Weisgerber (1985).

Early Bronze Age miners first exploited the sources near the surface by means of open cut mining. Trenches, pits on flat and sloping surfaces are still visible today. Examples of these activities can be observed at Xeroxylon, Aghios Silvestros and Aghios Sostis, especially in mine 1. By more or less vertical drift mining deeper lying deposits were tapped. Generally these shafts, followed the sloping layers of the deposits. By means of galleries - usually ovoid in cross section (Fig. 8) - driven from the bottom of those shafts, the deposits were reached and the ore collected in chambers of occasionally considerable size. Heavy pebbles with clear flaking were the tools to drive galleries and shafts. The rock was shattered by heavy pounding. The ores were concentrated with smaller stone hammers and anvil stones already in the mines. Pine tapers may have provided the illumination.

Fig. 8: Mine 2 at Aghios Sostis on the Cycladic island of Siphnos (Greece). The two galleries of the Early Cycladic period were exposed by blasting during the 19th and early 20th century mining for iron ore. Their oval section is typical for the use of firesetting and heavy stone mauls.

Carefully packed mining debris in all prehistoric mines resulted in a complete sealing of the mines. Galleries and chambers were backfilled to the roof and the shafts to the top. Since this necessitated considerable unproductive work, this seems to represent another case for a religious background of mining, like at Rudna Glava or Ai Bunar. In Siphnos the backfill was compacted by sintering processes and became very hard. When, during the Archaic period, the Greeks resumed the mining activities, they first had to invest considerable efforts and time to reopen the mines and to dig out the sintered tips.

At least at Aghios Sostis the smelting of the ores took place in the immediate vicinity of the mines. Small pieces of slag and fragments of flat tuyères are scattered in the vicinity of the mines. Of particular importance are a few pieces of litharge (lead oxide) that were also found. Although not directly datable they make it seem very likely that the process of cupellation for the extraction of silver was practiced on Siphnos at this early date. Details remain unclear as to the technical execution of this process, as well as the function of some prehistoric crucible fragments from Aghios Sostis. Indirect confirmation for Early Bronze Age cupellation on Siphnos comes from Early Cycladic lead and silver objects, about half of which can be attributed to Siphnian ores based on their lead isotope ratios and their chemical composition.

4.2 LAURION

The most prominent ore deposit in Greece, archaeometallurgically and also economically until a few decades ago, is without doubt Laurion in the southeast of Attica. Altogether between two and three million tons of lead have been produced and although mining has ceased at present, the reserves are estimated to be several million tons more of relatively poor ore. The mineralization is of the so-called mixed sulphide type, i.e. the ore contains mainly sphalerite (ZnS), Galena (PbS), and Pyrite (FeS_2) in varying proportions together with minor amounts of chalcopyrite. The importance of this deposit for the rise of the city-state of Athens due to the production of silver from argentiferous lead ores is well documented in the ancient literature. The ancient mines and remains from ore dressing in antiquity have been often described (Weisgerber and Heinrich 1983, Jones 1988).

The date of the beginning of mining operations at Laurion was in dispute for a long time. Until recently, most authors thought that the mines were opened at the same time as, or slightly after the introduction of silver coinage in the sixth century B.C. and the discussion revolved about small details. Later, lead isotope analyses suggested that Laurion was the source for a number of lead and silver objects from the Aegean Late Bronze Age and even from the Early Bronze Age (Gale and Stos-Gale 1981). This was even earlier substantiated by excavations of a Belgian team at Thorikos (Spitaels 1984), just north of the town of Laurion where mining began at least as early as Early Helladic III times (around the middle of the third millennium B.C.). As on Siphnos, a find of litharge (PbO) - a material that does not occur in nature - proves extraction of silver by cupellation in the same period. Today the later mining remains of the Classical period completely dominate the appearance of the ancient mining district. They are distinctly different from the prehistoric ones, as can be seen in Fig. 9.

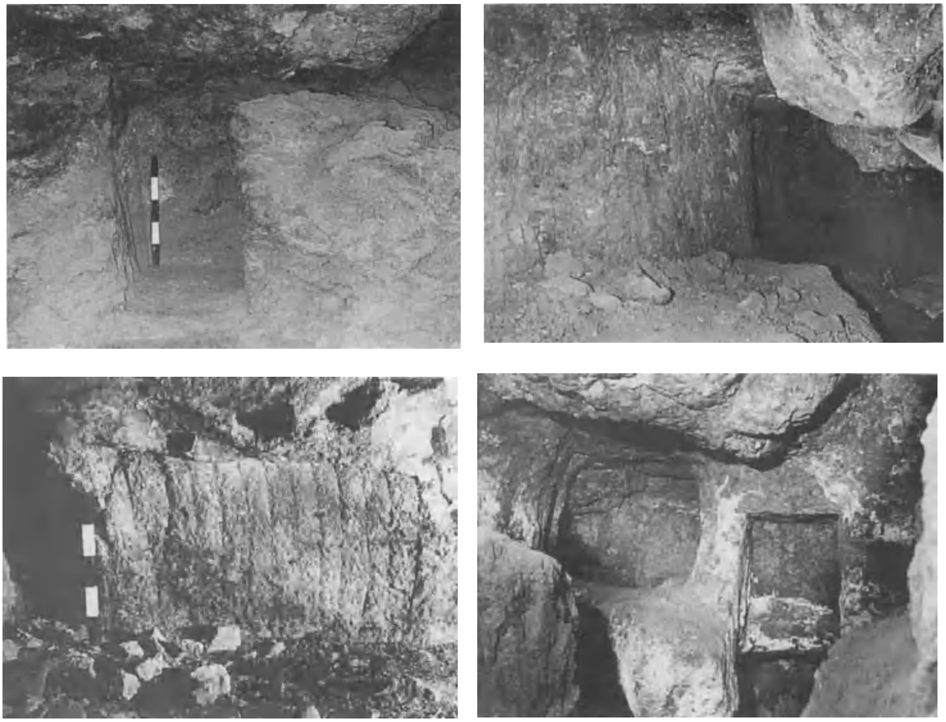

Fig. 9: The use of iron tools in antique mining resulted in prospection galleries with typical rectangular cross sections as demonstrated here at Laurion in southeastern Attica (Greece). When larger ore bodies were encountered they were completely removed, occasionally generating large and irregular chambers.

4.3 BALYA

Although not belonging to Europe in the strict geographical sense, mention should be made of a lead-zinc deposit of comparable size as Laurion, namely Balya, in the province of Balikesir in western Turkey. Its main product is argentiferous galena from which 400,000 tons of lead and 1000 tons of silver were produced in the years between 1880 and 1935. This mining district has been identified with the ancient Pericharaxis (Wiegand 1904) and from the field evidence there is no doubt about extensive ancient mining as well. However, several features within the mines date clearly before this period so that mining at Balya may well go back to the Early Bronze Age period like Siphnos and Laurion (Pernicka et al. 1984). No radiocarbon data are as yet available from this mine.

An even larger deposit of argentiferous lead ores that was utilized in prehistoric times is situated some 200 km further east at Gümüşköy in the province of Kütahya. Many hammerstones and crushing plates have been found that are reminiscent of tools from the Aegean. An uncalibrated radiocarbon date of 3900 b.p. has been reported (Demirok 1982) that is a strong indication for exploitation in the Early Bronze Age. The whole mining district still awaits archaeological investigation.

5. Gold

To our knowledge there is no evidence for hard rock mining of gold in Europe before the first millennium B.C. and, indeed, in the Old World altogether. Only in the Eastern Desert of Egypt is Bronze Age gold mining firmly established (Klemm and Klemm 1989), but it is not yet clear, how far it reaches back in time. Early Bronze Age mining is also well attested at Kestel in the Taurus region of southern Anatolia (Yener et al. 1989). Although it is claimed that the mine was exploited for tin (Willies 1992) this is not beyond doubt and there is a chance that it was gold that was actually sought there (Muhly et al. 1991). Indirect evidence for tin mining comes from a nearby settlement at Göltepe (Yener and Vandiver 1993).

The lack of field evidence for gold mining is usually explained by the fact that the earliest gold derived from placers and that remains of placer mining are much more difficult to detect, especially if the scale of the operations was small. Thus the early exploitation of gold placers, e.g. in southeast Europe, can only be inferred from the distribution of gold artefacts. This may be unsatisfactory but it is even more problematic to suggest possible regions of provenance for gold based on its composition. As an example, the presence or absence of platinum group elements - often in the form of of small inclusions of alloys of the platinum group metals - is far less indicative of the ore source than initially thought (Young 1972). Even the composition of the inclusions themselves did not provide a clue for provenance (Meeks and Tite 1980). Thus the suggestion by Hartmann (1978) that the presence of platinum in a large fraction of the gold artefacts that have been analyzed from the Varna cemetery on the Bulgarian Black Sea coast would point to a source in the Caucasian region was probably precipitate. This conclusion was mainly based on the distribution of gold artefacts with measurable platinum contents from various periods and the assumption that no such gold occurs in Bulgaria or the Aegean. However, recently several occurrences of placer gold with significant concentrations of platinum group elements have been discovered in the rivers of northern Greece (Vavelidis et al. 1988, Vavelidis 1989, Boboti 1994) and it is very probable that the rivers north of the Rhodope mountains also contain some gold of similar composition. This is not only confirmed by a French traveller (Bellon 1555) who reported that gold was panned in the Marica valley but by modern prospection of Bulgarian geologists (Georgiev and Raškov 1971, Maksimov 1971).

Ancient hard rock mining for gold is attested at Astyra, some 30 km southeast of Çanakkale in northwesten Anatolia. Gold occurs in a steep dacitic intrusion of several meters thickness which has been mined to a depth of about 50 meters. Although most of the mining activity may date from the Greek or Roman period up to modern times - exploitation ceased in 1914 - there are some indications for pre-Classical mining on the the wall-rocks (Pernicka et al. 1984).

Finally, gold was mined on the eastern coast of the island of Thasos at least from the sixth century B.C. on. Although Herodotus writes that he had seen the mine himself and has given a detailed topographical description of the site, it was searched for in vain for a long period (Conze 1860, Speidel 1929, Davies 1932) so that serious doubts were cast on Herodotus' report in the archaeological literature (Holtzmann 1979). The relocation of this ancient mine (Wagner et al. 1979) not only confirms Herodotus but opens the possibility that gold may have been mined even earlier, since mining and smelting has a long tradition on Thasos (for a detailed account see Wagner and Weisgerber 1988). According to Herodotus the inhabitants of Thasos also had possessions on the main land, called Skaptehyle, where gold was mined in antiquity. This site has never been unambiguously identified but it seems likely that it could be located in the area of Palea Kavala north of the modern town of Kavala, where gold contents of up to 37 ppm have been found in small occurrences of iron-manganese ores (Chalkias 1985, Photos et al. 1989). Old workings are encountered at most of these mineralizations. However, no detailed archaeological investigation has yet been conducted.

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Chapter 3

GOLD DEPOSITS AND THE ARCHAEOLOGICAL DISTRIBUTION OF GOLD ARTEFACTS:
A case-study of the La Tène period in the Swiss Midlands

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ABSTRACT. For the territory of modern Switzerland there exist documentary and archaeological sources relating to the extraction and use of gold in antiquity, specifically in the La Tène period between the fifth and first centuries BC. These will be compared with the medieval and modern historical sources, as well as with present-day knowledge of gold deposits in the rivers of the Swiss Midlands. The map of natural gold deposits, insofar as they are known at present, does not coincide with the archaeological distribution of gold artefacts. The gold in the Bernese graves might have come from the Napf river, but this hypothesis awaits further verification. The following study encompasses roughly the territory of the Celtic tribe of the Helvetii who, according to Julius Caesar, in the year 58 BC inhabited the area between the Rhine, the Jura mountains and Lake Geneva (De bello Gallico 1.2.3).

1. Ancient historical sources

First and foremost among the ancient literary sources come the writings of the Greek grammarian Athenaeus of Naucratis, who lived around AD 200. In his rich anthology of quotations is found the following passage (6.233d): *"In the most remote parts of the world there are certain small rivers which contain gold nuggets. These are sieved out of the sand by women and physically weak men, and then brought in for smelting as, according to my informant Poseidonius, was common amongst the Helvetii and some other tribes"* (Howald and Meyer 1940, 60-63). It is significant for the quality of this information that, in referring to the Helvetii, Athenaeus explicitly invokes Poseidonius of Apameia (circa 135-51 BC) as his source. The Greek polymath Poseidonius, whose works are in part only fragmentarily preserved, is regarded as an extremely reliable informant. The credibility of the report that, in the first century BC, the Helvetii were indeed panning for gold, is thereby greatly enhanced.

Another important passage comes from Strabo of Amaseia, who lived and was active in the first century BC. He too explicitly refers back to Poseidonius when he writes (7.2.2): *"...the Cimbri...moved down among the Helvetii, to a people rich in gold but peaceful. When the latter saw that the wealth which they had acquired by plunder exceeded their own, they were carried away with delight, most of all those among them of the Tigurini and the Tougeni, and joined up with them. The Romans, however, annihilated them all..."* (Howald and Meyer 1940, 58-61). This text should doubtless be understood as meaning that at that time (around 100 BC) the Helvetii were able to dispose of enough gold of their own as to be considered affluent. Furthermore, Strabo's text alludes to two Helvetic constituent tribes, the Tigurini and the Tougeni, who have been variously interpreted by modern scholarship. It is consi-

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dered as certain that the Tigurini inhabited the western Swiss Midlands. The Tougeni, by contrast, have been the subject of debate among ancient historians. Today, most scholars would identify them with the Tutoni/Teutones who, together with the Cimbri shortly before 100 BC, kept Europe in fear and trembling with their military campaigns (Staehelin 1921, 144ff.; Frei-Stolba 1976, 300f.).

On the basis of the textual excerpts cited above, and on the assumption that, at the time of their earliest mention, the Helvetii already lived in the Swiss Midlands, Eduard Norden as early as 1920 attempted to pinpoint the relevant gold-bearing rivers in the area concerned (Norden 1920, 230-232). He identified them as the Grosse and the Kleine Emme on the border of the present-day cantons of Bern and Luzern. In this he was uncritically followed by Swiss historiography until very recently (Staehelin 1935, 362; Staehelin 1948, 29f.; Frei-Stolba 1976, 295). In particular, this interpretation derived on the premise that the two Emme rivers are essentially the only gold-bearing water-courses, and was further influenced by the high reputation enjoyed by the gold from their catchment-area, the Napf, in the eighteenth to nineteenth century. Norden's argument, whereby Poseidonius' Greek word "potamion" expressly referred to the Emme (Celtic "ambis" = river), was rejected early on by Felix Staehelin on internal evidence (Staehelin 1921, 132f.).

Of general interest is a further quotation from the ancient ethnographer Diodorus Siculus (also in the ambiance of Poseidonius) which shows that people in the ancient world were well aware of where the gold in rivers originated from (5.27.1): *"For the rivers as they course through their winding bends and dash against the banks of the mountains which lie alongside, break off large masses from them and become filled with gold-dust"* (Tierney 1960, 249).

Taken overall, the information of ancient authors concerning the incidence of gold in the territory of present-day Switzerland is admittedly meagre, and to some extent debatable in substance. Nevertheless, it retains as valid its central testimony that "washed" or panned gold was extracted in the territory of the Helvetii around the first century BC.

2. Later historical sources

Following up this lead with the aid of medieval and post-medieval sources is no easy matter, since there exists as yet no comprehensive study of the history of gold extraction in Switzerland. Still indispensable is a 1927 work by L. Rütimeyer, in which not only documentary sources but also eye-witness accounts and his own field-work were used (Rütimeyer 1927, 41). If one draws together the concrete information on places where gold was washed, the streams rising in the Napf emerge as the most important providers of gold. The earliest references date from the twelfth century, when the abbey of Muri imposed on its dependent peasants a levy in the form of gold (probably raw, uncoined gold), which they could really only have obtained from the river Reuss. The references progressively multiply during the subsequent centuries, especially after the authorities in Luzern promoted the extraction of gold from the Kleine Emme and the Reuss river in order to supply their mints. Of particular interest are the lists published by H. Walter of the quantities of washed gold supplied to the state (Walter 1923). Between 1701 and 1800 these amounted to 15.4 kilograms, in the preceding one hundred years (1601-1700) only half as much; for the three centuries (1523-1800) during which accounts were kept in the Luzern archives, more than 31 kilograms are recorded. Since gold was one of the prerogatives of the authorities, it had to be surrendered to the state at an officially fixed price. Both the quantities provided and the price were subject to sharp fluctuations. For example, in 1771, an unusually good year, 27 gold-panners delivered an average yield of 12 grams each (Walter 1923, Rütimeyer 1927, Rykart 1969). In this same year, one gram of gold would have bought 37.5 kilograms of corn or 2.11 kilograms of sugar; the equivalent of 104.18 grams was needed for a horse (Villiger and Rawyler 1976).

Gold was also panned on the lower reaches of the streams and rivers rising in the Napf. In 1612 L. Thurneisser deemed the course of the Aare as far as the Rhine to be especially lucrative, and also mentioned Bern. According to another source, between 1834 and 1839 about 40 gold-washing stands were in operation between Olten and Klingnau, that is, along a 50-kilometre stretch of the river (Rütimeyer 1927).

There are then some references to very appreciable deposits in the Rhine, especially in the territory of Baden. No fewer than 40 kilograms of gold found their way to the mints of Baden between 1800 and 1819. In the Upper Rhine valley, where the river could meander freely in a many-branched system, the gold flakes or *tinsel* were especially liable to be deposited in the sand- and gravel-banks (Kirchheimer 1965, Spycher 1983). The account of the Castilian traveller Pero Tafur of 1438/39 is also instructive. He describes the extraction of gold at an unidentified site below Basel as follows: *"By the river a board rests on a stand, with one end at the water's edge and the other end raised, and to it are attached a form of steps made of staves of the thickness of an arm. Sand is shovelled up from the water's edge and thrown onto the board; it immediately runs down and leaves a sort of white sludge behind on the steps; as soon as the steps are full up, this is filled into an adjacent trough; as the gold is heavy, it sinks to the bottom..."* (Stehlin and Thommen 1926). It should be added that, finally, the gold would have had to have been washed out with pans. This operational sequence corresponds to the procedure described and recorded pictorially by the mining expert Georgius Agricola in the sixteenth century (Fig. 1).

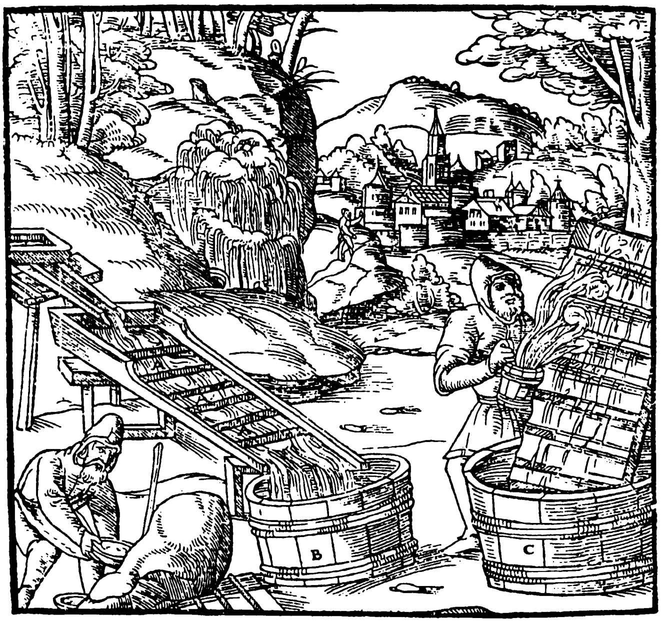

Fig. 1: The technique of extracting fluvial gold in the sixteenth century. The gold-bearing sand is shovelled onto the sluice box (A), where the gold "tinsel" collects in the transversal grooves. The concentrate is rinsed in a tub (C), and then washed out presumably using pans. After Georgius Agricola, De re metallica (1556).

The wooden sluice box is basically the same as the installations still in use around the turn of the century at Umiken near Brugg on the Aare (Rütimeyer 1927).

3. Present-day knowledge of washed gold deposits

Although the most important gold deposits in Switzerland remained known and indeed were mapped, it is only since around 1960 that academic discussion of the subject by the earth sciences has intensified (Kündig and de Quervain 1953, Hofmann 1965, Schmid 1973). Nowadays it is generally assumed that the gold found its way into the Midlands through erosion in the Alps and transportation in glaciers. Awareness of new deposits has increased considerably as a result of the growing importance of gold-panning as a leisure activity. This knowledge has often been confined to a small circle of insiders, without getting into the literature. Nevertheless, it has been confirmed that the streams rising in the Napf do indeed contain the most gold. (Instructive in this regard are the panning trials by Peter Pfander, Sülberg 1991, 24f.). The newly discovered deposits in the river-systems of north-eastern Switzerland and in the canton of Fribourg have emerged as the most significant from the point of view of archaeological research (Fig. 2). One can safely assume that in times past even more favourable conditions prevailed; for before the correction and canalisation of the streams and rivers, the gold would readily have settled into gravel-banks in places where this could no longer happen.

Systematic panning trials by Franz Hofmann have produced surprisingly large quantities of gold "tinsel" in the eastern Swiss tributaries of the Rhine, although the value of these yields is distinctly less than from the Napf (Hofmann 1984). The size of individual flakes and grains varies a great deal, but as a rule it diminishes with the distance travelled in the water. The labour involved in extraction varies accordingly (Table 1). In terms of a model, labour intensity can be extrapolated on the basis of the empirical data gathered by Hofmann. Assuming optimum conditions of 800 milligrams of gold per cubic metre of gravel, a full 300 man-day of work would be required to produce 125 grams. This would approximately correspond to one of the neck-rings from the Erstfeld hoard (Hofmann 1991, Wyss 1975, 26).

Table 1. Gold contents of individual sections of rivers and fluvial systems in Switzerland (Hofmann 1991).

	Gold content of good panning sites mg/m^3	Number of particles to 1 gram of gold
Confined Napf region	800	1,500-3,000
Emmen-Aare-Reuss	40-160	10,000-15,000
Geneva region	400	8,000
Fribourg region	ca. 100	
Source of Rhine	40-50	
Rhine at Schaffhausen-Zurzach	20-40	ca. 25,000
Upper Rhine	50-450	ca. 200,000

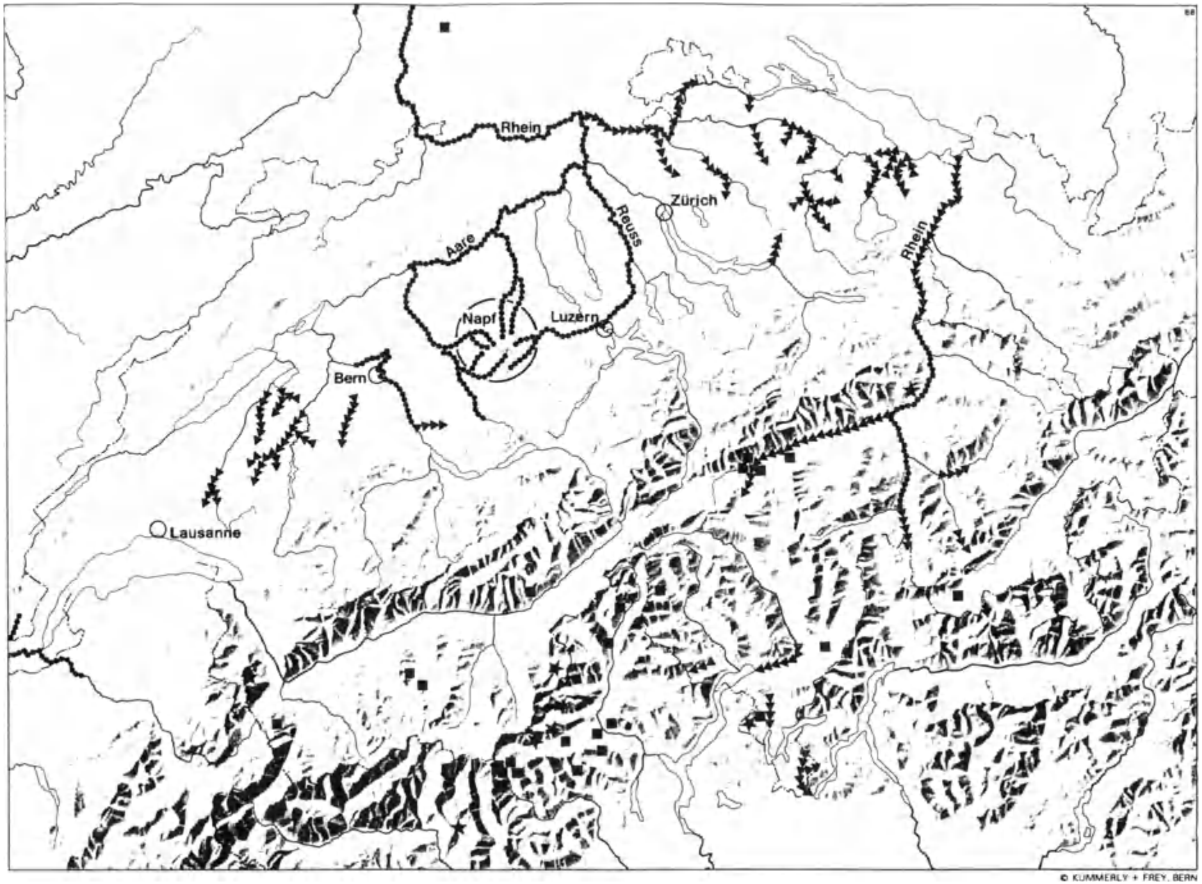

Fig. 2: Gold-bearing rivers and primary gold deposits in Switzerland and adjoining parts of neighbouring countries (according to the state of knowledge in 1990). Linear dots: river with historically attested gold-washing activity; linear triangles: river only recently identified as gold-bearing; star: historically attested gold-mining site; square: primary gold deposit without mining activity (Hofmann 1991).

Most recently, "tinsel" up to 13 millimetres in length and 660 milligrams in weight has been reported from the Grosse Fontanne, a tributary of the Kleine Emme. Also worth mentioning, since they were all but unknown until a few years ago, are remarkably rich gold deposits in the Anterior Rhine valley of Graubünden, near Disentis (Jaffé 1989).

True primary gold deposits in the mountains of Switzerland are only small to very small (Fig. 2). Attempts at mining them over the past two centuries have invariably been unprofitable.

4. Single archaeological finds

From the Celtic period in the Swiss Midlands there is a small handful of gold artefacts which are of particular technological and cultural-historical interest. From the Late Hallstatt period, that is, immediately preceding the La Tène period, comes a noteworthy female grave found as long ago as 1878 beneath a burial-mound at Unterlunkhofen in the canton of Aargau. Its composite assemblage of jewellery includes a pair of bracelets composed of a bronze tube overlaid with a thin silver foil. In addition, the wider cuffs of the coupling clasps are gilt, although the technique of this gilding has not yet been clarified beyond doubt. It is probable that an extremely thin gold foil was applied at high temperature to the silver ground. Eluère (1989, 27) has also been able to identify this process used on a silver dish with gold omphalos from the famous "princess's grave" of Vix in eastern France. The graves of Vix and Unterlunkhofen both date from the first half of the fifth century.

Of only slightly later date are the three gold foils from a burial-mound on the Üetliberg near Zürich. Their ornamental style dates them to the Early La Tène period of around 400 BC. The archaeological excavation of 1979 was unable to furnish many clues about them, since the grave had already been robbed when found (Drack 1981). The two larger discs with floral decoration are the frontal foils of two so-called disc brooches, and were originally fastened to an iron backing-plate. The small rosette weighing a mere 0.03 grams is more likely to have served as a mount on the leather strap of a drinking-horn. The manufacture and decorative style of all three gold pieces are rare for Switzerland, and find their closest parallels in the so-called princely graves of southern Germany.

As unusual as it is aesthetically pleasing is the solid gold bracelet from Schalunen in the canton of Bern (Fig. 3). It consists of a single smooth wire whose deeply overlapping ends are wound in spiral fashion around the main body of the ring. The ring, weighing 89 grams, was unearthed during ploughing in 1864 and retrieved by a young boy as a curiosity. There are thus no archaeological clues as to the significance of the find-spot. The ring should most likely be seen as a votive offering to an unknown Celtic deity. Even its dating to around the second half of the second century BC is of a somewhat hypothetical nature (see also Rieckhoff-Pauli 1981).

The find-spots thus described may have yielded outstanding single items of high quality, but their very uniqueness precludes general statements about the use and perceived value of gold in the Celtic period. It is all the more unfortunate that it is precisely in these cases little or nothing is known of the archaeological context. It is another category of finds, namely the flat-graves, which is most likely to provide an archaeological comparison with the geological and historical background previously described.

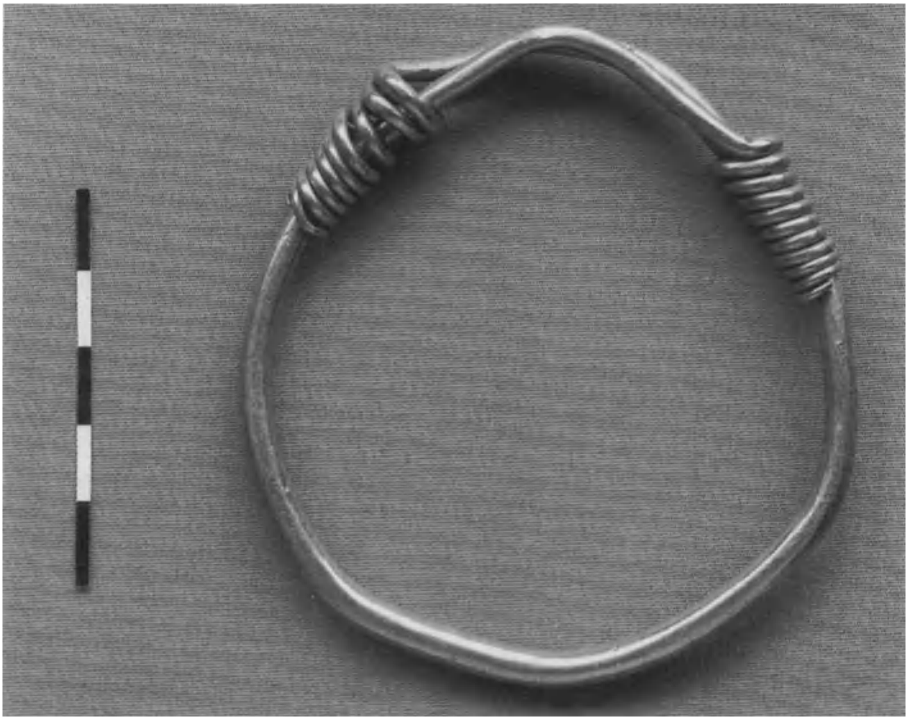

Fig. 3: Schalunen, canton of Bern (probably second half of the second century BC): solid gold wire bracelet, weighing 89 grams. Photograph courtesy of the Historical Museum, Bern.

5. Celtic graves as archaeological evidence

Graves of the Celtic period are present in unusually large numbers in the Swiss Midlands, displaying concentrations in both their chronological and geographical distribution. Chronologically they belong mostly to the Early and Middle La Tène periods (second half of the fifth to the first half of the second century BC), while the last century before the birth of Christ - to which refer the reports of ancient authors cited above - remains largely unrepresented. A main concentration of find-spots exists in the Bernese Aare valley in the wider hinterland of the city of Bern (Stähli 1977, Müller 1991). Thanks to their large quantity, it has been possible to greatly refine the dating of these graves with the aid of stylistic typology and seriation techniques. A prerequisite is that the same types of artefacts on which the general dating framework is based, should also be represented in a particular find. Currently, in favourable circumstances, a dating precision to within 50 years appears feasible (Müller and Kaenel 1986). The state of research and publication of this category of finds can be considered as advanced. All in all, as far as the sources of evidence are concerned, no other period of prehistory in the Swiss Midlands is better provided for.

The flat-graves forming the basis of the present study begin around 450 BC, and are attributed to the ethnic grouping of the Celts as known from the Classical literature. From the outset one is dealing with so-called inhumation graves; only from the second century BC did the custom of cremating the dead before burial gain ground. In consequence, the archaeological material becomes scarcer, until it dries up almost completely in the first century BC. The necessary data-base for statistical analyses in research is largely lacking for this final phase.

Individual flat-graves were dug to different depths in the soil. There may well have been surface markers which, however, would no longer be visible. The dead often lay in a coffin, of which the traces only rarely survive. They comprise men, women and children of varying ages, who might be buried separately or else within large burial-grounds. The most extensive and thoroughly researched of these cemeteries, with over 220 graves, is at Münsingen to the south of Bern (Hodson 1968, Kaenel 1992).

The relatively high quality of grave goods for all of the dead is striking. Women as well as girls were often wearing elaborate and composite bronze jewellery, while the men were frequently placed in the grave armed with an iron sword, a spear and a shield. One is compelled to take the view that the survivors were equipping their dead with considerable material wealth for the journey into the afterlife. From this one can no doubt conclude that the accompanying objects were symbols of rank; that they had already been used in life is frequently suggested by signs of wear and repair. Evidently these insignia were required if one was to resume one's rightful place in the social hierarchy of the afterlife. This further implies that the Celts perceived the afterlife as a mirror-image of this life, at least as far as the social order was concerned. Differences of rank undoubtedly existed and evidently could not be easily surmounted. For the time being, it remains purely conjectural that the archaeologically attested graves represent only a social elite, with the mass of the contemporary population being buried in a markedly less lavish manner (Müller 1991).

In the case of the women, the wealth is most strikingly expressed in the materials such as coral, amber and glass paste used in jewellery and dress-fittings. The basic material consists mainly of bronze or iron, and less commonly of the precious metals gold and silver (also glass from the middle of the third century). With rare exceptions, precious metal was used exclusively for the manufacture of finger-rings. Gold neck-rings, bracelets and anklets are not found in the graves of the Swiss Midlands.

With a few exceptions, the finger-rings occur as two types (Fig. 4), which were especially popular in the fourth and third centuries, and also feature in silver and bronze:

1. Bent-plane finger-rings, which feature four kinks and are formed of a closed hoop with a smooth surface.
2. Spiral finger-rings, composed of a coiled gold wire which was either smooth, twisted or profiled, and could bear decorative punch-marks.

Other types formed of a sheet-gold band or with a bezel are rather rare. With exceptions, finger-rings were worn only by women, in the cemetery of Münsingen mostly on the right hand and with a preference for the ring- and middle fingers (Sankot 1980, 31f.).

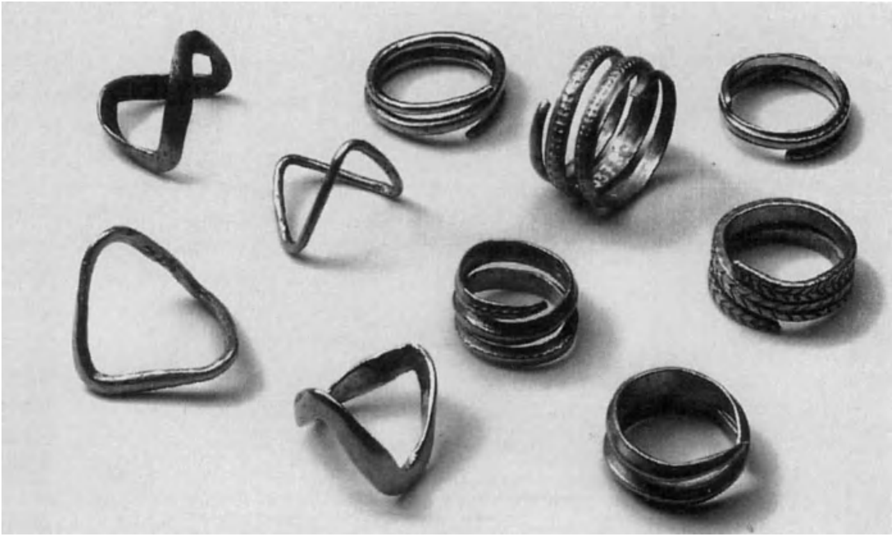

Fig. 4: Bern and its environs: selection of gold bent-plane finger-rings (left) and spiral finger-rings (right). Photograph courtesy of the Historical Museum, Bern.

In the following paragraphs, then, the question to be explored in detail is: do the known natural deposits of washed gold find a reflection in the distribution of archaeological finds-material from graves of the Early and Middle La Tène periods? In order to address this question, the study-area has been divided into four zones (A, B, C and D) of roughly equal area, whose inner boundaries follow the courses of the rivers Saane, Grosse Emme and Reuss. The Napf thereby lies on the periphery of Zone C. Employing first of all a straightforward distribution-map, a distinct concentration of gold finger-rings emerges in the region of Bern (Fig. 5). However, the evidential value of this distribution is slight, for several reasons. For instance, one must take into account the fact that the graves are unevenly represented in the different regions, and in particular display a heavy concentration around Bern. The 1974 survey of La Tène period graves by René Wyss can serve to illustrate this phenomenon (Wyss 1974). His figures may be out-of-date for particular areas which, in the meantime, have been the subject of special studies; but for the present purposes Wyss's lists have the advantage of representing a particular stage of research which was roughly comparable for all areas, and was based upon uniform criteria. The rounded minimum figures alone show clearly that in Zone B there are more find-spots and, even more clearly, more graves. Evidently the cemeteries here are larger than elsewhere.

It also needs to be taken into consideration that it was not everywhere the custom for women to wear finger-rings. Thus, for example, there are no finger-rings at Saint-Sulpice, the largest cemetery in western Switzerland (Lorenz 1978, Kaenel 1992). In order to highlight the zones with richer finds of gold, it is therefore methodologically imperative to compare only those graves which contain finger-rings (Table 2). The holdings of the Historical Museum of Bern have served as a basis for this, as well as the data of Viollier (1916) and Kaenel (1992).

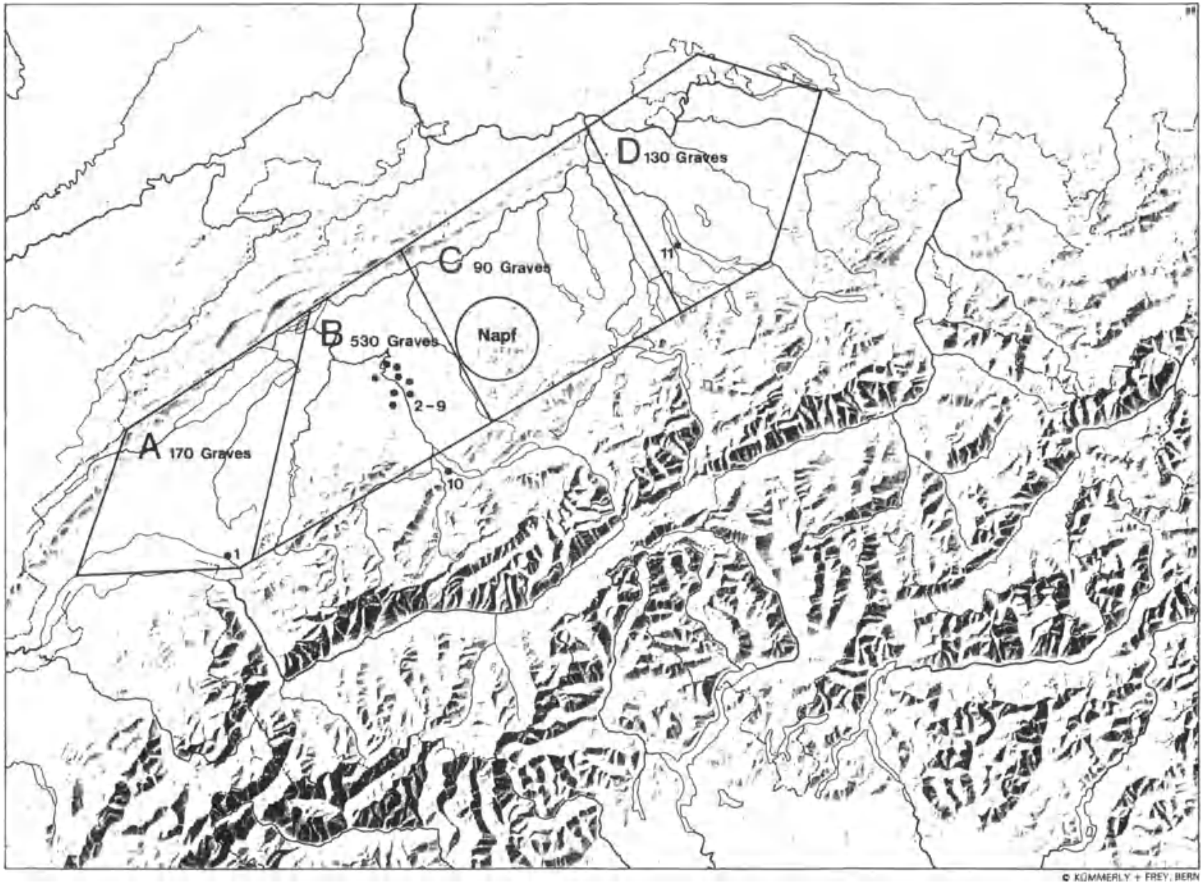

Fig. 5: Graves and gold finger-rings in the study areas (Zones) A, B, C and D. Find-spots of finger-rings: 1 Vevey; 2-9 Belp, Bern-Morgenstrasse, Bern-Spitalacker, Kirchenthurnen, Münsingen, Muri, Stettlen, Worb; 10 Spiez; 11 Horgen.

Table 2. The quantitative basis for finger-rings from graves and find-spots (with one or more graves) in Zones A-D (cf. Fig. 6).

Zones	A	B	C	D
Graves (minimal, rounded figures)	170	530	90	130
Graves with finger-rings	8	80	9	15
Find-spots (minimal figures)	39	83	41	46
Find-spots with finger-rings	6	21	7	9
Graves with finger-rings	8	80	9	15
Graves with finger-rings of gold (also silver and bronze)	2	19	0	1
Graves with finger-rings of silver (and bronze)	1	28	4	2
Graves with bronze finger-rings	5	33	5	12
Find-spots with finger-rings	6	21	7	9
Find-spots with finger-rings of gold (also silver and bronze)	1	9	0	1
Find-spots with finger-rings of silver (and bronze)	0	4	3	2
Find-spots with bronze finger-rings	5	8	4	6

The percentage allocations of graves with gold, silver and bronze finger-rings do not differ significantly between the four zones (Fig. 6), but too much should not be read into the still relatively small absolute figures. Taking the number of find-spots as the common denominator, however, it is apparent that the incidence of precious metals is higher in Zone B than elsewhere. Behind the individual cemeteries one can doubtless suppose there to be corresponding settlement units. From this it could be deduced that in the region of Bern (Zone B) there was apparently a greater number of settlements inhabited by a social class that could afford gold and silver. However, the source of this affluence, where applicable, is not clear, and a direct connection with the natural gold deposits is not conclusive. As the most striking result it may be noted that Zone C does not appear to have had any share in the gold from the Napf; at any rate, such ownership is not reflected in the presented maps and tables. It also has to be considered whether more intensive 19th/20th century activity around Bern has biased the distribution.

All efforts at clarifying the provenance of the gold with the aid of scientific analyses have, up till now, met with little success. The reason has often lain not so much in the analytical procedures themselves, as in the archaeological interpretation of the data thus obtained. This also applies to the finger-rings under discussion here (Hartmann 1970, 1978, Voûte 1991). Among the data published so far, the extreme variations in the composition of the gold are striking. The proportions of silver and copper are regularly quite high, with higher values than could have been expected from natural fluvial gold, including, for example, those of the Napf (Table 3).

While the single ring from Stettlen-Deisswil consists of almost pure gold, the pair from Worb contains barely 5 per cent, so that in this case they can not really be described as gold at all. Tin and platinum have sometimes been detected in small amounts, sometimes only as trace elements.

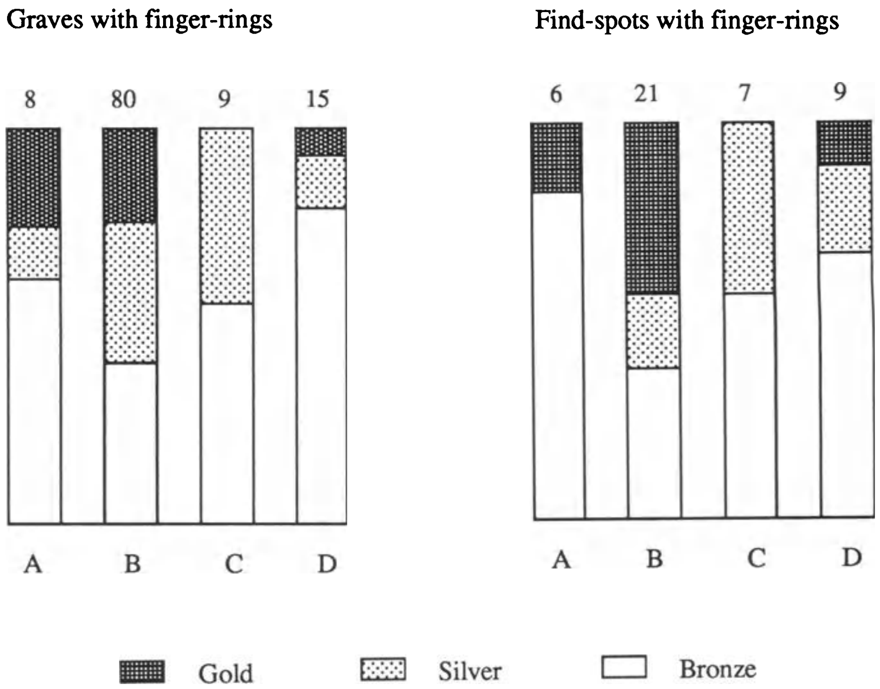

Fig. 6: The distribution of finger-rings by graves and find-spots (with one or more graves) in Zones A-D (cf. Table 2).

The gold compositions which have been determined do not permit any conclusive interpretations. Since, according to Hartmann, tin is typical of fluvial gold (Hartmann 1970, 9-12), it remains most likely that silver and copper were alloy additives to the fluvial gold concentrate. Importation of the raw material (or, where applicable, of finished products) cannot, in theory, be ruled out. Thus, for example, platinum is said to be characteristic of washed gold from the Upper Rhine, although whether it might not already be present in gold from the Napf still needs to be clarified. Higher copper contents than from the Napf might make the Upper Rhine gold somewhat more reminiscent of our finger-rings, but they are still a good deal too low. In this case too the copper would have had to have been added to produce the extant alloys; technically this appears to have been perfectly feasible. Finally, it should always be borne in mind that impurities and disproportionate constituents could also have arisen through repeated re-casting and re-use of the gold alloys.

Table 3. Metallurgical analyses of La Tène period gold finger-rings and riverine gold samples from Switzerland and the Upper Rhine in Baden (the analysis reference numbers after Voûte 1991)

Find-spot	Weight in grams	Au %	Ag %	Cu %	Sn %	Pt %	Analysis Ref. No.
Finger-rings							
50 Münsingen	1.2g	72.0	26.0	2.0	-	-	VT0449 8.72
51 Münsingen	1.8g	68.4	30ca	1.6	0.003	-	Ha0495
52 Münsingen	2.6g	57.6	37	5.3	0.13	-	Ha0476
53 Münsingen	9.7g	92.4	7	0.5	0.021	0.014	Ha0474
54 Horgen	3.4g	87.5	12.2	0.3	-	-	VT0435 2.72
55 Horgen	2.9g	87.5	12.2	0.3	-	-	VT0435 2.72
56 Horgen	1.4g	86.7	13.0	0.3	-	-	VT0435 2.72
58 Muri	8.0g	87.5	11.5	0.46	0.015	0.012	Ha0472
58 Muri	8.0g	93.3	6.2	0.5	-	-	VT0449 8.72
79 Münsingen	4.4g	71.4	26ca	2.6	0.009	-	Ha0494
80 Worb	2.6g	5	75ca	20ca	-	-	VT1292 5.90
81 Münsingen (?)	5.5g	90.3	8	1.7	0.003	-	Ha0493
82 Münsingen	2.1g	47	45ca	7.8	-	-	Ha0496
83 Belp	3.6g	66.9	29	4.1	0.065	0.027	Ha0475
84 Bern	3.6g	65.2	31	3.8	-	-	VT1292 5.90
85 Bern	3.7g	71.2	27.1	1.7	-	-	VT1292 5.90
86 Kirchenthurnen	4.7g	82.4	15	2.5	0.085	0.017	Ha0491
87 Kirchenthurnen	7.6g	87.3	10	2.6	0.049	0.021	Ha0492
88 Münsingen	3.5g	70.6	27	2.3	0.061	0.025	Ha0479
89 Muri	8.0g	89.6	8.5	1.8	0.070	<0.01	Ha0473
89 Muri	8.0g	91.7	7.5	0.8	-	-	VT0449 8.72
90 Stettlen	7.0g	97.2	2.5	0.31	0.011	0.012	Ha0471
91 Stettlen	8.0g	99.0	0.6	0.4	-	-	VT1292 5.90
92 Worb	4.5g	5	87ca	8ca	-	-	VT1292 5.90
96 Spiez	0.6g	91.2	7.5	1.3	-	-	VT0449 8.72
Riverine gold							
Rhein, Zurzach		75.2	22	2.8	-	-	VT1282 90
Rhein, Rheinau/Ellikon		85.8	13	1.2	-	-	VT1282 90
Rhein, Neuhausen "Flurlingen"		87	13	-	-	-	VT1282 90
Rhein, Neuhausen		89.5	8.5	2	-	-	VT1282 90
Oberrhein, Kembs		91.5	8	0.5	-	-	VT1282 90
Oberrhein, Kembs		97	2	1	-	-	VT1282 90
Wigger, Hergiswil		98.7	1.1	0.14	-	-	VT0827 80
Grosse Fontannen		91.7	8	0.2-4	-	-	VT0827 79
Grosse Fontannen		96	3-4	0.2-6	-	-	VT0827 79
Grosse Fontannen		96.3	3.5	<0.2	-	-	VT0827 79
Grüne, Sumiswald		98.4	1	0.01	-	-	Hartm. 63
Grüne, Sumiswald		91.8	8	0.01	-	-	Hartm. 63
Krümpelgraben, Trubschachen		96.9	3	0.02	-	-	Hartm. 63
Krümpelgraben, Trubschachen		95.8	4	0.03	-	-	Hartm. 63
Krümpelgraben, Trubschachen		97.9	2	0.02	-	-	Hartm. 63
Aare, Aarau		97.4	2	0.02	-	-	Hartm. 63

6. Concluding remarks

The ancient sources which testify that gold was panned in the territory of the Helvetii, provide few chronological and no geographical points of reference since, in the final analysis, it remains unknown where the Helvetii lived at that time. It seems to the author quite arbitrary to link the Helvetian attribute of being "rich in gold" exclusively with the sandy gold-bearing streams of the Napf, and to follow from that, as a "quite definite conclusion", that the Helvetii were settled in the vicinity of the Napf at the time of their earliest mention (Staehelin 1948, p.29f.). For medieval and, above all, modern sources bear witness to gold deposits not only in the Napf and the entire Aare-Reuss system, but also on the Upper and Higher Rhine. From post-medieval times onwards the amounts of gold extracted were considerable, if not exactly enormous. The experience of recent history (for example in California) has shown that even rich deposits can be exhausted in a short time. The quantities extracted in antiquity can thus scarcely be estimated on the basis of present-day deposits.

In the Swiss Midlands there are altogether too few graves known from the Helvetian period (that is, the first century BC) for gold finds to be represented. By contrast, in the graves of the Early and Middle La Tène periods (especially of the fourth and third centuries) are found, from time to time, gold finger-rings whose material could theoretically have come from indigenous prospection. Their localised concentration in the vicinity of the modern city of Bern is not conclusively based upon the rich gold deposits of the Napf; at any rate, no corresponding concentrations of finds occur to the north and east of the Napf massif. In this case-study, then, natural gold deposits find no direct reflection in the archaeological record. The reasons for this could be of a historical nature, or might also have to do with the survival and transmission of evidence.

Acknowlegements
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Chapter 3

GOLD IN THE ALPS: A VIEW FROM THE SOUTH

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ABSTRACT. To the south of the Alpine watershed there are important primary gold ore deposits located in the Western Alps and in the Ligurian Apennines; during Roman and Medieval times the Po plain placers were panned for gold. This contribution will provide a general picture of the gold-bearing primary and secondary deposits at present recognized in Northern Italy (section 2). Their distribution is compared with that of prehistoric gold finds (section 3). The ancient workings attesting placer exploitation in the Bessa highlands are briefly discussed (section 4). The written evidence is examined as well: both references in the classical sources from the middle of the 2nd century B.C. onwards (section 5) and in the medieval documents from the IX to the XIV century (section 6) are taken into account. Pre-Roman gold finds are not numerous and do not date earlier than the Middle Bronze Age. The distribution of most of those finds does not suggest a precise link with the gold-bearing deposits.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 199–218.

1. Introduction

To the south of the Alpine watershed the primary gold deposits are mainly in the Western Alps and in the Ligurian Apennines, while the secondary deposits are found chiefly at the foot of the mountains and in the plain. It has been recorded that gold was panned in the Po River during Roman times and in many tributaries of the Po River during the Middle Ages. Some of these have gold-bearing sands even today.

In spite of this potential, prehistoric gold artifacts found in Northern Italy do not seem to date back any further than the Middle Bronze Age; gold objects appear here much later than in most areas North of the Alps. There does not appear to be any obvious geographical link between the well-documented western mining areas and the distribution of gold artifacts. A gold nugget from an Iron Age tumulus in the Aosta Valley could possibly be the first archaeological proof available at present that, at that time, gold was being recovered from western Alpine deposits. According to the classical historians gold was extracted on a large scale in the area lying between the Alps and the Po River from the 2nd century B.C. onwards and gold panning was widely practicised in the Middle Ages.

2. The geological context

2.1 PRIMARY GOLD OCCURRENCES (BY M.C.)

The greatest concentrations of gold ore were found in the Western Alps (Graie and Pennine Alps in Northern Piedmont) and to a lesser extent in the Central Western Prealps (Lombardy and Canton Ticino in Switzerland). In the Apennines most gold ore was found in Liguria and in Southern Piedmont (Fig. 1).

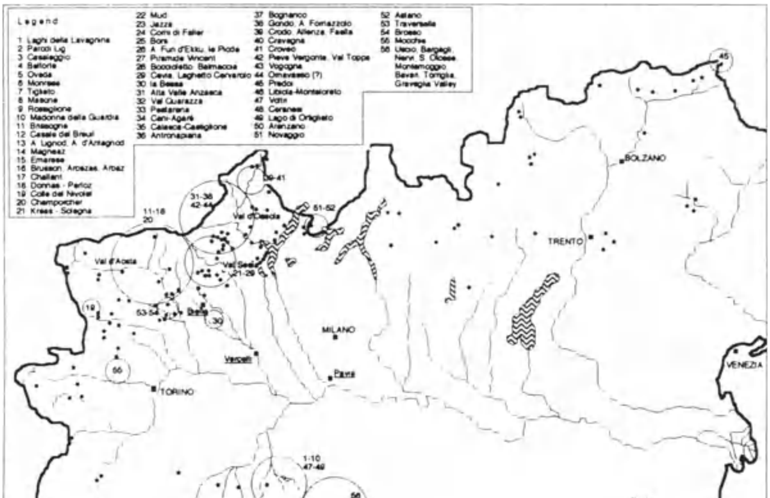

Fig. 1: Primary gold occurrences in Northern Italy.

In the 18th and 19th century, Di Robilant (1786) and Jervis (1873), observed that gold was quite widespread between the Western Alps and the Ligurian Sea and that it was concentrated mainly in the district between Gran Paradiso and Monte Ceneri. In the geological literature of the beginning of this century, this area was known as the "gold-bearing district of Monte Rosa", because most veins were located around the Monte Rosa massif (Fenoglio 1929, Novarese 1935, Huttenlocher 1934, Stella 1943). Today (Omenetto and Brigo 1974), one would rather make reference to the "gold-bearing province of the Western Alps", which also includes the smaller areas further to the west. Outside these areas, gold is rarely found in the Italian Alps. There are no deposits as such, but only isolated discoveries of gold in the pyrites of the Central and Central Eastern Alps: Introbio (Como), Bovegno (Brescia), in Valsugana (Trento), in Valle Aurina (Bolzano) (RIMIN 1987, Ogniben et al. 1988, Leonardelli and Suardi 1988).

In the Apennines the largest number of primary deposits lies to the west of Genoa. These are found in a rough square, marked out by Sestri Ponente, Varazze, Ponzone and Voltaggio, and are known as the "Voltri Group". Other small deposits lie to the east of Genoa in the region of ophiolithic rocks of the Bracco Pass (Ministero di Agricoltura etc. 1900, Giordano 1969) (Fig. 2).

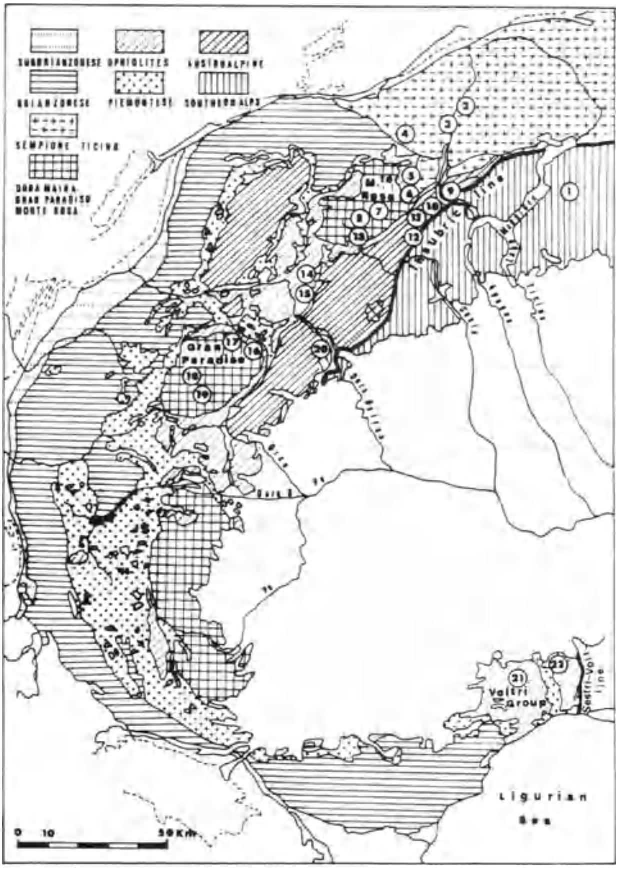

Fig. 2: The gold district of the Western Alps. 1: Astano; Novaggio (Ticino); 2: Alpe Formazzola (Ticino); 3: Crodo (Alfenza, Faella, Maglioggio); 4: Gondo (Vallese); 5: Valle Antrona (Mottone, Mee); 6: Val Bianca (Cani, Agaré); 7: Valle Anzasca (Pestarena, Lavanchetto); 8: Val Quarazza (Quarazzola, Col Badile); 9: Vogogna; 10: Val Toppa, Vallaccia; 11: Val Segnara, Monte Capezzone; 12: Val Mastallone (Fobello); 13: Valsesia Alagna (Kreas, Mud); 14: Valle d'Ayas (Brusson, Arbaz); 15: Valle d'Ayas (Targed, Sache); 16: Val Soana (Rancio, La Reale); 17: Valeille; 18: Val Locana (La Cuccagna, Alpe Mei); 19: Val Locana (Bellagarda); 20: Tavagnasco; 21: Tiglieto; 22: Laghi di Lavagnina (after Mastrangelo et al. 1983).

2.1.1 Primary gold occurrences in Western Alps

The Alpine domains (Table 1, Fig. 2) with gold-quartz veins include: the Southern Alps, Austroalpine and Pennine tectonic domain, as well as the ophiolitic units of the "Voltri Group".

Table 1. Tectonical and geological situation as well as mineral association of primary gold occurrences in Northern Italy

Tectonic context	Deposit	Geological context	Form of deposits and ore texture	Ore elements
Strona Ceneri Zone	Astano (CH)	"Serie dei Laghi": micaschists and finegrained gneiss, diabases	concordant strata hydrothermal veins	pyrite, Aspyrite, (galena), (blende), Au and Ag (in sulphides), etc
bidem	Novaggio (CH)	Schists	discordant strata veins with tectonic control	pyrite, (bismutinite, Aspyrite, galena, blende) and Au and Ag (in sulphides) etc
Dioritic Kinzigitic Zone	Monte Capio	"Ivrea Zone": gabbro-granulites (piroxenites, peridotites), Kinzigitic complex (metamorphic siltstones, marbles, anphibolites)	stratabound mineralization in black schists interlayered with metamorphic siltstones	Fe-Cu-Au etc
"Sesia Zone"	Tavagnasco	Brosso-Traversella's diorite in eclogitic micaschists	stockworck	quartz with sulphides etc
bidem	North of Brosso	Brosso-Traversella's diorite in eclogitic micaschists	=	Au native etc
bidem Canavese's ores	Mastellone and Strona Valleys	at the contact between Ivrea Zone and Fobello-Rimella's schists	stockworck (1) and tabular-lentiform, locally stockworck (2)	pyrite, calcopyrite, pyrrhotite, blende, Au, mackinavite, rutile, cobaltite + galena, graphite and molybdenite and tetrahedrite (1) or Aspyrite and cubanite (2) etc
bidem Canavese's ores	Toppa Valley (Ossola Valley)	Fobello-Rimella's schists	tabular-lentiform strata concordant veins	pyrite, chalcopyrite, blende, galena, pyrrhotite, Aspyrite, Au, cubanite, mackinavite, cobaltite, rutile etc
bidem Canavese's ores	Vogogna-Pieve Vergonte		strata concordant veins and strata discordant veins	galena, blende, pyrrhotite etc
Monte Rosa	Pestarena	K-feldspar Gneiss and mica-schists	tabular-lentiform discordant veins and strata concordant veins	galena, blende, Au, pyrite, chalcopyrite etc
Monte Rosa	Alagna Valsesia	K-feldspar Gneiss, mica-schists and quartzites		Aspyrite, pyrite, galena etc
Arceza-Brusson	Val d'Ayas	Arceza's ortho gneiss and calce-schists with ophiolites	veins and stockworck	pyrite, chalcopyrite, pyrrhotite, blende, galena makinawite, Au, molybdenite, Aspyrite, and minors elements etc.
Gran Paradiso	Val Soana	metamorfic paraschists and intrusions of granitoids	lenses or strata concordant veins in thin grainedgneiss	pyrite, chalcopyrite, blende, galena, Au, tetraedrite, Aspyrite, marcasite, bornite, Jamesonite, chalcostilbina etc.
Gran Paradiso	Val Locana	K-feldspar Gneiss	strata discordant veins or stockworck	ibidem etc
Camughera - Monte Rosa-Moncucco-Antrona Zone	Valle Bianca (Anzasca Valley)	Antrona's anphibolites and ophiolites, Camughera's orto-gneiss and Camughera-Muncucco's paragneiss and micaschists	strata concordant veins and strata discordant veins	pyrite, chalcopyrite, blende, galena, makinawite, Au, Aspyrite, marcasite, bismutinite, Bi etc.
Camughera-Monte Rosa-Moncucco-Antrona Zone	Cani's mine (Anzasca Valley	Camughera-Moncucco Zone	tabular-lentiform strata concordant veins	pyrite, Aspyrite, chalcopyrite, mackinawite, blende, galena, pyrrhotite, Au, rutile, graphite etc
Antigorio Nappe	Gondo	Antigorio's Gneiss	tabular-lentiform strata concordant veins	pyrite and Aspyrite, Au bearing, blende, galena etc.
Antigorio Nappe	Alfenza (Antigorio Valley)	Baceno's Mica schists	tabular-lentiform strata concordant veins	pyrite, chalcopyrite, pyrrhotite, hematite, Au, magnetite, boulangerite etc
Antigorio Nappe	Maglioggio (Antigorio Valley)	triassic marbles and paragneiss	stratabound mineralization	pyrite, chalcopyrite, pyrrhotite etc
Antigorio Nappe	Faella	Antigorio's Gneiss	tabular-lentiform strata discordant veins	pyrite, chalcopyrite, hematite, Au etc
"Voltri Group"	Lavagnina Lakes, Parodi Lig., Casaleggio, Belforte, Ovada, Monrese, Tiglieto, Masone, Rossiglione, M della Guardia, Voltri, Ceranesi, Lago di Ortiglieto, Arenzano	Serpentinites from Lherzolites and Prasiniti, calceschists	disseminations and stockworck	Fe-Cu-Zn-Mo-Au-C-Pb etc.
"Bracco Pass Group"	Libiola-Monteloretomines	Ophiolites	massive mineralizations	pyrite, chalcopyrite, blende, galena, Au, Ag and sulphides etc

The deposits in the Austroalpine (Sesia-Lanzo, Canavese, zone of Fobello-Rimélla schists) and Pennine domains (Monte Rosa, Gran Paradiso, Camughera-Moncucco units, Antigorio Nappe and Antrona zone) are more numerous than those in the Southern Alps (Strona-Ceneri and Dioritic-Kinzigitic units).

The lithologic and tectonic units containing the ore veins (Table 1) are of different kinds, such as:

a) gneiss of the "ghiandone" variety (gneiss with K-feldspar) and mica-schists on the Gran Paradiso and Monte Rosa units;

b) orthogneisses, mica and garnet schists, in the "Antigorio Nappe" and Camughera-Moncucco zone;
c) fine-grained gneiss in the "Sesia-Lanzo" zone;
d) schist formations in the "Fobello-Rimella" zone and with sericite in the "Canavese" zone;
e) mica-schists in the so-called "Strona-Ceneri" zone
f) amphibolite in the "Camughera-Monte Rosa" zone;
g) serpentinite and other lithologies of the volcano-sedimentary "Voltri Group".

Several deposits are concentrated along faults and folds, particularly along the "Insubric Line" and along the "Sestri-Voltaggio Line" (Fig. 2). The gold-bearing veins in the Western Alps are probably of Alpine age. Scheiderhöhn (1952), Andreatta (1955), Omenetto and Brigo (1974) and Leonardelli and Suardi (1988) suggested that the veins formed by hydrothermal activity in areas of intense folding and tensional pull-apart that remobilized preexisting mineralizations found in the basement. The morphologies of the gold occurrences are (Table 1):

1) columns, pipes and randomly arranged discordant veins
2) veins concordant to the schistosity of the wall rocks
3) stockworks.

The gangue of the veins is often quartz with occasional small quantities of carbonates. Ore minerals are mainly pyrite, arsenopyrite and chalcopyrite with subordinate sulphides like sphalerite, galena, pyrrhotite. Accessory minerals are tetrahedrite and bismuthinite (Table 1). Gold seems to be linked mainly to pyrite and arsenopyrite. Gold is found also under particular conditions in quartz gangue associated with galena (Val Toppa).

2.1.2 Primary gold occurences in the Ligurian Apennine (by M.D.S.).

In the so called "Voltri Group", which in spite of belonging geographically to the Apennines is geologically an Alpine lithotectonic unit, gold is found in thin quartz veins, or in quartz patches in the serpentinites belonging to the "lherzoliti tettonitiche", or between "prasiniti" i.e. greenschists and calc-mica-schists. Those local gold mineralizations were exploited in historic times by local enterprises. A very interesting gold mineralization in sulphide bodies is found to the east of Genoa, in the ophiolithic sequence of the Bracco Pass area of Middle to Upper Jurassic age. The largest of these sulphide ore bodies has been mined at times since the Bronze Age as the so called Libiola copper mine (Maggi and Vignolo 1987). During the second half of the last century in the nearby Monte Loreto copper mine a few gold nuggets, one weighing 800g were discovered.

2.2 SECONDARY GOLD DEPOSITS (BY M.D.S.)

The secondary gold deposits to the south of the Alps belong to two types: morainal and alluvial or fluvial (Jervis 1873; Ministero di Agricoltura 1900) (Table 2, Fig. 3). Among the morainal gold deposits the most important example is "La Bessa", a terrace formed by the glacial moraine of the Dora Baltea glacier (Micheletti 1976, 107). This gold occurrence was exploited in the pre-Roman and Roman period (see section 4). Alluvial deposits or stream placers are found in the fine sediments of many Po Valley rivers. Here gold was panned in ancient times using the simplest form of sluicing called in Italian "pesca dell'oro" (gold fishing) (Table 2, Fig. 3 and the documents quoted in section 6).

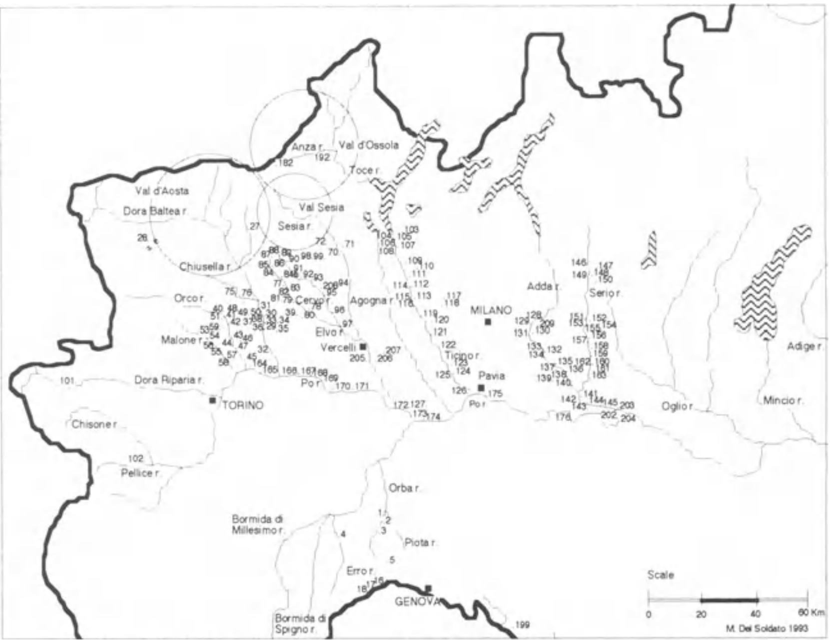

Fig. 3: Secondary gold occurrences in Northern Italy. The numbers refer to Tables 2 and 3. The circles are the areas of the main primary gold districts of NW Italy (see Fig. 1).

Gold-bearing sands were dug mainly in parts of Piedmont and Liguria (Jervis 1873; Issel 1892; Annali di Agricoltura 1887-1890; Mostra Parigi 1900; Giordano 1969):

a) Placers found in the Ticino, Agogna, Sesia (with the tributaries: Sessera, Cervo and Elvo) and Dora Baltea river beds come from the Monte Rosa zone deposits.
b) Placers found in the Canavese and in the whole area between the Orco and Malone rivers come from the Gran Paradiso zone deposits.
c) Placers found in the Tanaro river bed with its left tributary Ellero and its right tributaries Bormida, Erro, Orba, Piota and Gorzente come from the "Voltri Group" deposits. These deposits appear to be rather small but they were exploited since the Middle Age up to the last century. The production from the Gorzente deposits during the nineteenth century, was significant (Leonardelli and Suardi 1988, 67, Fig. 3).

Table 2. Secondary gold occurrences in NW Italy.

River Basin	Place	Content
"Bracco Pass Group"	199. Monteloreto and Libiola	gold dust
"Voltri Group"	1. Carpeneto, 2. Tigliolo, 3. Ovada ; (Erro Stream) 4. Cartosio; (Vezzola R.) 5. Masone, Bormida River, Tanaro River, Secca Stream, (Varenna and Lupara Stream)16. Arenzano, 17. Lerca, (Antra Stream) 18. Cogoleto;	0,293% - 1,039% 0,20 g/q
Po River	164. Chivasso, 165. Verolengo, 166. Crescentino, 167. Fontanetto Po, 168. Palazzolo Vercellese, 169. Camino, 170. Pontestura, 171. Morano, 172. Sartirana Lomellina 173. Suardi, 174. Pieve del Cairo, 175. San Martino Siccomario and Travacò Siccomario, 176. San Rocco al Porto;	
Pellice and Chisone R. Basin	102. Bricherasio;	
Dora Riparia R. Basin	(Val Susa) 101. Oulx	
Malone R. Basin	53. Barbania, 54. Front, 55. Lombardone, 56. Rivarossa, 57. S. Benigno, 58. Volpiano, (Viona R.) 59. Rivara and Busano ;	0,20 g/q
Orco R. Basin	(Canavese), 40. Courgné, 41. Valperga, 42. Salassa, 43. Lusigné-Feletto, 44. Foglizzo, 45. Montanaro, 47. Bosconero; 46. S. Giusto, 48. Castellamonte, 49. Bairo-Aglié, 50. Ozegna-S. Giorgio, (Gallega Stream) 51. Canischio;	also gold nugget
Dora Baltea R. Basin	*Val d'Aosta:* (Lys Stream), 27. Gressoney St. Jean, (Dora River) 28. Brissogne (Punta Laures Lakes); *Outside the Val d'Aosta:* (Val Chiusella) 75. Strambinello, 76. Parella; 29. Mazzé, 30. Vische, 31. Strambino, 32. Rondissone-Rivarotta; 33. Villareggia, 34. Moncrivello, 35. Cigliano, 36. Caluso-Candia, 37. Orio, 38. Barone, 39. Alice;	minor contents
La Bessa Higland	(Elvo Stream) 82. Salussola, 83. Cerrione, Borriana, (Lobbia Str.) 84b. Mongrando, (Viona Str.);	0,75 g/mc gold dust gold evidences
Cervo R. Basin	(Elvo Stream) 78. Casanova Elvo, 79. Carisio, 85. Occhieppo and Gaglianico, 86. Pollone, 87. Oropa, 80. Santhià, 81. Cavaglià, 84. Biella, 88. S. Paolo Cervo, 89. Scagliano Micca and Miagliano, 90. Andorno Micca and Tollegno, 91. Candelo, 92. Cossato, 93. Castelletto Cervo, Mottacciata, 94.Villarbóit, 95. Formigliana, 96. Collobiano, 97. Quinto Vercellese, 208 "Burontium"; (Sessera Stream) 98. Masserano, 99. San Maurizio;	
Sesia R. Basin	*Outside the Val Sesia:* (Rovasenda R.) 70. Gattinara-San Maurizio; 71. Romagnano, 72. Sostegno, 205 Pezzana, 206 "Rosascum", 207 "Castrum Novum";	
Agogna R. Basin	127. Lomello, Agogna River undetermined;	
Ticino R. Basin	*Val d'Ossola:* (Anzasca Valley) 182 Belvedere Glacier on Monte Rosa, Anza Stream, 192 Val Toppa; *South of Lago Maggiore:* 103. Somma Lombardo, 104. Golasecca and Coarezza, 105. Varallo P., 106. Pombia and Marano Ticino, 107. Vizzola Ticino, 108. Oleggio, 109. Turbigo, 110. Robecchetto con Induno, 111. Cuggiono, 112. Bernate T., 113. Buffalora, 114. Galliate, 115. Romentino, 116. Trecate, 117. Magenta, 118 Robecco sul Naviglio, 119. Cerano, 120. Abbiategrasso, 121. Cassolnovo, 122. Vigevano, 123. Bereguardo, 124. Torre d'Isola and Corpi Santi di Pavia, 125. Zerbolò, 126. Travacò Siccomario;	gold dusts always combinated with small grains of titaniferous magnetite
Adda R. Basin	128. Rivolta d'A., 129. Comazzo, 130. Merlino, 131. Zelo Buon Persico, 132. Boffalora d'A., 133. Galgagnano, 134. Montanaso Lombardo, 135. Lodi, 136. Abbadia Cerreto, 137. Corte Peloso, 138. Cavenago d'A., 139. San Martino in Strada, 140. Turano Lodigiano, 141. Gombito, 142. Bertonico, 143 Castiglione d'A., 144. Formigara, 145. Camairgo, 202 Corno Giovine, 203 Lardara, 204 Roncarolo, 209 Bertario;	
Serio R. Basin	146. Grassobbio, 147. Cavernago, 148. Ghisalba, 149. Cologno S., 150. Martinengo, 151. Trezzolasco, 152. Vidolasco, 153. Sergnano, 154. Bottaiano, 155. Picengo, 156. Pianengo, 157. Crema, 158. Madignano, 159. Ripalta Nova, 160. Ripalta Guerima, 161. Ripalta Arpina, 162. Credera, 163. Moscazzano-Montodine	
Oglio R. Basin	(Mella River Val Trompia): Bovegno, Oglio River unprecised;	
Isarco-Adige R. Basin	Adige River umprecised;	

Table 3. Primary (P) and secondary (S) gold occurrences in Northern Italy.

River Basin	Place
"Bracco Pass Group"	P- 49. Monteloreto and Libiola mines; 56. Uscio, Nervi, Bargagli, Bavari, S. Olcese, Graveglia Valley (?), etc.; S- 199. Monteloreto and Libiola area, Graveglia Valley (?);
"Voltri Group"	P- Gorzente Stream: 1. Laghi della Lavagnina (Alcione, Maggetta, Moggia Ferraio, Cassinotto, Fresconi), 2. Parodi Ligure; 3. Casaleggio; Piota Stream: 4. Belforte; 6. Mornese; Orba Stream: 5. Ovada, 7. Tiglieto (Fresconi and M. Calvo), 8 Masone (Bric dell'Oro), Val Vesulla; 9. Rossiglione, 10. Madonna della Guardia, 47. Voltri, 48. Ceranesi, 49. Lago di Ortiglieto, 50. Arenzano; S- 1. Carpeneto; 2. Tigliolo; 3. Ovada ; Erro Stream: 4. Cartosio; 5. Masone (Vezzola R.); Bormida River, Tanaro River, Secca Stream; Varenna and Lupara Stream: 16. Arenzano;17. Lerca;18. Antra Stream: Cogoleto;
Po River Basin	S- 164. Chivasso; 165. Verolengo; 166. Crescentino; 167. Fontanetto Po; 168. Palazzolo Vercellese; 169. Camino; 170. Pontestura; 171. Morano; 172. Sartirana Lomellina; 173. Suardi; 174. Pieve del Cairo; 175. San Martino Siccomario and Travacò Siccomario; 176. San Rocco al Porto;
Pellice and Chisone R. Basin	S- 102. Bricherasio;
Dora Riparia R. Basin	P- Val Susa: 55. Mocchie (Rocca della Mina); S- Val Susa:101. Oulx;
Malone R. Basin	S- 53. Barbania; 54. Front; 55. Lombardone; 56. Rivarossa; 57. S. Benigno; 58. Viona R.: Volpiano; 59. Rivara and Busano;
Orco R. Basin	P- [Gran Paradiso deposits]. Val Locana: 19. Colle del Nivolet, La Cuccagna, A. Mee, Bellagarda; Val Soana: Valeille, Rancio, La Reale; S- Canavese: 40. Courgné, 41. Valperga, 42. Salassa, 43. Lusigné-Feletto, 44. Foglizzo, 45. Montanaro, 47. Bosconero, 46. S. Giusto, 48. Castellamonte, 49. Bairo-Aglié, 50. Ozegna-S. Giorgio; Gallega Stream: 51. Canischio;
Dora Baltea R. Basin	*Val d'Aosta:* P- Valtournanche: 12. Casale del Breuil; Evançon Stream/Val d'Ayas: 13. Alpe Lignod and Alpe d'Antagnod, 14. Magneaz, 15. Emarese, 16. Brusson (Fenillaz and Gae Blanche, Monsalé), Arcésas, Arbaz St. Anselme, 17. Challant-St. Anselme, Challant St. Victor (Obeglio, Grand Goleil, Targnod);11. Dora Baltea River: Brissogne St. Marcel; 18. Arnaz, Bard, Donnaz-Perloz; Ayasse Stream: 20. Champorcher; S- Lys Stream: 27. Gressoney St. Jean; Dora River: 28. Brissogne (Punta Laures Lakes); *Outside the Val d'Aosta:* P- Tavagnasco; Val Chiusella: 53. Traversella, 54. Brosso; Vico Canavese, Quincinetto, Quassolo; S- Val Chiusella: 75. Strambinello, 76. Parella, 29. Mazzé, 30. Vische, 31. Strambino, 32. Rondissone-Rivarotta, 33. Villareggia, 34. Moncrivello, 35. Cigliano, 36. Caluso-Candia, 37. Orio, 38. Barone, 39. Alice;
La Bessa Higland	S- Elvo Stream: 82. Salussola, 83. Cerrione, Borriana; Lobbia Str.: 84b. Mongrando; Viona Str.;
Cervo R. Basin	S- Elvo Stream: 78. Casanova Elvo, 79. Carisio, 85. Occhieppo and Gaglianico, 86. Pollone; 77. Biella, 80. Santhià, 81. Cavaglià, 87. Oropa, 88. S. Paolo Cervo, 89. Scagliano Micca and Miagliano, 90. Andorno Micca and Tollegno, 91. Candelo, 92. Cossato, 93. Castelletto Cervo, Mottacciata; 94.Villarbóit, 95. Formigliana, 96. Collobiano, 97. Quinto Vercellese, 208 "Burontium"; Sessera Stream: 98. Masserano, 99. San Maurizio;
Sesia R. Basin	P- *Val Sesia:* Alagna (21. Kreas-Solegna, 22. Mud, 23. Jazza, Acqua Bianca, 24. Corni di Faller, 25. Bors, 26. A. Fun d'Ekku, Piode Gacier, Mammellone, Salati, 27. Piramide di Vincent, Rosita, Cimalegna, Garstelet, Salati II, Corno del Camoscio, Hochlicht, 28. Bocciolетto, Balmaccia, 29. Cevia-Laghetto, Cervarolo); Val Mastellone: Fobello, M. Capio; S- *Outside the Val Sesia:* Rovasenda Stream: 70. Gattinara-San Maurizio; 71. Romagnano, 72. Sostegno, 205 Pezzana, 206 "Rosascum", 207 "Castrum Novum", Sessera Stream;
Strona R. Basin	P- Valle Strona: Campello Monti;
Agogna R. Basin	S- 127. Lomello, Agogna River undetermined;
Ticino R. Basin	*Val d'Ossola:* P- Valle Antigorio-Formazza: 39. Crodo, Alfenza, Faella, 40. Cravegna, 41. Croveo, Maglioggio; Val Divedro: 38. Gondo, A. Formazzolo (Canton Tessin); Val Bognanco: 37. Bognanco, San Lorenzo-A. Varcencio; Valle Antrona: 36. Antrona (Locasca, Prabernardo, Mottone, Mée), Schieranco; Valle Anzasca : 31. Pestarena, 33. Lavanchetto,Val Quarazza: 32. Quarazzola, Col Badile; Val Bianca: 34. Cani, Agaré, 35. Calasca-Castiglione; Val Toce: Pieve Vergonte-Fomarco (Motta, Cropino, Ortofreddo, Gerbidi della Piana dell'Asino); 42. Val Toppa : (Fontanelle and Tagliata),Val Segnara: Cortitti, Capezzone; 43. Vogogna (Fontane, Ronco, Genestredo, San Carlo, Giavinello Dresio); 44. Ornavasso; S- Valle Anzasca : 182 Belvedere Glacier on Monte Rosa, Anza Stream, 192 Val Toppa; *South of Lago Maggiore:* S- 103. Somma Lombardo, 104. Golasecca and Coarezza, 105. Varallo P., 106. Pombia and Marano Ticino, 107. Vizzola Ticino, 108. Oleggio, 109. Turbigo, 110. Robecchetto con Induno, 111. Cuggiono, 112. Bernate T., 113. Buffalora, 114. Galliate, 115. Romentino, 116. Trecate, 117. Magenta, 118 Robecco sul Naviglio, 119. Cerano, 120. Abbiategrasso, 121. Cassolnovo, 122. Vigevano, 123. Bereguardo, 124. Torre d'Isola and Corpi Santi di Pavia, 125. Zerbolò, 126. Travacò Siccomario;
Olona R. Basin	P- Monte Ceneri-Canton Tessin: 51. Novaggio, 52 Astano, Valganna: Brizio;
Adda R. Basin	S- 128. Rivolta d'A., 129. Comazzo, 130. Merlino, 131. Zelo Buon Persico, 132. Boffalora d'A., 133. Galgagnano, 134. Montanaso Lombardo, 135. Lodi, 136. Abbadia Cerreto, 137. Corte Peloso, 138. Cavenago d'A., 139. San Martino in Strada, 140. Turano Lodigiano, 141. Gombito, 142. Bertonico, 143 Castiglione d'A., 144. Formigara, 145. Camairgo, 202 Corno Giovine, 203 Lardara, 204 Roncarolo, 209 Bertario;
Serio R. Basin	S- 146. Grassobbio, 147. Cavernago, 148. Ghisalba, 149. Cologno al S., 150. Martinengo, 151. Trezzolasco, 152. Vidolasco, 153. Sergnano, 154. Bottaiano, 155. Picengo, 156. Pianengo, 157. Crema, 158. Madignano, 159. Ripalta Nova, 160. Ripalta Guerima, 161. Ripalta Arpina, 162. Credera, 163. Moscazzano-Montodine;
Oglio R. Basin	P- Mella River-Val Trompia: Bovegno; S- Mella River -Val Trompia: Bovegno, Oglio River unprecised;
Isarco-Adige R. Basin	P- Valle Aurina: 45. Predoi, Vetta d'Italia; S- Adige River umprecised;
Brenta R. Basin	P- Valsugana: Calceranica, Vetriolo, Val di Sella, Val Fersina: Viarago, Prementil, Palù del Fersina (Erdemolo, Knappenwald, Laner, Frotten);
Piave R. Basin	P- Valle del Cordevole: Voltago, Valle Imperina;

3. Prehistoric gold finds from Northern Italy (by G.B.)

Prehistoric gold artifacts from Northern Italy are being systematically inventoried. A fair quantity of gold items from the Bronze and Iron Ages was identified some years ago by von Hase (1975). In a recent paper Bergonzi and Cardarelli (1990-1991) list Middle Bronze Age finds.

3.1 THE BRONZE AGE

Gold seems to appear much later in Northern Italy than it does north of the Alps. The earliest Northern Italian gold objects are dated to the Middle Bronze Age. While two isolated Copper Age silver finds are well known (i.e. the pectoral from Villafranca Veronese and the hammer-headed pin from Remedello: Barfield 1971, 57, Fig. 24a, pl.24; Primas this volume), there are as yet no certain gold objects from either Copper Age or Early Bronze Age Polada sites. One should not forget, however, that Early Bronze Age archaeological sites found in Northern Italy are mainly settlements, together with a number of bronze hoards as well, while tombs are very few. In Italy to find gold artifacts which date back to the Copper Age one has to go as far as Sardinia, where gold armrings were found in a Beaker site (F. Lo Schiavo, personal communication).

As shown in Fig. 4a, where known occurrences are reported with no claim to be exhaustive, most Bronze Age gold finds are located in North-Eastern Italy. Their distribution suggests a relation with the Isarco-Adige valley, which during the Bronze Age was a well-known and important link to the Alpine copper mining areas and beyond that to Central Europe. In the west there is only the recently found, still unpublished, discovery from the Middle Bronze Age lake-settlement at Viverone (Vercelli) (F.M. Gambari, personal communication). Viverone, located next to the Bessa gold placers, is the only find which could be linked to an early exploitation of westalpine gold placers. The other sites do not seem to support the hypothesis that the western placers were already being exploited in the Bronze Age.

Middle and Late Bronze Age gold finds are small spiral rings or sheet discs. In addition one bronze fibula plated with gold foil is said to come from Peschiera (Verona) (von Hase 1975, 11 n.57 Fig. 4). Sheet discs are found in the Gualdo Tadino hoard (von Hase 1975, 101, n.6, Figs. 1, 2, tav.14) and in the settlements at Borgo Panigale (von Hase 1975, 105, tav.14) and Redu' (Bermond Montanari 1990; von Hase 1975, 111, n.56). The composition of the Redu' disc, examined by XRF spectrometry was: 84.94% Au, 10.0% Ag, 4.9% Cu, no trace elements mentioned. This composition seems to indicate that copper was intentionally added to the alloy, already a fairly common practice elsewere in Europe. The small spiral rings are found in settlement such as Peschiera (von Hase 1975, 111 n.56), Fiavè (Perini 1987, 17, 36, Fig. 14a), Castione dei Marchesi (Mutti et al. 1988, 161) and in graves, such as those at Stenico (Perini 1987, 36, Fig. 15b), at Franzine (Aspes 1987, 99) at Fontanella Mantovana (von Hase 1975, 111 n.56). Several Late Bronze Age cemeteries are fairly well known, but a find like Frattesina Le Narde tomb 227 with a gold ring, bronze "buttons" inlaid with gold, and an Allerona type sword with gold rivets (Salzani 1990, 16-17, Figs. 16-17) stands out as a unique example.

During the Middle to Late Bronze Age silver finds appear to be even rarer than the gold ones; there are but a few heterogeneous tiny artifacts from settlements, including a bead from Castellaro Lagusello (Piccoli 1982, 471), a conical sheet object from Isolone del Mincio

(Capoferri 1988, 62, tav. 10-19), a hollow-headed pin from Sanpolo (Saeflund 1939, 63, tav. 61, 14). Pending analyses of the alloys, the identifications of the metal are those proposed by the authors but not confirmed.

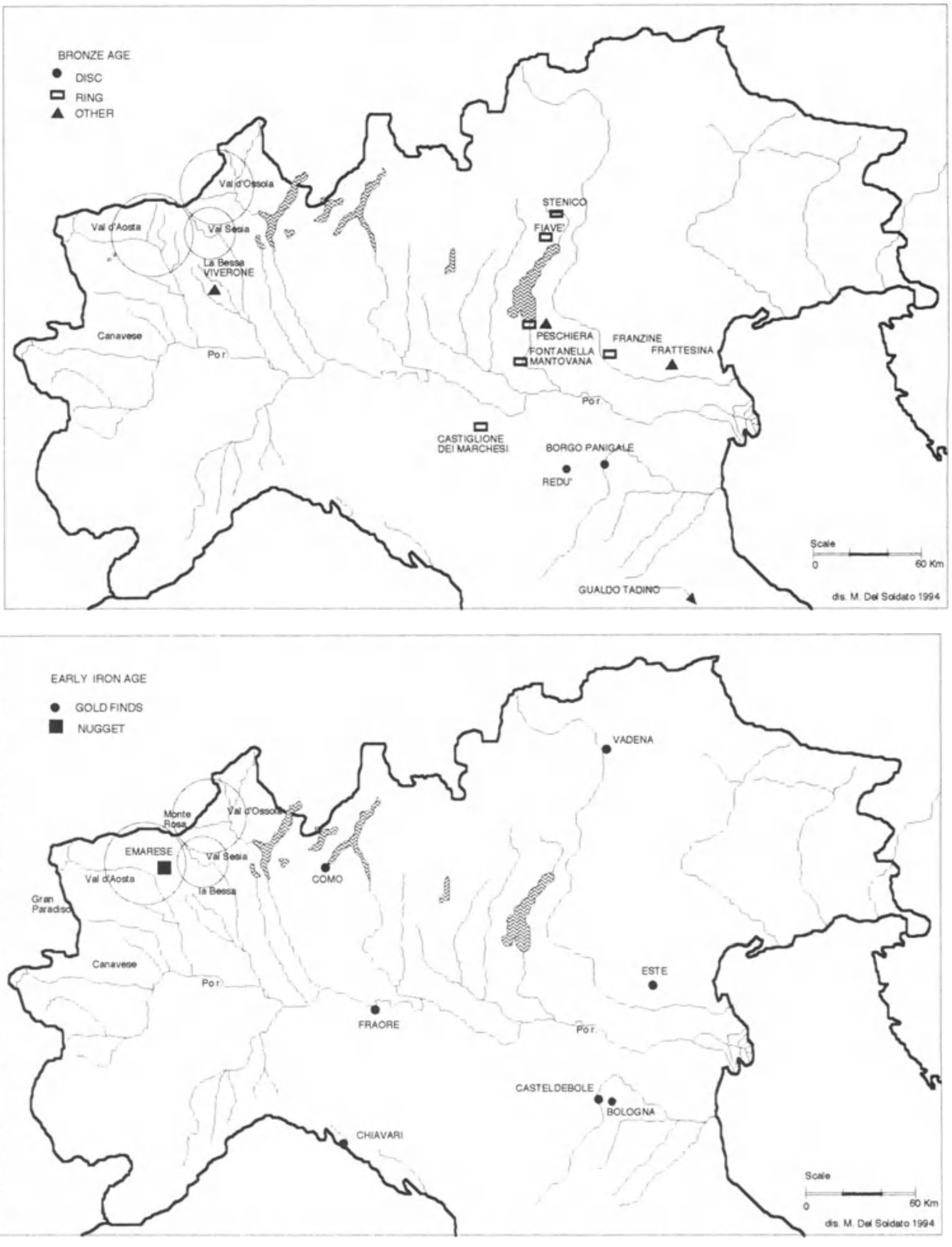

Fig. 4: Occurrences of Bronze (a) and Iron Age (b) objects in North Italy

3.2 THE EARLY IRON AGE

Fig. 4b, where known occurrences are reported with no claims to be exhaustive, shows that during the Early Iron Age gold finds are rather scattered, their distribution giving no clue to the provenance of gold. The earliest significant concentration of gold (and silver) ornaments is found in Early Iron Age Villanovan Bologna. There are little spirals often inserted into brooch pins, small rings, brooches, some of them decorated with granulation or filigree. The most outstanding among these objects are regarded either as imports or as imitations of Villanovan objects from Central Italy (Pincelli 1959; von Hase 1975). Later on, during the Arnoaldi and Certosa periods; there is a number of silver brooches, sometimes plated or otherwise decorated with gold foil (see for instance Cristofani and Martelli 1985, 123, 274). Gold brooches like the Certosa ones from Bologna and the serpentine bow ones from Fraore (Cristofani and Martelli 1985, 200, 303-305) are exceedingly rare, and bronze brooches plated with gold are also rather rare (Saltini 1992). Precious gold and silver objects are also occasionally found in minor sites like Casteldebole near Bologna (P. von Eles, personal communication) or Fraore.

Another remarkable concentration of gold (and silver) ornaments (mainly pendants and beads) is found in the Veneto, especially in the proto-urban center at Este (Padova) (Bergonzi et al. 1981, Chieco Bianchi and Calzavara Capuis 1985, Tosi 1992). The same types of objects are also occasionally made of bronze plated with gold foil. There are about a hundred such small finds, which however cannot be listed in detail here (A. Ruta Serafini, personal communication).

In Lombardy, in the so-called Golasecca area, gold is rare. Around Como, thin gold thread is used in the manufacture of a brooch with a long catch and coral segments inserted in the bow (De Marinis 1981, 223). There are also the toilet-set silver pendant from Rebbio with gold foil decoration (De Marinis 1988, 231, Fig. 191) and the gold ring found with a silver serpentine bow brooch in the tomb 1/1930 from Cà Morta near Como (De Marinis 1988, Fig. 189). Another gold ring was found on the Leuchtenburg of Vadena, Trentino Alto Adige. In Liguria in the cemetery at Chiavari, gold (as well as silver) is used for making small objects such as "earrings" or buttons (von Hase 1975, Guzzo 1975, Marini and Zucchi 1982, De Marinis 1988, 251-253, Fig. 195).

While the finds from Lombardy and Liguria could possibly be linked with the western Alpine and Ligurian Apennine mining areas, the largest concentrations are found in protourban centres which are far away from the ore deposits. The concentration of precious finds in these centres is likely to be a consequence of their central political position.

There is only one direct clue, still to be verified, to the possible exploitation of west Alpine sources during the Iron Age: a gold nugget is said to have been found inside the stone setting of an Iron Age tumulus at Emarese in Val d' Ayas (Val d'Aosta) in front of the entrance of an asbestos mine where traces of gold were found (Mezzena 1982). If confirmed, that could be a very interesting indication that the alpine ores were already being mined during the Iron Age. The distribution of gold finds during the Late Iron Age is discussed in some detail in Bergonzi (this volume).

4. Pre-Roman and Roman gold extraction: archaeological findings in "La Bessa" (Biella) (by F.M.G.)

In northern Piedmont, to the south of the town of Biella, an area of at least 3 square miles is predominantly occupied by man-made pebble hills. Frequently discussed by local historians from the18th century onwards (Di Robilant 1786, Donna 1936, Scarzella 1973, Micheletti 1976, Calleri 1985 etc.) this area has been researched during the last ten years by the Soprintendenza Archeologica del Piemonte and it has now been established as a Regional Park. The visible remains of ancient canals, as well as temporary workers settlements, interspersed with old quarries have been recently revealed by surveys and regular excavations. These structures appear to be connected with the enormous enterprise of sieving and washing the fluvial-glacial drift to separate the sand from the gravels, and to recover the heavy gold-bearing ore in it. Geomorphological studies demonstrate that the sand-washing was carried out by diverting the Viona river having its flow through artificial canals into the Elvo river. There can be no doubt that this area is to be identified with the famous mines of the Victimuli described by Pliny (N.H., XXXIII, 78). These mines were abandoned in the 1st century B.C. because of the greater profitability of Iberian mines and the exhaustion of the richest part of the drift. In addition, local security problems, which led to the lex censoria cited by Pliny, limited the work force to 5000 men. This very large number is probably to be explained by the utilisation of indigenous *"dediticii"*, derived from wars between the Romans and the Salassi from 143 B.C. onwards presumably on a pretext related to gold mining.

Victimulae, a town described by Strabo (V, 1, 12) and Anonimus Ravennatis (IV, 30), can be identified with the archaeological remains found near the modern village of Salussola: There a *"Ponderarium"* (public bureau of right weights for measurements of metals) was estabilished, probably in the second half of the 1st century B.C. It was mentioned by a citizen of Eporedia (Ivrea) and documented by an inscription. With the foundation of Eporedia in 100 B.C., all the lands of the Victimuli, who before the war were a *"pagus"* of the Salassi, came under the control of this colony. Beyond the visible remains of works from the Roman age, the coarse pottery of the surrounding villages and some more limited works of canalisation and drift-testing may be dated to the second Iron Age phase (2nd and probably also 3rd century B.C.).

5. Gold panning and mining in Northern Italy: classical written sources (by P.P.A.)

Classical authors name several places where gold would have been extracted. In Northern Italy these were: the mines belonging to village of Victimulae (Plin.N.H. XXXIII, 78) and Vercellae (Strab. Geogr. V, 1, 12.15), the mines belonging to the Salassi (Strab. Geogr. IV, 6.7), the placers in the Po River (Plin.N.H. XXXIII, 66), the mines (Polyb. in Strab. Geogr. IV, 6, 12; Strab. Geogr. V, 1, 8) and the placers (Strab. Geogr. V, 1, 8) from the outskirts of Aquileia. In Southern Italy, outside of the area considered in this paper, there were mines in the Ischia Island near Naples (Strab. Geogr. V, 4, 8) and in Bruttium, which is today Calabria (Cassiod. Var. IX, 3.1).

The mines on the "outskirts of Aquileia, belonging to Taurisci Norici" (Pol. in Strab. IV, 6, 12) are in reality those in the Hohe Tauern in the Noric kindom (Holzer 1986, 25-26). However, they are situated to the north of the Alpine watershed. Pliny (N.H. XXXIII, 66) mentioned that gold straw was recovered in the Po River (fluminum ramentis, ut in Tago Hispaniae, Pado Italiae etc.), and his report appears well-founded in the light of several medieval documents mentioning gold panning along the Po River, while giving no precise location. From the present perspective the extractive activities are likely to have taken place in the region of Victimulae near Vercellae and in the area near the Dora Baltea inhabited by the Salassi are more interesting. These regions are adjacent and rich in gold deposits: the former containing morainic and fluvial deposits; the latter, primary and secondary deposits.

Several authors were persuaded that all mentions found in the classical sources must have referred to the same area, since significant evidence for ancient extractive activities is found only between Biella and Ivrea in the La Bessa highland (De Sanctis 1923, IV/1, 417). Other authors have mantained the opposite, i.e. the classical writers distinguished between one area belonging to the Victimuli and Vercelli and another belonging to the Salassi (Pais 1918, 408, Gribaudi 1928, Artom 1935).

The ancient written sources were recently reexamined by Perelli (1981) and many of his conclusions appear convincing (Cresci Marrone 1987). As to the location of ancient mining activity, he maintains that the *"aurifodinae"* situated near Victimulae are to be identified with the morainic deposits in the Bessa, while on the other hand the mines belonging to the Salassi are, as Strabo reported, near the Dora Baltea, a river which is separated from the Bessa highlands by the ridge of the Serra. However, since no traces of extractive activities have been found along the Dora River, the identification of a site for the mines belonging to the Salassi is a question still to be resolved. Strabo supplies the following information:

a. the gold mines had been exploited by the Salassi and continued to be used by the Romans after 143 - 140 B.C.;
b. the waters of the Dora Baltea were employed in the working and washing of the ore; thus both activities were pursued in the vicinity of the river;
c. the facilities for washing (krusoplousia) consisted of a network of canals constructed so as to capture all the water from the river;
d. the Romans, intervening in 143 B.C. on the pretext of resolving the quarrel between miners and farmers concerning the rights on uses of the water from the Dora, took control of the gold mines but not of the waters necessary for the mining of gold because the Salassi still controlled the sources. Nothwithstanding these observations, identifying a deposit that is consistent with Strabo's account is not easy. Unfortunately, is is not known whether in 143-140 B.C. the Romans conquered only the territory of the Salassi lying outside the Val d'Aosta, as suggested by Fraccaro (1941), or whether they were able to enter into the valley itself.

Another issue concerns the type of activity, whether panning or mining. Perelli (1981) is convinced that the Salassi quarried gold from mines, a view already supported by Gribaudi (1928) and Artom (1935). However, this view clashes with the notion that gold was collected only from placers, an opinion put forth by Pais in 1918 without having examined the question in great detail. According to the writings of Pliny (N.H.XXXIII, 66-79), the primary deposits were being mined in ancient times using water to transport the waste materials (Piaskowsky 1957). Moreover, the terms used by Strabo (kruseia and krusourgeion) (Stephan 1865, col. 1755 s.v. krusorukeion = *"aurifodina, locus ubi aurum foditur"*), indicate mining activities (Gribaudi 1928, Perelli 1981) as opposed to panning.

Perelli (1981) takes into account two possible locations for the mining by the Salassi. The first one is the Brosso mine in the Ivrea basin, close to but just outside the Val d'Aosta. Here there is evidence pointing to ancient working, but the site is too far from the Dora to have used water derived from that river. A mine not considered by Perelli (1981) is the Tavagnasco mine which is located nearer to the Dora. The second possible location of the mines Perelli (1981) proposes is inside the Val d'Aosta, in the Val d'Ayas, located in such a way that the water channels could have flowed through the field situated immediately further down stream into the Evançon, a tributary of the Dora.

Perelli (1981) is aware that the solutions proposed are not final. The water would not be derived from the Dora, but rather from Evançon, one of its tributaries. Any struggles between miners and farmers would have involved a very small area and would hardly seem likely to arouse the interest of the Romans to intervene and put an end to those struggles. Whether or not the mines in the Valle dell'Evançon-Val d'Ayas are those referred to by Strabo, in this area there are a few rich gold veins (the Ciamusera-Fenillaz Group including deposits of Lignod, Antagnod, Brusson-Arceza (Fenillaz, Gae Blanche, Monsalé mines) Arbaz-St.Anselme, Challant St.Anselme et Challant St.Victor (Orbeillaz, Grand Goleil, Targnod mines)(Servizio Geologico d'Italia, 1975, 22). A few among these mines could have been used during the pre-Roman period as evidenced by at a gold nugget said to be found inside an Iron Age tumulus at Chassan near Emarese (Mezzena 1982, 57-58, Fig. 34).

There are gold deposits situated in other places which could fit Strabo's description better. Mines in the Val d'Aosta are numerous (see Fig. 3) and some have evidence of ancient working (Finocchi 1966). Leaving aside those which are situated in the high valleys and which were controlled by the Salassi up to the Augustan age (mines of Cogne, Gressoney, Ollomont-Champ de Praz, Courmayeur), it seems reasonable to consider the mines near the Dora River (Brissogne, Bard, Donnaz) or in lower Val d'Aosta (Champorcher in the Valley of Ayas Stream, which was used in 1279; Bottino et al. 1975, 21), if one holds that the Roman conquest in the years 143-140 went no further the lower Valley.

Clearly, much fieldwork remains to be done to clarify the picture of mining and panning activities during Roman times.

6. Medieval written documents (by M.T.)

Here is a selection of the earliest documents (up to the first half of the 14th century) that deal with gold mining and panning in Northern Italy. Quotation from documents which do not have an explicit mention of gold has been avoided because the sand and gravels quoted in such documents could have had other uses, for example as building materials:

a. 28 September 872. The Emperor Ludwig II gives all the lands from Corno to Lardera between the rivers Adda and Po and the island of Roncarolo *"excepta auri lavatione quam camere reservavimus nostre"*, to the Convent of Saints Sisto at Fabiano and of the Resurrection at Piacenza.
b. The same grant is asserted again on the 31 October 1061 by the Emperor Henry III (Ficker 1868, 19-20 n.14; Vignati 1879, I, 66-67).

c. 1 November 1000. The Emperor Otto III gives *"totum aurum quod invenitur et elaboratur intra Vercellensem episcopatum, et Vercellensem comitatum, et infra comitatum Sanctae Agatae, et infra iura et infra pertinentias S.Michaelis in Laucejo et infra alias terras ad episcopatum Vercellensem, et ad comitatum pertinentes"* to the bishopric of Vercelli (Durandi 1804, 142).

d. 1002. The King Arduino gives *"omnem redditum auri, quod in amne levatur" ..." in toto dominio castellorum Cavenaci et Galgagnani, qui redditus pertinere videntur Camerae Nostrae"... to the bishopric of Lodi (Milan) because of the "paupertatem prefatae Ecclesiae Laudensis"*. (Ughello 1719, IV, col.661, Vignati 1879, I, 42).

e. 4 May 1039. The Emperor Conrad II gives and confirms to *"Uala de Casale filius quondam Antonii"* the following sites. *"Casauallonus, Pezana, Rosascum, Castrum novum, Castro Beluardi, Bulgari, Lerio, Burontium"* with their own rights, among which there are: *"aurilevam, navigium, rivaticum, ex utraque parte fluminum, que in eius predia, coherentia tenentur"*. (Bresslau 1909, IV, 386-389).

f. XI century. *"Sunt etiam omnes auri levatores qui mittunt rationem ad cameram Papiensem; et numquam debent alicui aurum venudare nisi per Sacramentum, et debent ad illud consignare et camerario. Et debent omne illud aurum comparare, gradinam solidos duos, id est octava parte unzie, id est denariorum solidorum (?) duorum cum dimidio, solidi sedecim, alias unam unziam, in fluminibus, ubi aurum levant, que sunt haec: Padus, Ticinus, Dorica, Sicida, Stura, Minor Stura, flumen Orco, Amalone et Amaloncello, Duria, Elavum, Urba, Sarvus, Sesedia, Burmia, Agonia, Ticinus a laco Maiori ubi intrat in Padum. Sunt etiam ista flumina: Abdua, Oglus, Mentius, Sarno, Atese, Brenta, Trebia. Et per omnia alia flumina predicta debent aurum levare."* (Bruhl and Violante 1983, 20-21; 94-104).

g. May 1172. Agreements about the sale of gold between Bertolotto Achiley and a group of people panning gold ("aurilevas") in the sands of river Adda, in the jurisdiction of the Bishop of Lodi (Milan) (Vignati 1883, II, 66).

h. 1195. *"Hoc anno siccitas fuit magna, et tunc inventum fuit aurum in Bovagno"* (Bovegno, Brescia) (Bethmann 1863, 815).

i. 20 May 1230. Umberto de Bulgaro and Bertolino de Saluzzola, with some relatives of theirs, hand over to the Comune of Vercelli all their rights *"in illa argenteria sive argenti, auri, azurri et aliarum rerum"* which is on *"mons Asolate"* (Biella). (Historiae Patriae Monumenta 1876, II, col.118, CCXXVII; Ordano 1970, II/1, 224-226).

j. 1311?. Fragment of a petition sent by the Bishop of Lodi (Milan) to the Emperor Henry VII asking for the allotment of the *"reditus auri quod annue levatur in ripis fluminis Adue ab utraque parte ipsius fluminis a Cornaiano Bertaro usque ad Castrumnovum buce Adue, vel saltem intra curtem Galgagnani et curtem Castioni"* (Vignati 1883, II, 474).

From these documents one can see that the emperors assert their rights on the mines and placers, that may be given to somebody only by special concession.

It is possible that the group of *"aurilevas"* mentioned in the document of the year 1172 formed a society. Mining societies are already known from many medieval Northern Italian documents, such as those about the silver mines in the district of Bergamo, but this is the earliest known at present about a society for gold panning. In the same document the prices for gold are quoted and they are low. This is not surprising since the economy and the monetary system of the period was based on silver and not on gold.

7. Current field researches on gold exploitation in Northern Italy

In Italy the last active gold mine at Pestarena in Val d'Ossola closed down as recently as 1962 when its activity appeared to be no longer profitable. During the last years geological field research concerning gold ores has been resumed by RIMIN Company both in the Alps and the rest of Italy (RIMIN 1987). There are also scientists and historians (affiliated both with both Universities and Museums) interested in the past exploitation of gold who are undertaking field research (Badino et al. 1992). A meeting on the Alagna gold mines organized in 1990 by a research team working in the Val Sesia (Piedmont), was supposed to be followed up by a conference wider in scope on the same subject (Cagna Pagnone et al. 1990). This however has not yet taken place. The Soprintendenza Archeologica del Piemonte is studying the deposit of the "La Bessa" highland (Vercelli) (see section 4).

In the Val d'Ossola (Novara) a multidisciplinary research project is under way. The primary aim is to study the mining and the processing of metalliferous ores in the pre-industrial age. Another of its purposes is to compile a comprehensive record of mining from geological and archaeological field evidence as well as historical and archival data. The study of archival documents (Milan, Novara, Turin, Pallanza States archives and some private ones) is the starting point for the fieldwork. "Mining topografical unit" records are being compiled in which geological and mineralogical data are registred and an attempt is made at assessing the impact on the environment (Cattin 1988, Del Soldato 1988, 1989a, 1989b, 1989c, 1991 a, 1991b).

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Chapter 3

CELTIC GOLD MINES IN WEST CENTRAL GAUL

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ABSTRACT. Archaeological researches recently carried out on ancient gold mines in the Limousin (west central Gaul) have revealed an intense extractive industry. The Lemovici people developed opencast mining following outcropping veins (hydrothermal veins with native gold and gold associated with sulphides) in their territory throughout the second (La Tène) Iron Age. Mining activity started in the 4th century B.C. At that time, extraction was by small open-pits followed by underhand stoping. Abundant traces of nearby dwellings have been found in the backfill, as well as stone-tools used in working the ore. In contrast, in late La Tene (from 2nd to early 1st century B.C.), the mines were in the form of large open casts of a length of about 250 m, a width of 80 m, and a depth of 30 to 40 m. From these opencasts exploratory galleries and crosscuts were driven along cross-cutting veins. Crosscuts were also driven for drainage. From a depth of about 20 m, mining went on underground in stopes driven up to 10 m depth and fully propped (with the complete timbering still existing in its original position).
At the site of these long excavations, ore treatment areas have been located. They include roasting hearths, ore, fragments of millstones, crushing-tables, crushers and touchstones. At the middle La Tène site of Cros Gallet-Nord, ore washing areas and crucibles have been also found. Near these areas were discovered the foundations of earthern and timber structures of middle and late La Tène date.

1. Introduction

Archaeological researches over the last seven years have uncovered a number of Celtic gold mines, located in the Limousin region at the south-western margin of Massif Central in west-central France (Fig. 1).

Gallic gold is famous from the ancient authors, especially the gold placers from the Pyrenees and central France (Strabo, 4, 1, 13; 4, 2, 1; Diodorus, 5, 27, 1; Ausonius, Mosella, 465), but, on the other hand, there is neither text nor inscription referring to gold mines in the Limousin. Moreover, the rare mentions of the Lemovici people who lived in that territory (first reference in Caesar, De Bello Gallico, 7, 4; 7, 75; 7, 88), never refer to their mining heritage and still less to their gold. Only mining archaeology has allowed to identify the techniques and the chronology of that mining activity.

2. Discovery of ancient gold mines in the Limousin in the 19th century

In the second half of the 19th century, geological research recognized the existence of outcropping gold veins in northern and southern Limousin (Mallard 1866), by the identification of very ancient human works, still visible in many places under woodland, as ancient gold opencast mines. These ancient opencast mines appear in the landscape as long and deep exca-

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 219–240.

vations, the depth of the works being accentuated by the up-cast dumps along their edges. The interior of the pits is concealed by several metres of collapsed dumps (Fig. 2).

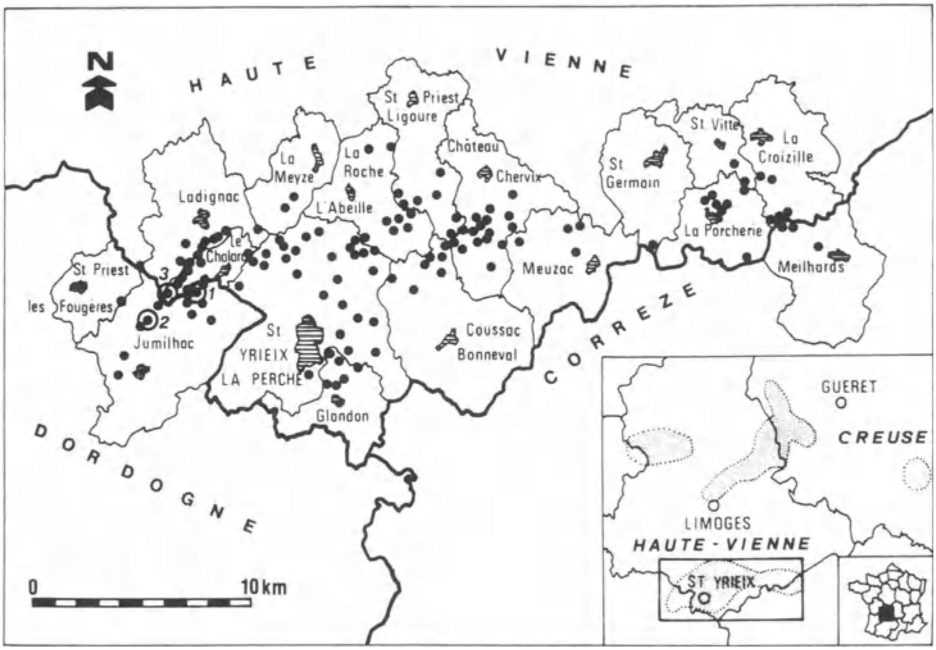

Fig. 1: Ancient gold mines in the southern district of Saint Yrieix-la-Perche, Limousin, France; 1 - La Forge de Tindeix; 2 - Les Fouilloux; 3 - Cros Gallet.

Fig. 2: Site of Les Mines (Ambazac, Haute-Vienne), a Celtic gold mine deserted since antiquity.

That discovery led to a renewal of interest in the potential of the Limousin as a mining area. Since the beginning of the 20th century, geologists and prospectors have looked for and recorded hundreds of these ancient opencast mines as indications of gold (Sagui 1940, Sevensma 1941, Laporte 1965).This created a minor gold rush in the region. From that period onwards, prospecting and mining, mainly for gold, have followed each another with more or less favourable success depending on the time and the techniques used. A new gold mining revival has recently taken place in the south-western part of Limousin (around the town of Saint-Yrieix-la-Perche, Haute-Vienne), where a gold mining company, the Société des Mines du Bourneix (a subsidiary of C.O.G.E.M.A) has been active since 1982.

The mining history of the Limousin goes back to antiquity. Ancient miners worked veins and veinlets of tin and gold bearing quartz in northern Limousin and, mainly, auriferous quartz hydrothermal lodes outcropping in the southern part. The host rock of these auriferous veins are metamorphic rocks such as gneisses, micaschists or granite. The width of the veins may go up to tens of centimetres, more rarely to over a metre. The gold generally appears as small, thin flakes, occasionally visible to the naked eye, but usually only of microscopic size, associated with sulphides like arsenopyrite, stibnite, pyrite and sphalerite. Most of these veins and veinlets cropped out which made their early discovery possible.

The drainage pattern of this region is rather steep so that few viable alluvial gold deposits have been able to form. Still, some auriferous alluvial sediments from the Tertiary period have been located at the south-western margin of the area (the north-east of the Dordogne department); these sediments were also exploited in antiquity. The modern exploitation clearly shows that the ancient miners had not worked the lodes completely out, although they had looked at any outcrop, however small.

3. Recent mining archaeology

It took some time for the discovery of the ancient mining works at so many sites in the Limousin to interested historians and archaeologists. Nevertheless, mining exploration in the first quarter of this century in the form of shafts and galleries, generally driven from the ancient opencasts, had revealed the hidden parts of the mines. Thus, in the administrative files of the regional mining department for the Limousin, one can read the reports of the discoveries of ancient underground mining works. These remains, generally filled up or flooded and sometimes with preserved timbering, were intersected by early 20th century mining works.

What deterred historians and archaeologists was the inaccessibility of these ancient mines, where the faces and the entrances of the underground mining networks were hidden under metres of old mining dumps (Figs. 2, 3). As a result the historical interpretation of these remains was for a long time wrong. They were usually regarded as Roman works from the Gallo-Roman period because of the extent of the remains which could only refer to a Roman civilization considered technically advanced. In the same way, the abundance of gold coinages from the Merovingian period found in this region was sufficient to lead to the idea that these gold mines had been worked at that time, even that they had been first opened by the Merovingians.

These assertions reflect the limited interest taken by the archaeologists in the old mines in France until the beginning of the seventies, when Claude Domergue started to give a real impetus to the discipline by his researches in Spain (Domergue 1970, 1978; see also his syntheses of 1987 and 1990). Mining archaeology is indeed a new field in French archaeology; this type of research often needs specialized speleological techniques, which took time to spread among the archaeologists.

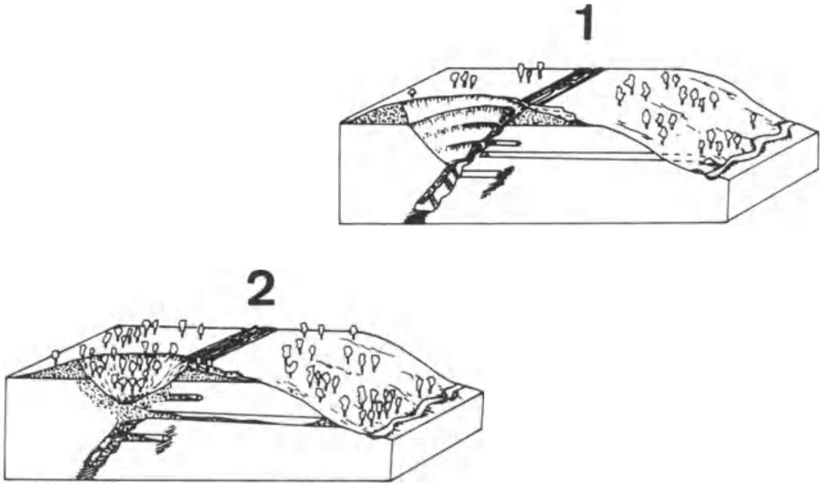

Fig. 3: Sketch map of a La Tène gold mine; 1 - active; 2 - abandoned.

Meanwhile, in the Limousin, geologists and prospectors had recorded hundreds of ancient opencast mines, even speaking of about 2,000 excavations, having started on the veins outcropping in this region (Laporte 1965). So, in 1984, when the author started to study these mines using archaeological methods, the first task was to record and systematically map the mining sites before attempting any archaeological excavations (Cauuet 1989). The mining inventory at the moment numbers about 230 ancient gold mines, spread over five distinct districts in the Limousin (Fig. 1). The southern district of Saint Yrieix-la-Perche is the most important with about 130 sites; it is in this district that the archaeological research presented in this paper started. Although archaeological prospection and the inventory of mining sites are the starting point and basis of this research, the approach is incomplete without the move to excavation.

Ancient mining works in the Limousin appear as long excavations, from 10 to 100 m long, 5 to 40 m wide, and from 3 to 15 m deep (Fig. 3). As the veins crop out, mining has always started as opencast. However, is it known from the early mining researches of this century, that there were also underground mining works. As usual, the waste had been dumped up near the excavations. Piled up in hillocks at the sides of the opencast mines, these dumps had gradually subsided inside the mining works after the end of mining activity. The subsidence of these dumps has contributed to the partial filling of the interior of these opencast mines, completely hiding the entries of the underground works (Fig. 3).

The initial excavation started in 1986 with the study of an ancient mining gallery which remained partly accessible at the site of La Forge de Tindeix (Jumilhac, Dordogne) (Fig. 1). In the filling of this gallery the first ceramic evidence was found, dating to the end of second

(La Tène) Iron Age (Cauuet 1989, p.64-66, 1992, p.11-16). In 1988, modern mining exploitation, restricted until that date to underground activity, has turned to intensive opencast mining. It then became possible to undertake large scale excavations in the context of rescue archaeology.

Important archaeological rescue operations were developed at two sites, at Cros Gallet (Le Chalard, Haute-Vienne) and at Les Fouilloux (Jumilhac, Dordogne) (Fig. 1). Digging here allowed to study mining remains as a whole, over an area as well as in depth. However, depending on the urgency of the situation, choices have had to be made. Thus on the site of Les Fouilloux, where excavation gradually developed ahead of modern mining from 1988 to 1992 (Cauuet 1988, 1991, 1992, Cauuet and Didierjean 1992), the most recent and largest ancient mining works, dating to late La Tène, have been studied (Fig. 6).

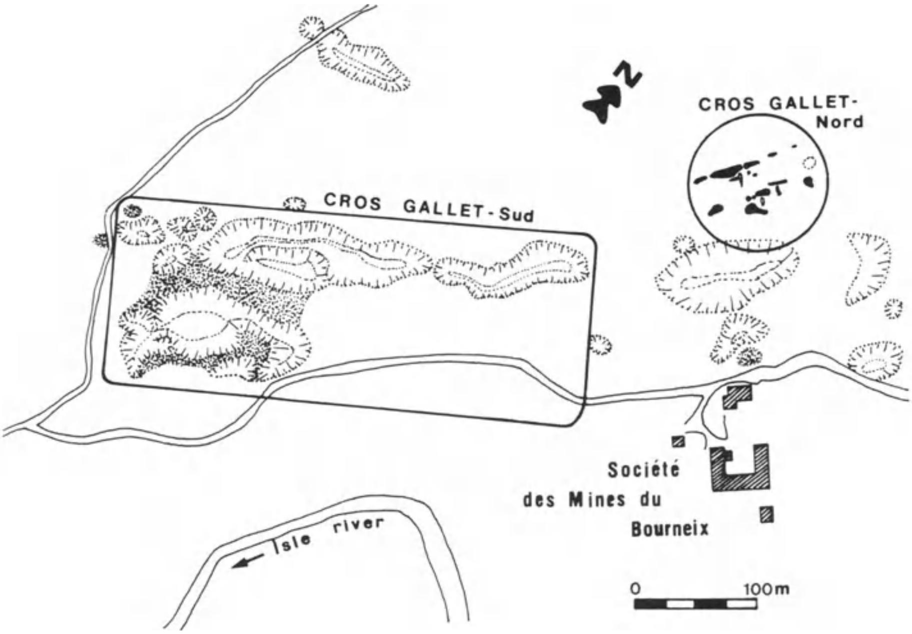

Fig. 4: Site of Cros gallet with its opencast pit (Le Chalard, Haute-Vienne).

On the site of Cros Gallet, two distinct areas have been examined (Fig. 4). The southern part, called Cros Gallet-Sud, corresponds to large mining works of late La Tène, similar to those studied in Les Fouilloux (Cauuet 1992, p.16-17). So far only a few excavation tests have been made. In contrast, the north part, called Cros Gallet-Nord, saw extensive excavations in 1993; they have revealed an ancient complex of shallow mining works of middle La Tène date (Fig. 5).

4. Celtic mining techniques

The excavations at the sites of Cros Gallet and Les Fouilloux have given the possibility of elucidating the Iron Age mining techniques developed in the south-western Limousin from the 4th to the 1st centuries B.C. On these two sites, characterised by large opencast mines dating to the final phase of the exploitation (2nd to early 1st century B.C.), the earliest works from the Middle La Tène, (4th to 3rd centuries B.C.) have been found sited at the edge of the later, larger works. They have been preserved from later reworking because they were opened in areas of rather poor mineralization, and were worked only for a short time. The discovery of two types of mining remains, older surface works and more recent deep works, allow to demonstrate the evolution of mining techniques used in the Limousin from Middle to Late La Tène.

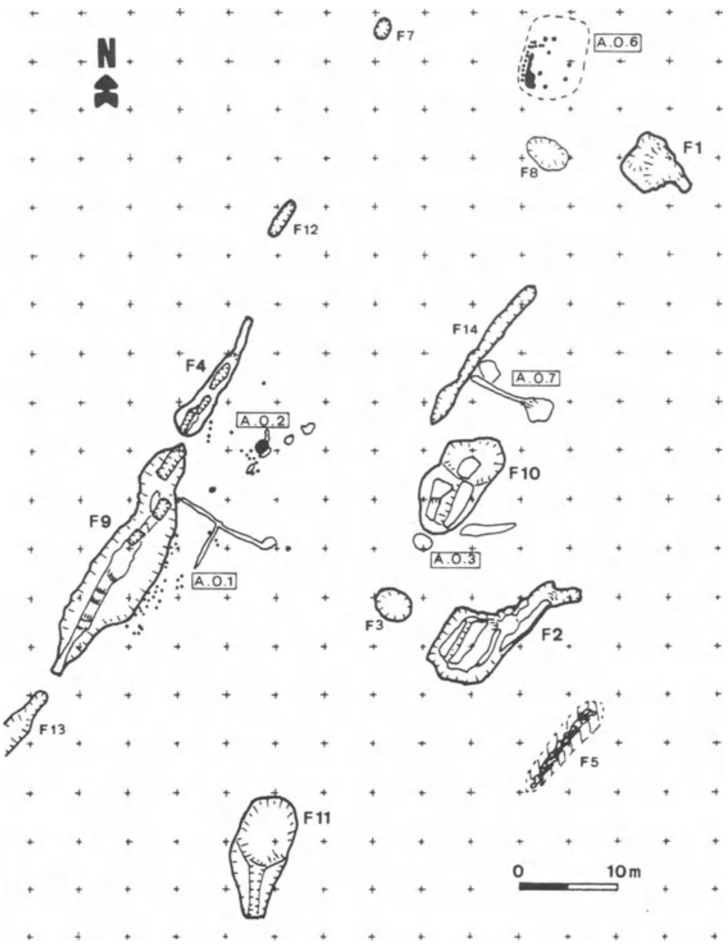

Fig. 5: Plan of Middle La Tène site of Cros Gallet-Nord and the main structures excavated (Le Chalard, Haute Vienne). Crosses mark a 5 m x 5 m grid.

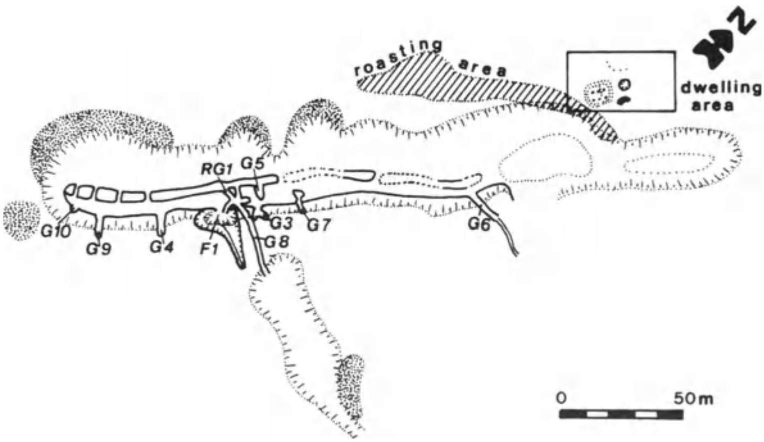

Fig. 6: Plan of Late La Tène site of Les Fouilloux and the principal structures excavated (Jumilhac, Dordogne).

4.1 EXTRACTION FROM OPENCAST MINES

4.1.1 Iron tools: cutting and firesetting

In the mines, ore extraction may have been performed by firesetting. This technique consists of heating the rock surface with a wood fire built against the face. The rock fissures and breaks under the thermal stress. For the moment, there have not been found clear evidences of this type of operation in the Limousin's mines. On the other hand, many faces bear traces of *pointerolle*. This is a specialised iron miner's tool having the shape of a hafted chisel, the top of which miner would strike with a sledge hammer. This sort of miner's tool is well known from ancient to late medieval mines. Unfortunately, the opportunity of finding any miner's tool in the Limousin's mines has not yet arisen. It appears the chisel cutting technique was the main one, either carried out alone, or combined with a previous firesetting of which traces would have been destroyed by the last cutting operation.

4.1.2 Mining in stopes

The Celtic miners progressed to the depth by descending underhand stopes in both opencast sites and the underground works. In middle La Tène (4th to 3rd century B.C), on the site of Cros Gallet-Nord (Fig. 5), two types of opencast mines have been identified, whose forms derive directly from the shape of the lode (Figs. 7-10).

In gently dipping veins, mining was by staggered descending stopes (underhand stoping), following the inclination of the vein. This stepwise progression has left a succession of benches in the footwall of the vein (Figs. 7, 8), while the face of the excavation has a straight, oblique outline. This pattern might have assisted the movement of the miners up and down, and the evacuation of the mined ore.

In sub-vertical veins, digging has been done by vertical, descending stopes, forming long, deep and narrow excavations with almost vertical walls (Figs. 9-10). The digging would progress by successive cuts which have left transverse benches in the bottom of the excavation (simple underhand stoping). In the deepest excavation studied (Fosse 9, Fig. 10), wooden struts might have been inserted across the cutting to prop the walls. In that cutting, in fact some small cavities have been found hollowed out of the walls, presumably to fit the props. However, in these shallow mining sites, with a maximum depth of 9 m, wood has not been preserved in sufficiently waterlogged conditions.

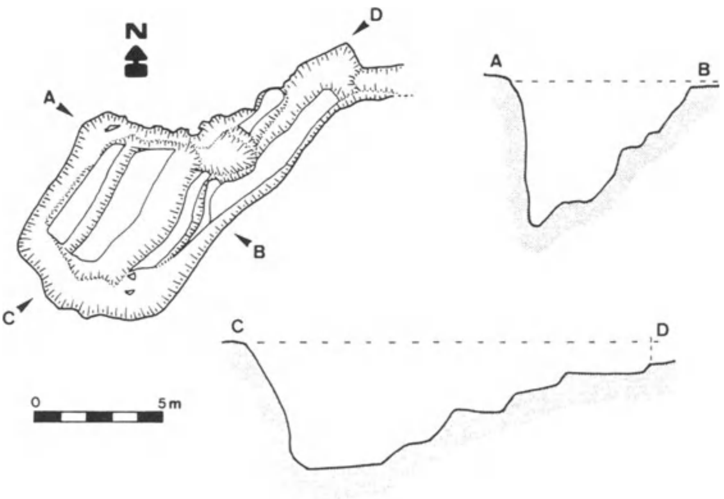

Fig. 7: Stope F2 from Cros Gallet-Nord worked by descending stopes.

Fig. 8: Stope F2 from Cros Gallet-Nord showing benches visible in the sidewall of the vein.

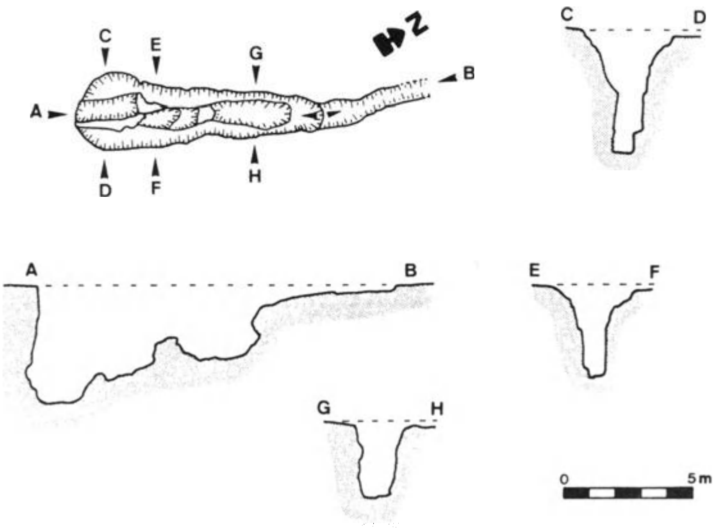

Fig. 9: Stope F9 at Cros Gallet-Nord worked by simple underhand stopes.

Fig. 10: Stope F9 and F4 at Cros Gallet-Nord opened on a sub-vertical vein.

In Late La Tène, opencast mines reached huge proportions: 250 m long, 40 m wide and 20 m deep at the site of Les Fouilloux (Fig. 6); 300 m long, 55 m wide and 18 m deep at Cros Gallet-Sud (Fig. 5). Here, the extraction left benches on the floor of the vein, while leaving an oblique face in the vein roof (Figs. 3 and 11).

Fig. 11: Benches in the roofwall of the vein at Les Fouilloux.

From the opencast stopes, small galleries were driven underground perpendicularly to the strike of the vein. (Figs. 3, 12). These underground works were limited in extent; they followed secondary veinlets, found adjacent to the main vein in the first twenty metres of depth.

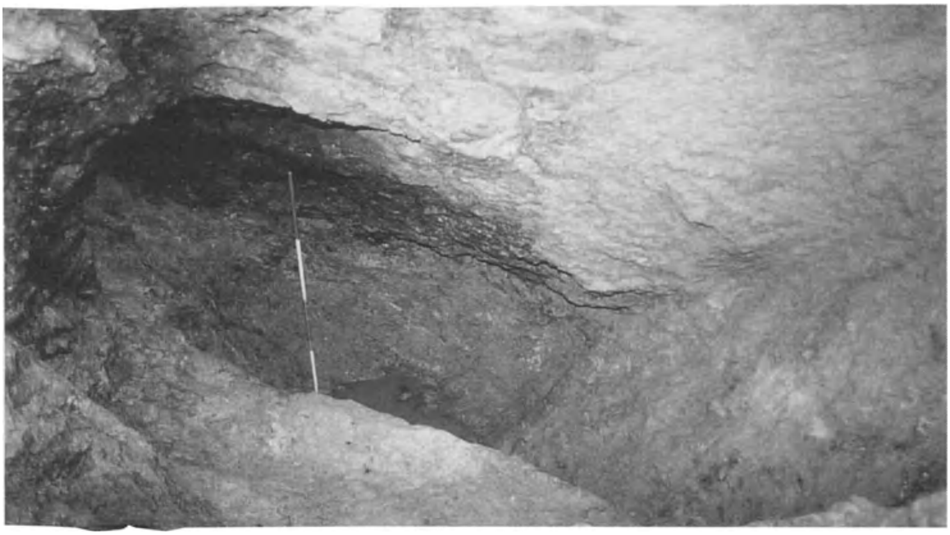

Fig. 12: Stoping in underground gallery G7 at Les Fouilloux.

Some sections of these galleries present the characteristic rounded-shape left by firesetting (Fig. 16). But here too there is no obvious trace of that operation since the walls all bear visible marks of the iron tools work with chisel and hammer.

4.2 UNDERGROUND MINING

The gold mines of Cros Gallet-Nord dating from Middle La Tène were opencast mines, not exceeding 8 to 9 m in depth. In contrast, in the final La Tène sites, from 20 m depth onwards, extraction continued underground, e.g. to 30 m depth at the site of Les Fouilloux. These long, narrow underground works were driven along the strike of the main mineralization, starting from the bottom of the opencast excavations. At Les Fouilloux, miners have followed the slope of the vein, in a stope 2 m wide, 10 m deep and almost 200 m long (Fig. 6). At Cros Gallet-Sud (Fig. 4), the work has remained subvertical, because of the rather slight inclination of the vein (Cauuet 1992, p. 12-17). In the southern part of Les Fouilloux, it has been possible to study these underground works in a section made by the modern opencast (Fig. 14). At about 20m depth, the host rock was much more harder than in the higher levels. This must have forced the ancient miners to abandon opencast mining to pursue only underground works. Besides, at this depth, the water table was reached. They then had to solve two problems, the timbering and the draining of their underground works.

4.2.1 Timbering

At Les Fouilloux props were of two types. First of all, miners have left rock pillars, about 1 m x 1 m every 6-8 m. One of these pillars has been sampled giving a high gold grade of about 90 grams per ton, which clearly indicates that this ore had been left in place only for safety purposes (Fig. 13).

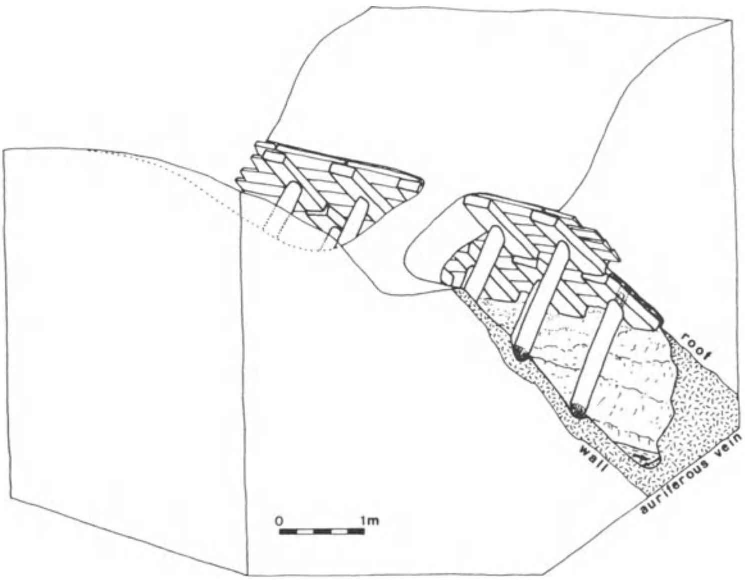

Fig. 13: A reconstruction of the system of supports at Les Fouilloux.

This system of supports must have proved insufficient as the depth of mining increased, when an additional type of propping was used. It consisted of the complete timbering of the underground works and there was the opportunity to study it at a depth of 10m. That part of the mine, being under the water table, was flooded after mining activity ceased, and had remained so ever since. Thus, to the great satisfaction of the excavators, the whole timbering was preserved *in situ*, and survived in a perfect state. Consequently it was possible to salvage more than two tons of mining props. This timbering used three types of wood: oak, beech and birch.

Fig. 14: Elevation of the celtic mining works at Les Fouilloux, seen in the face of the modern mine.

In these inclined underground works, the risk of subsidence came from the roof. So miners have put a very dense timbering, including mortise-and-tenon, thrusting perpendicularly to the inclination of the work (Figs. 13-15).The principal load-bearing strut, of birch or beech, had a sharpened toe bearing in a hole cut in the footwall. At the other end was a cap housed in voint cut in a squared oak beam. Thus forced against the roof of the working, it supported fitted oak boards which completely covered that vulnerable surface. The mortised beams themselves bore against cuts in the roof or the face to prevent any movement down-slope (Fig. 13).

A radiocarbon date has been obtained from one of these wood props: it gave a large age range, from 359 B.C to 77 B.C, with a date most probably situated in the 2nd century B.C, between 190 B.C and 120 B.C (Cauuet 1991, p. 165). A dendrochronological study is in progress; it will yield a more precise dating for this mining activity and allow to follow the rhythm of the mining, and to determine the date of its abandonment.

Fig. 15: Timbering preserved in situ in the underground works at Les Fouilloux.

4.2.2 Drainage

To be able to mine below the water table, Celtic miners had to find a solution to the flooding of their works. At Les Fouilloux, two galleries driven as cross-cuts have been discovered. One of them, gallery G6 (Fig. 6), was 13 m long, 2 m high and about 0.9 m wide. It had an opening outside the opencast, in a channel cut in the slope of the hill. The other gallery, called G8, was 35 m long, 2.20 m high and about 0.8 m wide. It also opened outside the mine, but at the bottom of an abandoned mining excavation (Figs. 6, 16). These two cross-cut galleries had been driven with a downwards slope towards the outside of the mine and thus they could supply drainage for the site. Celtic miners employed natural drainage to dry their works.

However, in that mine, with the increasing depth of the workings, these two galleries became obsolete. Then drainage was probably affected by lengthening the works towards the north-east extremity of the site, where the mine opened on the hillside (Fig. 6). Unfortunately the modern mine has prevented the investigation of that part of the ancient mine.

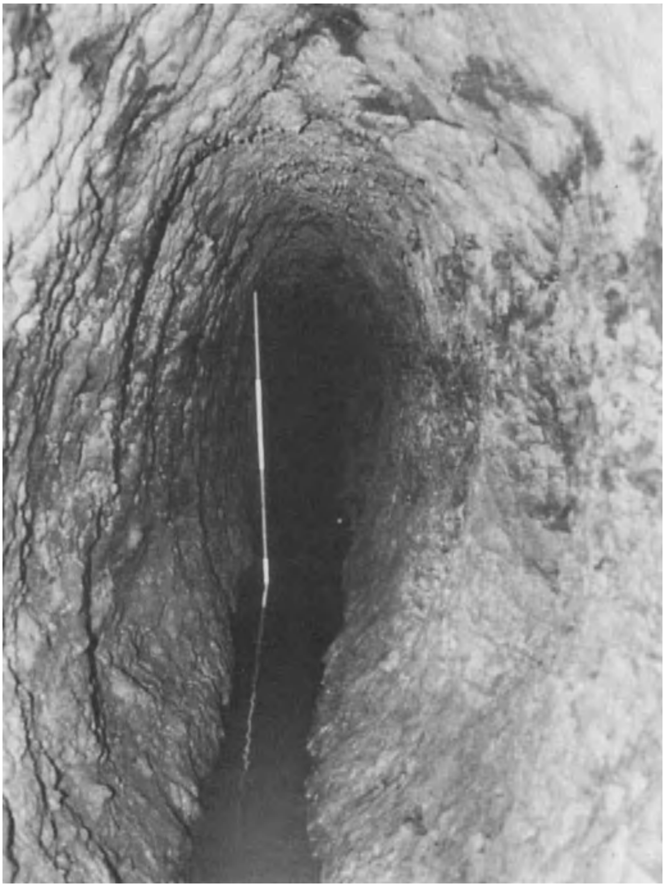

Fig. 16: Cross-cut gallery G8 driven to drain Les Fouilloux gold mine.

4.3 ORE TREATMENT

The excavations at the sites of Les Fouilloux and of Cros Gallet-Nord have uncovered areas for the treatment of the gold ore.

4.3.1 Crushing and grinding

Once extracted, the auriferous quartz was crushed and ground down to dust. Mortars, crushing-tables and grinders used for these operations, have been discovered in the dumps filling the excavations, dating to Middle La Tène at the site of Cros Gallet-Nord (Fig. 17). These stone tools were made out of local rocks, such as gneisses, micaschists, granite, and river pebbles. Deep and regular scores mark their surfaces and show that they were used to grind rock and not grain. At the Late La Tène site of Les Fouilloux, mortars, crushing-tables, grinders and rotatory millstones with deep scores on its surfaces were also found (Cauuet 1991, p. 179, Cauuet 1992, p.21).

Fig. 17: Mortars, crushing tables and grinders used to crush and grind gold-bearing ore at the site of Cros Gallet-Nord.

4.3.2 Ore roasting

At Les Fouilloux, ore treatment areas were installed all along the western edge of the long opencast pit (Fig. 6). They were covered by hearths with charcoal, ore fragments, some burnt, and broken millstones. It seems that miners in Late La Tène times used to roast the gold ore before crushing and grinding it. This operation would make it brittle and simplify its milling.

4.3.3 Washing area

After the ore was ground the gold-bearing fines were washed in water to concentrate and recover the gold particles. The Middle La Tène site of Cros Gallet-Nord has washing areas, but they have not yet been found at the Late La Tène site of Les Fouilloux. At Cros Gallet-Nord, these washing areas were situated immediately adjacent to the opencasts (Figs. 5, 18). They comprise small trenches cut into the slope in stony ground, and ending in a small pit. The miners would have fitted such trenches with wooden cleats, or even sheep-skins, to make which would catch the gold particles carried in the slurry. Because of its high density, gold tends to be carried in the lower part of the stream.

On this site, miners would have used a small quantity of water, stored nearby in a perishable container (perhaps a barrel?). For each operation, they mixed the gold sands with water and let the mixture flow down the trench. At the end the muddy mixture collected in the terminal basin could have been recovered and recycled many times to extract the majority of the gold. A gold-bearing concentrate is retained in the trench by the traps. It appears that the miners preferred to do this enrichment of the ore directly at the pit-head, rather than by the small stream running down from the mine. It shows a wish to control the gold production as close as possible to the place where the ore was extracted.

Fig. 18: Wet cleaning preparation plant where the ground ore was concentrated and gold separated from the quartz dust (Gros Gallet-Nord).

4.3.4 Ingot casting

The site of Cros Gallet-Nord, which corresponds to the oldest phase of mining that is known today in the Limousin, has also produced small crucibles, a complete one of 4 cm in diameter, and fragments of others, especially one of about 7 cm in diameter. They have been used in metallurgical operations connected with gold. A first analysis by neutron activation has revealed the presence of gold traces in the vitrified surface of the upper parts of the crucibles. Also a tiny gold sphere has been found, still visible to the naked eye, in the vitrified surface of a crucible fragment. These crucibles, found in the filling of the excavation F 1 (Figs. 5, 19), seem to have been used for making small ingots in situ.

At the end of the ore treatment operations, the miners essentially obtained gold dust. By fusing that gold dust in crucibles, they obtained small ingots. Analyses, currently in progress on this material, should give a more precise test of this hypothesis. On the more recent site of Les Fouilloux found a touchstone has been found left at one of the roasting hearths near the opencast mine (Figs. 6, 20). That stone, made of lydite, still bears thin gold particles on its smooth black surface. That attests its use as a touchstone, probably to test the grade of the gold cast into ingots. For the moment, there is not found any crucible at the Les Fouilloux site.

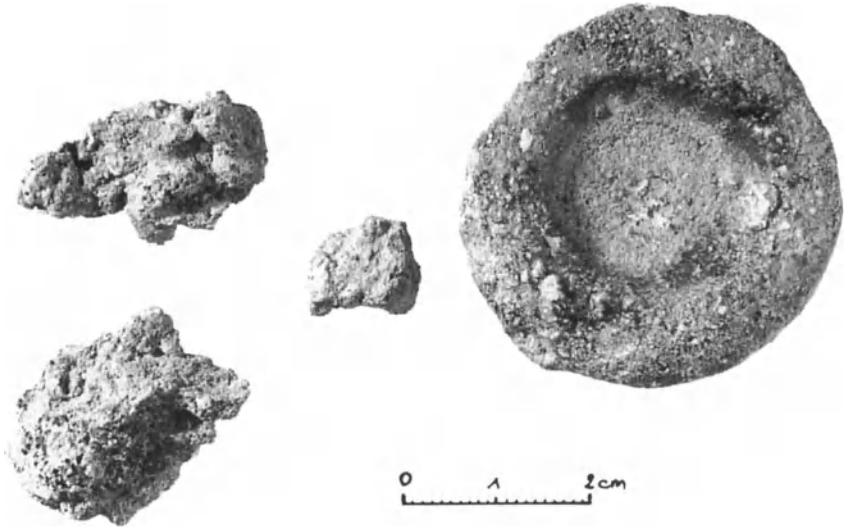

Fig. 19: Crucibles found in the fill of pit F1 at Cros gallet-Nord.

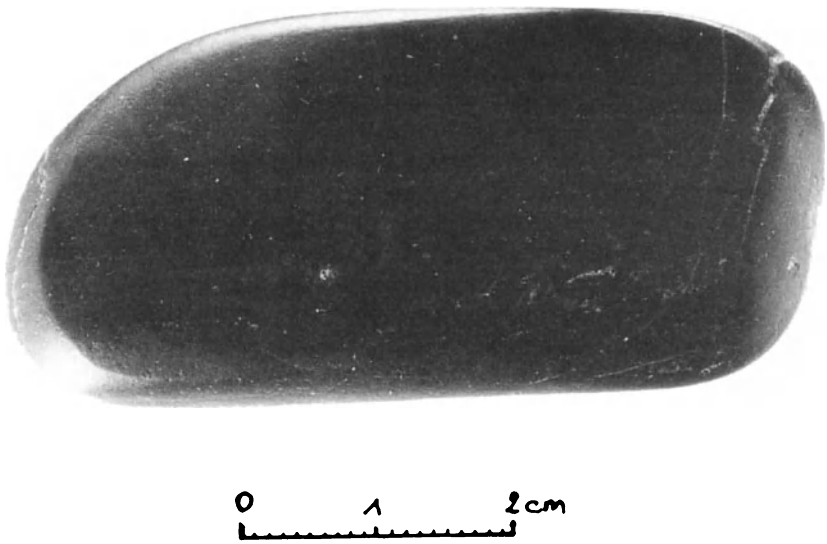

Fig. 20: Touchstone found in the ore-roasting area of Les Fouilloux.

5. Miner's dwellings

Mine dumps that accumulated in the opencast excavations of Cros Gallet-Nord have yielded an abundant assemblage of ceramics, dated to 4th to 3rd centuries B.C. This was associated with fragments of thatch, and charcoal from domestic hearths, including carbonized seeds and acorns. These remains indicated the existence of dwellings close by, while the opencast pits have been used as domestic dumps once extraction was abandoned. At Les Fouilloux, fewer ceramics were found, because they were dispersed in a larger mass of dumps.

5.1 ARTIFACTS DISCOVERED

Ceramics represent the great majority of the artifacts found.

5.1.1 Middle La Tène artifacts

The Middle La Tène ceramics from Cros Gallet-Nord are very varied. Here only some of the more representative ones are presented (Fig. 21), dated from the 4th and 3rd centuries B.C (Boudet 1987, p. 81-105). They include thrown, well finished vessels of good quality: opened forms with a smooth profile, marked shoulder and straight neck (Fig. 21, no. 1) or flared neck (Fig. 21, no. 3). Some other pots of good quality are small closed forms, with straight neck, decorated with hollowed impressions (Fig. 21, no. 6) or undecorated (Fig. 21, no. 2); there are also globular vases with a thin lip and flat bottom (Fig. 21, no. 4).

Coarse wares are mainly represented by globular forms, with everted rims and marked shoulders, and a wheel finished neck decorated at the base by hollowed impressions (Fig. 21, no. 5 and 11). The last group contains thrown, open forms, such as burnished bowls with a characteristic sharp internal profile to the lip (Fig. 21, no. 9 and 10), and small modelled cheese-bowls with perforated bottoms (Fig. 21, no. 7 and 8).

To the ceramics can be added some iron fibulae in poor condition, among which is an incomplete one with bilateral, double spiral springs and bent bow; also lignite or clay bracelets, bronze or clay beads, as well as spindle whorls and loom-weights.

5.1.2 Late La Tène artifacts

At Les Fouilloux ceramic forms are less diverse; they mainly comprise two forms. The first consists of many closed globular vases with slightly flared, wheel finished neck, decorated at the basewith hollowed impressions and with a decorated body (Fig. 22, no. 1-4 and 8). The second form groups together both thrown cups and modelled ones with a rounded internal profile to the lip (Fig. 22, no. 6 and 7). All these forms have flat bottoms (Fig. 22, no. 5 and 9). Associated with these later La Tène ceramic products (Boudet 1987, p. 109-110), fragments of undecorated lignite bracelets have been detected.

5.2 EARTHERN AND WOODEN CONSTRUCTIONS

While miners' villages are imagined to be situated away from the mining sites, the remains of earthern and wooden constructions built close to the pithead have been discovered.

5.2.1 Middle La Tène construction

The site of Cros Gallet-Nord has given an almost complete plan of an earth and timber construction (Fig. 5 and 23, no. 1). A series of post holes defines a thatched roof construction with a post frame. The outside wall was founded on a sleeper beam, recessed into the subsoil. A range of upright stakes, set into that beam, formed the frame of a wattle and daub wall. Ceramics found in this structure date it to Middle La Tène.

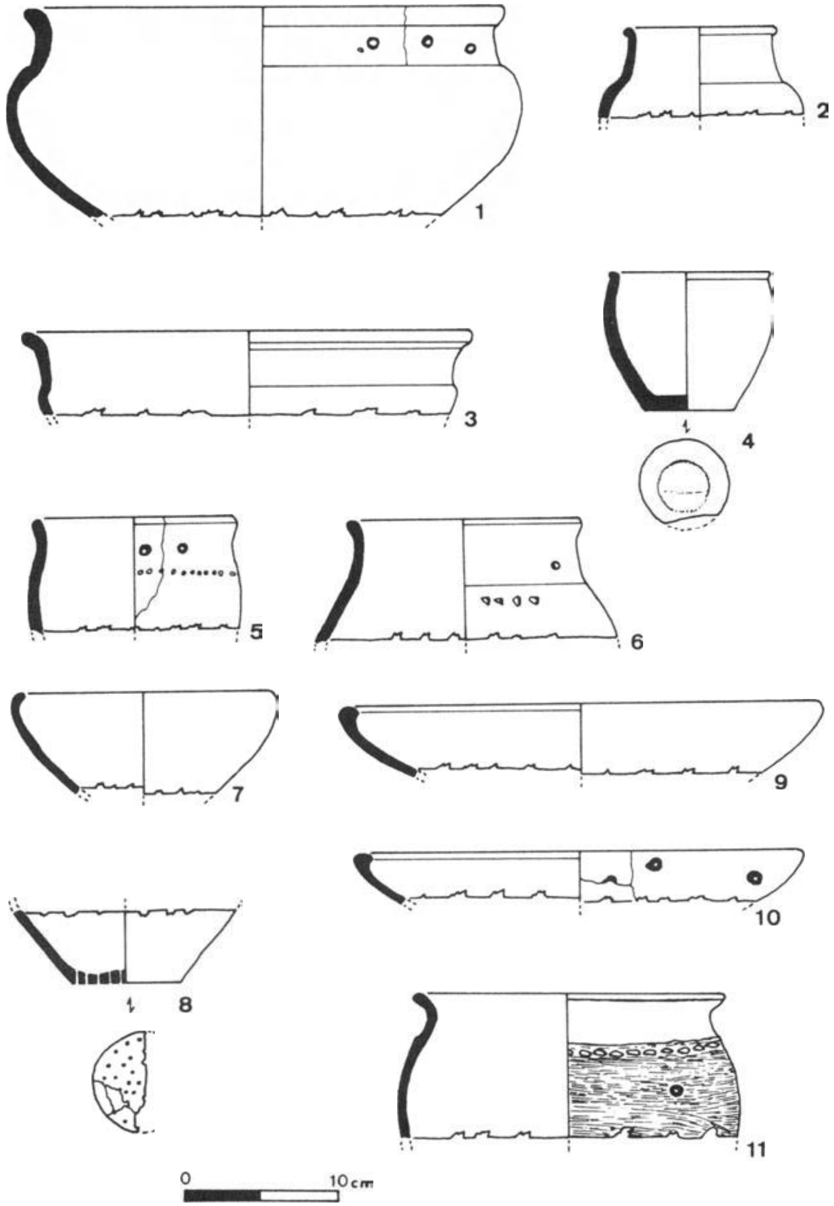

Fig. 21: Middle La Tène ceramics from Cros Gallet-Nord.

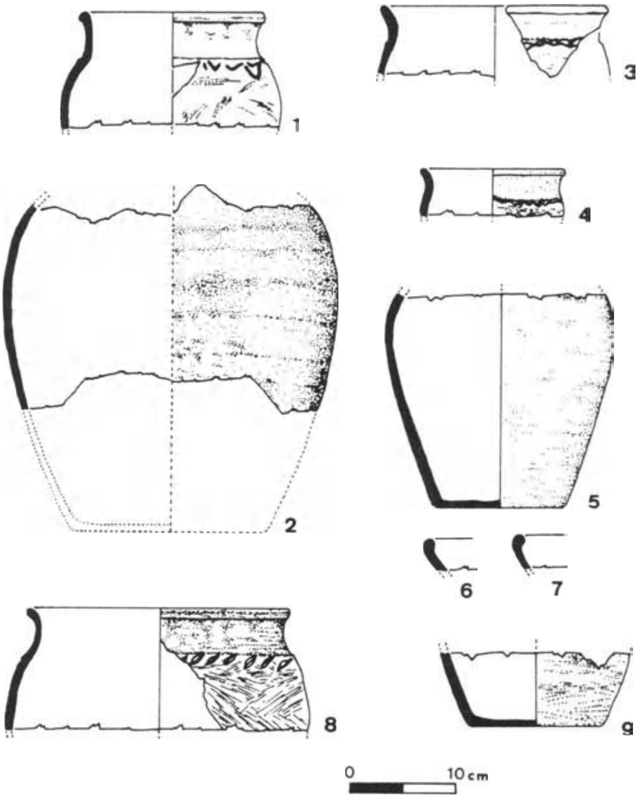

Fig. 22: Late La Tène ceramics from Les Fouilloux.

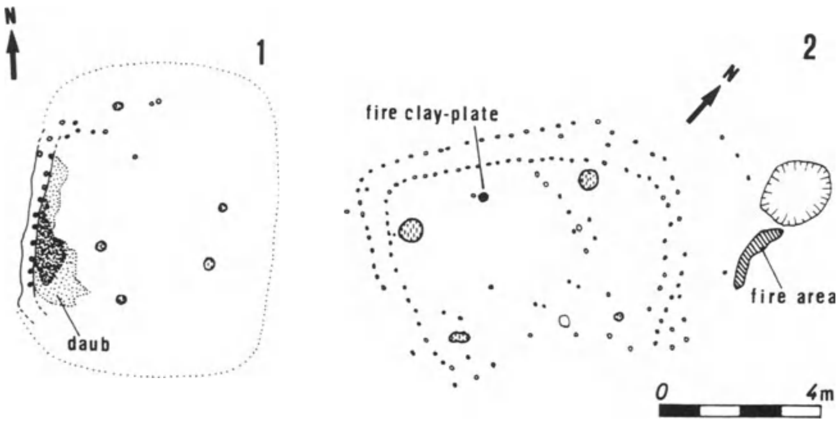

Fig. 23: 1 - Plan of Middle La Tène building from Cros Gallet-Nord;
2 - Plan of Late La Tène construction from Les Fouilloux.

5.2.2 Late La Tène construction

On the site of Les Fouilloux, remains of an earthern and wooden construction associated with ceramics from late La Tène were also found. The complete plan of the construction, which measured 6 m large and 8 m wide was built on the edge of the opencast mine in the north-western part of the site (Fig. 6). That construction differs a little bit from the one found in Cros Gallet-Nord. It was based on a post frame as well, since four post holes were found in the ground, but the outside wall, without sleeper beam, was framed by a double range of stakes driven into the soil (Fig. 23, no. 2). It also had a dividing wall. A fire clay-plate was found inside and a fire area outside, near a small rubbish pit. Further excavations are planned for this protected area where other similar structures seem to be present.

If two buildings are still not enough to enable to speak of a village, the abundant domestic artifacts, found in the mining excavations of Cros Gallet-Nord, indicate nevertheless a family life taking place by the side of the opencast mines during the whole period mining activity. Even if larger miners' villages should exist between the mining complexes, the dwellings discovered on our mining sites reveal a permanent occupation, closely related to the continuing mining activity on these sites.

6. Conclusion

Recent archaeological discoveries in the Limousin have given to the author the possibility of demonstrating different aspects of the developing mining activity of the second La Tène Iron Age. The excavated remains reveal the principal mining techniques known in antiquity and mastered by these Celtic miners. Already active in the 4th century B.C, gold production seems to have been pursued and regularly developed until the beginning of the 1st century B.C, when it stopped, some time before Roman conquest. The gold lodes were not exhausted, but technical constraints linked to the depth of the works, driven into waterlogged hard rocks, have probably led to this halt in mining activity.

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CHAPTER 4

Gold Metallurgy, Alloying and Chemical Analysis

Chapter 4

THE METALLURGY OF GOLD AND SILVER IN PREHISTORIC TIMES

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ABSTRACT. The paper discusses aspects of the beginning of the metallurgy of gold and silver and compares them with modern results on the behaviour of impurities in similiar processes. For gold, sintering and melting experiments are presented which point out that in the very beginning of handling gold it was most likely completely or partially sintered and never really melted. This is confirmed by the rough surface structure of early objects as well as by their content of minerals in the surface and in the core and by their rather low density. The same is true for silver.
The reaction of the most common alloying constituent of gold and silver, copper, with air during thermal treatment of alloys is discussed in connection with own experiments as well as with earlier published data. By leaching the copper oxide out from the surface a gold enriched zone is most likely for artifacts in Europe with more than 1% copper. On the other hand the copper oxides may be reduced by charcoal at a final step, forming a copper rich layer.

1. Introduction

The most famous textbook of metallurgy, "Georgius Agricola: De Re Metallica" begins in the translation of H.C. Hoover, himself a famous mining engineer and his wife (Hoover and Hoover 1950, p.1.), with a statement which is an excuse too: *"Many persons hold the opinion that the metal industries are fortuitous and that occupation is one of solid toil and altogether a kind of business requiring not so much skill as labour. But as for myself when I reflect carefully upon its special points one by one it appears to be far otherwise".*

It reads even better in the middle age German *"es seind vil leut der meinung / das sie den handel des bergwercks / für ein schlecht / unachtbar ding / auch für einflätig werck halten und nür ein sölchs geschefft / das mehr arbeit dan kunst bedörffe.*

Aber so ich alle seine teil / bey mir in sonderheit fleißig betrache / hat die sach vil eine andere gestalt."

Agricola understood by "metallurgia" mining as well as metal winning or smelting. Today it is different in the various languages. In English "Metallurgy" corresponds to a certain extent still to the old "Metallurgia" whilst in German "Metallurgie" is closer to "Hüttenkunde" than to "Metallkunde" and certainly different from "Bergwesen". This paper sticks closer to "Hüttenkunde" and mixes in only a little of "Metallkunde" or "Metal Science" - both being the author's area - the more since in this volume quite some contributions on "Lagerstättenkunde" and "Bergwesen" can be found.

Nonetheless the toil and labor involved to obtain the metal from its ores, once they are out of the mountain, is in many instances not much less than mining in the mountain itself. As will be seen one can only be impressed how much ingenuity was developed by our ancestors

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 243–259.

rather early in history, an ingenuity combined with a sharp sense of observation and deductions from them for practical use something which has been lost to quite an extent today.

The imagination and obsession of humanity with precious metals has been discussed by Eluère (1989) and others at various occasions.

Gold and silver - due to their chemical resistance and glamour - have been attributed to "sol", the sun, and to "luna", the moon, via their alchemistic signs. Still today these signs are the official hallmarks for gold and silver.

Nevertheless, even today an ambivalence - love and hate - with the precious metals exists. This can be shown by two remarks (Anon. 1973): In old German by Abraham a Santa Clara (1644 - 1709): *"Das Gold kann alles, wer güldene Flügel hat, der fliegt zum Höchsten. Wer einen guldenen Schlüssel hat sperret alles auf, auch die Hertze der Menschen. Wer mit güldenen Kugeln schiest, erobert auch die stärckeste Festung. ... Wer ein guldenen Praeceptor hat, der wird der Geehrteste."*

And in modern American by US Senator John J. Ingalls (speech at the occasion of coining of the silver dollar, Febr.15,1878): *"Gold is the money of monarchs; kings covet it, the exchanges of the nations are effected by it; it is the instrument of gamblers and speculators and the idol of the miser and the thief. ... It's the most cowardly and treacherous of all metals. ... It has no friend whom it does not sooner or later betray."*

Both remarks are still colorful enough compared to what one can read in a modern textbook of chemistry (translated from the German) (Cotton and Wikingson 1974): *"Silver and gold, as copper, have one single electron outside a filled d shell. Despite the similarity in electronic structure and ionisation potentials there are however only a few similarities between these elements. For many differences there is no simple and convincing explanation"*.

How difficult it will be to discuss the birth into technology of such controversial elements in few pages, the more so since there has been little change in the established processes for nearly 5000 years! Certainly totally new processes have come up, putting in one way or the other the old procedures into a corner of technology, but never totally abandoning them.

However, in those 5000 years many skills have been lost which could not be replaced by computers and lost in imagination - gold having only a filled 5 d shell!

2. Gold

2.1 GENERAL REMARKS

Gold, with a melting point of 1063°C, a boiling point of near 2600°C and a density of 19.3 g/cm^3 has - pure - a warm, brownish, deep yellowish color. It is very soft (hardness about 18 HB), and one of the most ductile metals. The rather high melting temperature made it difficult to melt in a charcoal fire without artificial draft. Native gold - silver alloys melt in a small melting range between 1050 and 1000°C (50 % Ag).

There is extensive literature on the mining and metallurgy of gold - from antiquity to modern times or from Plinius (70 B.C.) to Trueb (1992) (Fig. 1).

Fig. 1: Gold mining according to Agricola (1950)

Pimary deposits are in mountain ranges from where gold is transported by the forces of nature down the rivers. Here it accumulates in secondary deposits amongst the rocks of rivers, sometimes assisted by plants, in the form of alluvial gold dust. The famous gold resources of the Witwatersrand, Transvaal, South Africa are an alluvial deposit and the individual gold particles are found in the so called carbonaceous reef, together with quartz pebbles, in a quartzite rock (Rose and Newmann 1937, Coetzee 1976). The quartz pebbles are a characteristic sign of gold veins, e.g. for early prospectors, like Hans Merensky. Whilst mountain gold often consists of dendrites, flakes or needles with shiny surfaces, the alluvial gold grain, due to its transport, looks torn, compressed, built up of many thin layers. In a cross-section they sometimes resemble in a cut through a cabbage, the "gold" cabbage leaves being often only a few microns or less thick (Eluère and Mohen 1991) (Fig. 2).

This agglomeration or cold welding of the individual gold particles by the transport with water is due to the pressure exerted by water and stones in transport. Nearly all gold in nature is a gold - silver solid solution - the gold silver system exhibiting complete solubility in the solid state. Silver concentration can vary over a wide range, from practically nil to about 40 - 50 %, even within small flakes (due to their build up by cold welding even tinier flakes) as well as from nugget to nugget, many deposits having an average Ag-concentration near 10% (Adamson 1972). Copper is in general below 1 % - its content being of rather critical importance to archeology since it might point out artificial alloying (Eluère 1982). As other impurities of vein gold in textbooks of metallurgy (Tafel 1927, Pawlek 1983) iron, the PGE's (Platinum Group Elements) and quite frequently mercury and in rare cases tellurium and/or arsenic, antimony or bismuth are listed.

Tellurium is one of the most "dangerous" impurities, even today, since it embrittles gold at low concentrations and is difficult to detect by normal analytic methods, and similarily for selenium (Bugbee 1948, Pawlek 1983).

In alluvial deposits the agglomeration of gold particles by cold welding can lead to large lump-nuggets. One of the biggest ones was found in Australia. It weighed more than 230 kg!

Today, the profitable gold concentration for underground mining is in the range of 10 g/t, this value changing dramatically with a drop in the gold price and rising labor costs. Today's value of approx. 20 DM/g ($ 12) is close to profitability of underground mines and only the ones exploiting rich ores can persist. Gold in the earth's crust averages to about 0.004 ppm and in sea water to 8×10^{-6} ppm (Pawlek 1983).

Fig. 2: SEM-photo of a microsection through a gold grain from the decoration of the Big Dish, Varna.

The basic problem of metallurgy is to enrich the metal after getting the ore from the mine to such an extent, that its winning by whatever process becomes profitable. The enrichment of the metal can be done mechanically or chemically. The metal itself may be produced from the enriched ore by thermal or room temperature, chemical, or for more than 100 years electrochemical methods (Tafel 1927, Pawlek 1983, Adamson 1972, Rose and Newmann 1937).

In prehistory it must be assumed that gold-bearing rivers must have contained gold in very large amounts, since it had been transported - and accumulated - over geological times, as can be seen in the Witwatersrand deposits. The situation changed when men started to exploit it. When this happened for the first time is still open to discussion but it must be near 5000 B.C. Therefore it can be expected that these early metallurgists could grasp a real bonanza, mining fairly clean gold dust, produced by nature's gravity separation. The impurity, (mostly sand) concentration of the gold dust from the river increased the longer and the more the deposit was exploited. This however demanded more careful separation methods as well.

Out of this one must assume that in the beginning of gold production from river gold the gold resources were rather ample and the gold dust was rather free of sand and river bed minerals. This agrees with the earliest finds, e.g. from Varna (Eluère and Mohen 1991). At later times more and more impurities may show up, depending on the separation procedure.

Next one has to consider compaction of gold dust. Here one should keep in mind that the development of metals technology always required a highly developed clay technology - not only in managing the heat but handling the metal or metal dusts, too. For example, the manufacturing of a vessel from gold sheet only needs higher forces or pressures - exerted, e.g. by hammering - as compared to making a clay vessel, where the pressure of a human's hands is big enough to compact clay pieces. Later the shaping of a clay pot on a potter's wheel and the spinning of a metal vessel on a lathe are based on identical principles, only different forces are needed. The development of metals technology from handling clay may well explain - at least in part - why it took so long to invent wire drawing via a draw plate as compared to "block twisting".

For compacting from powder the two metals in discussion - as iron does too - do not need melting or the transition from a solid state to a liquid state followed by cooling and/or casting. They can be compacted into large lumps by application of pressure and/or temperature (hammering) (Fig. 3). This process, called "sintering", is one of the most intensively researched today's metal production since it permits mass production of complicated shaped parts without large losses of material, as is the case for gears, for example. Furthermore by this method oxides can be added to the metal and nicely distributed in the metallic matrix e.g. in order to produce heat resistant materials (Rapson and Groenwald 1978). This cannot be done if the metal is melted in one way or the other.

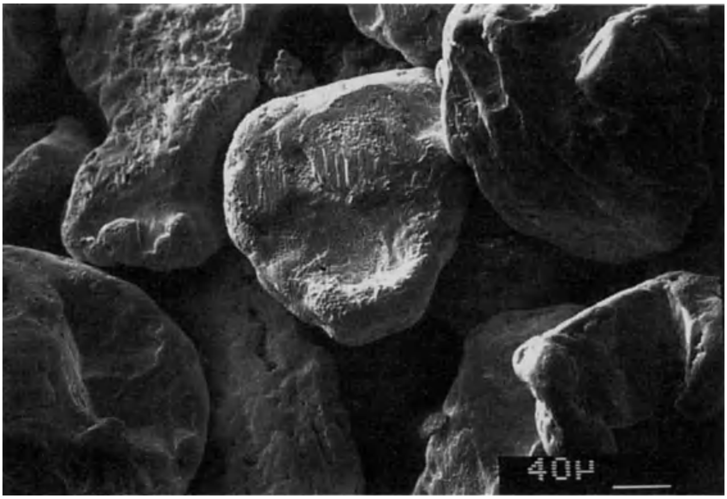

Fig. 3: SEM-photo of sintered alluvial gold power (uncleaned) from near Lugano. Sintering conditions: 10 h. 300°C, air, not compacted.

Sintering is dependent on the cold or warm welding of the individual metal particles by diffusion (self - or surface diffusion). For this good metallic contact between particles is necessary. Higher temperatures, through increasing diffusion rates and softening the material, speed up the sticking or welding together of particles and a material is produced which has never gone through a liquid state.

Gold and platinum, due to the fact that they practically have no oxide skin at room temperature, are the easiest to cold weld or sinter. As has been shown, this may already happen during transport in the water, where cold welding of the particles is facilitated by the increase in gold at the surface due to depletion of silver from the particles by the action of oxygen containing water. Today cold welding or bonding of gold to gold (with assistance of ultrasonics at up to 300 °C) is used as a decisive step in bondings in microelectronic productions, in dentistry for the filling of cavities with hammered gold foil, or simply in the usual hammer welding in artistic or technical gold and platinum manufacturing (Rapson and Groenwald 1978).

Due to surface oxide layers - which must be mechanically removed before cold welding between particles can happen - sintering of other metals, e.g. iron, aluminium, titanium, can be achieved today only at much higher pressures and/or temperatures or in inert atmosphere.

One of the most critical points in sintered pieces is their so-called "rest porosity". This is the explanation of the often lower density of sintered as compared to cast parts and their rather low surface quality too, which makes the method still unsuitable for jewellery production with its high surface quality requirements (Rapson and Groenwald 1978).

The rather poor surface quality with defects like overlappings, holes etc. and inclusions of sand, quartz or other minerals from the river bed (Fig. 4) leads to the assumption that the earliest archeological gold objects, e.g. of Varna, were either totally or partially sintered. In confirmation, in microsections of samples of such earlier objects these inclusions have been found too, generating a distorted small-grained structure, characteristic for sintering from impure powder (Eluère and Raub 1991) (Fig. 5).

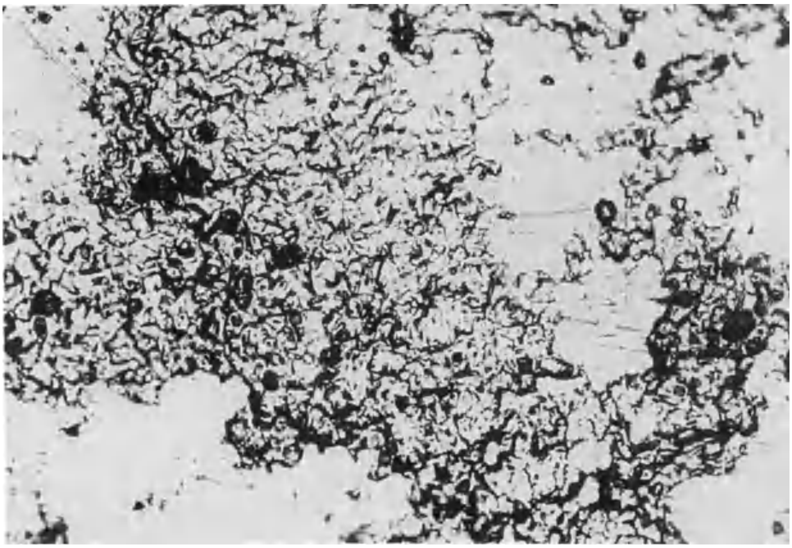

Fig. 4: Optical-microphotography of surface structure of a gold leaf prepared from alluvial gold by sintering, cold deformation (hammering + rolling) and annealing; Magnification 100x.

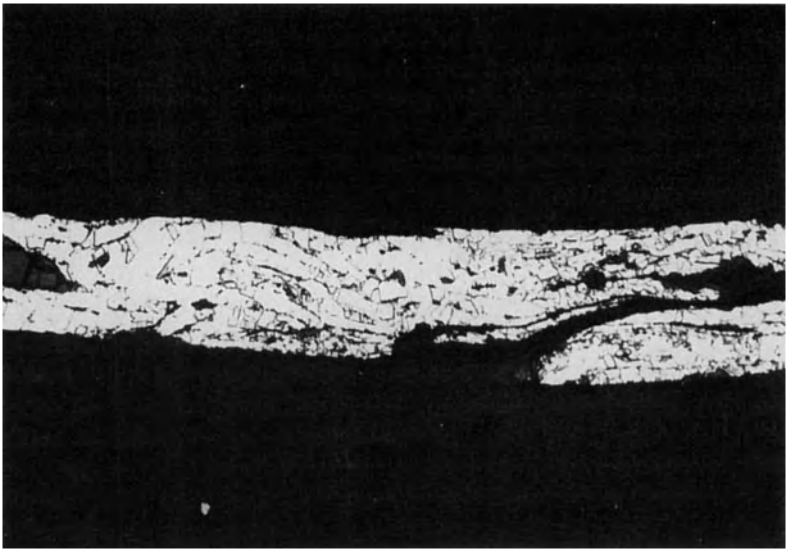

Fig. 5: Microstructure of a gold leaf (s. Fig. 4); Magnification 220x.

The density, lower than the one for a corresponding modern gold-silver alloy, supports the observation. Compacting by sintering is naturally followed up by hammering or further mechanical densification. The application of heat to the material facilitates sintering, without truly melting it. There are however certain transitions between true sintering and true melting, especially if a powdery substance is heated from outside with a torch. If heating is done with a torch from above, due to its rather low heat conductivity the powder heap may already begin to melt on its surface or outside whilst the inside becomes sintered. Such a partial melting and sintering may be the explanation of cracks in Celtic coins coming from incompletely melted blanks prepared from alluvial gold dust. In Egyptian wall paintings often heaps of gold dust are being offered to kings as gifts. In another drawing one even sees how little "flying stars" evolve during heating such a heap with a blow pipe, which is very characteristic (Fig. 6).

In experimental tests with panned alluvial gold dust and modern gold powder it was shown that gold dust will sinter after 12 hours at 300 °C in air without applying pressure. The sintering is much faster if done at higher temperatures and if the alluvial dust is freed from soil constituents by treating it with hydrochloric, or even better, with hydrofluoric acid. If care is taken, the dust sintered at 300 °C can be hammered into about a 50 micron thick sheet. This however tends to crack and tear during hammering. If sintering is achieved near 900 °C and the impurity content of the dust is rather low the sintered material can be manufactured into a foil practically without any loss. Even an alluvial dust with nearly 30 % nonmetallic inorganic contents, mostly sand containing iron, could be shaped into a foil: however it showed heavy edge cracking (Eluère and Raub 1991) (Fig. 7).

Fig. 6: Wall painting from the tomb of Rek-Mi-Re, Theben (Egypt) from 1475 B.C. showing more likely heat treatment (sintering) of gold powder then soldering (s. heap of gold in front of leg).

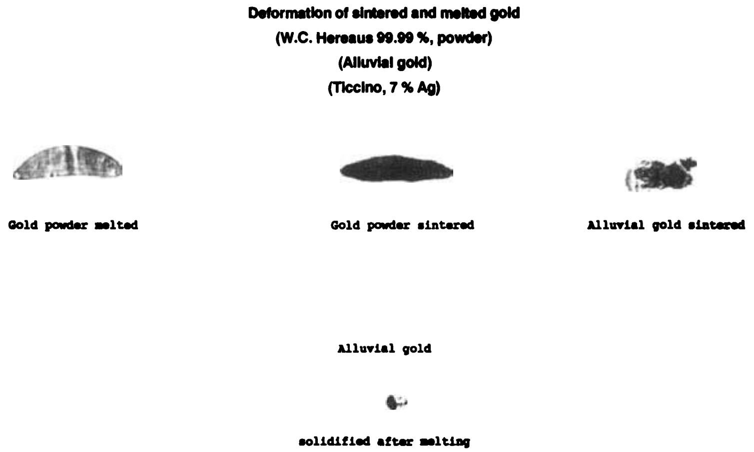

Fig. 7: Optical microphotography of edge cracking of gold foil produced from powder by various methods; Magnification 1:0.8.

Surface morphology and crack patterns of such artifical samples prepared from alluvial gold are identical to the surface of the earliest archeological objects with their rough snake-skin or tree bark like structure. The same is true for surface impurities: Early objects are fairly rich in sand and other river bed minerals, sometimes even cassiterite (Eluère 1982).

2.2 THE BEHAVIOUR OF IMPURITIES DURING SINTERING AND MELTING OF GOLD

In technical processing of gold the behaviour of impurities is especially important (Rapson and Groenwald 1978, Raub 1940), since it is well known from today's metallurgy that their concentration may change due to evaporation as a metal or compound or due to fluxing (Berzelius/Wöhler 1836, Tafel 1927, Pawlek 1983).

To test this some experiments with alluvial and modern gold powder were done: Fine gold powder (99.9 %) (Fig. 8) was mixed with 1 wt. % of cassiterite concentrate from the Altenberg/Erzgebirge and the mixture was sintered in air under various conditions, which proved to be no problem. The sintered mixture then was deformed 50 % by hammering, annealed 1 hour at 900°C in air, cold rolled by again 80 %, annealed again and cold rolled to a 60 micron thick foil.

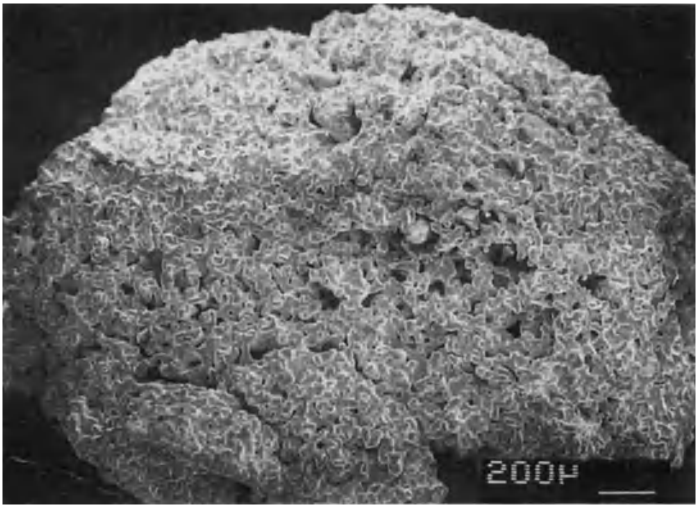

Fig. 8: Fine gold powder (DEGUSSA) sintered with 1 wt. % of casserite concentrate (Altenberg) (after sintering). Magnification 50x.

The surface of the foil exhibited the usual defect structure of sintered gold with impurities and in spectral analysis all elements of the starting mixture of gold and cassiterite showed up (Tab. 1). In the sintered piece a cassiterite crystal, similiar to cassiterite crystals in natural alluvial gold was found (Fig. 9). The microsection of this sintered, cold worked and annealed piece had the typical structure of sintered gold with many inclusions giving proof of the incorporation of cassiterite and its accompanying minerals into gold during sintering. It should be mentioned, however, that if this gold-cassiterite mixture leaf was remelted 4 times in air in a quartz tube (each time solidifying) and analysed again, the cassiterite impurities had disappeared completely. They apparently were fluxed out of the gold matrix during melting and remelting of the leaf. Similiar results were observed with river gold. If, however, modern gold powder is sintered, deformed and annealed it is much easier to work into leaf gold and practically no edge cracking is seen. Depending on the sintering conditions it can be deformed nearly 95 % before it has to be annealed for further deformation.

Table 1. Spectral-analysis of alluvial gold from Ticino, sintered with 1 wt. % cassiterite, before and after melting.

	Sample 1 after sintering + deformation	Sample 2 after sintering	Sample 3 melted in air 3 times	addition free Cassiterite (Altenberg)	addition free Gold (Ticino)
H:	Au	Au	Au	Sn,Fe	Au
StSp:	Ca,Sn,Si,Mg	Ca,Sn,Si,Mg		Cu,Al,Ca,Si	Ca
Sp:	Mn,Al,Ag,Cu,Fe	Cr,Cu,Mn,Al Ag,Ti,Fe	Ca,Ag,Cu	Mn,W	Ag,Cu
gSp:	W,Ti,As	W,As		Cr,Ti,Ag Pb,Mg,Nb	
sgSp:			Sn,Si,Mg		Si,Mg

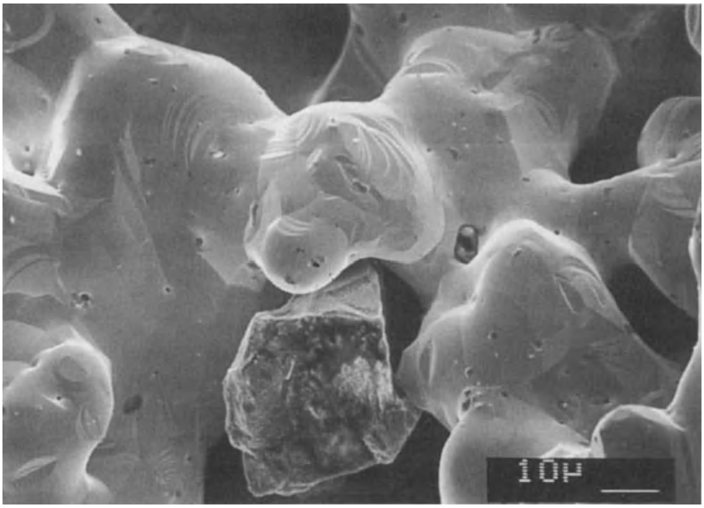

Fig. 9: SEM-photo of sintered fine gold + 1 wt. % casserite with casserite crystal inclusion.

Thus experiments show that sintered gold keeps more or less all its impurities, typically the river sand minerals. Once this river gold is melted as a sintered piece in air several times it purifies itself from all oxidic impurities and oxide-forming impurities in washing these out by slagging. Similiar results were observed earlier (Eluère and Raub 1991). If the experiment is done under reducing conditions in the presence of charcoal, part of the impurities is kept, since these are reduced and form metallic solid solutions or intermetallics with gold. In a later step they may however be transformed into oxides - by heating in air - and be slagged out again.

It is rather difficult to predict how impurities behaved during sintering and melting in prehistoric times, e.g. by heating with a torch or on a charcoal bed, since in this case oxidising and reducing conditions may change rapidly over short distances and times. The "thermal removal" of the impurities furthermore depends on the ratio of the size of the surface reacting with the sorrounding as compared to the mass of the gold, a huge surface area facilitating reduction of impurities. The above experiments however prove that one can not assume constancy of impurities during heat treatment of gold and gold alloys. It is especially critical if copper minerals are present in the gold dust. Under reducing conditions they may be preferentially and easily reduced forming gold-silver-copper alloys, pretending artificial alloying by melting.

It should be pointed out in this context that this fluxing of impurities and oxides is one step in the refining of gold and silver by cupellation and fire assaying, too, processes in use for thousands of years. The principles are still applied today to purify and recycle precious metals.

2.3 THE SEPARATION OF GOLD AND SILVER

One of the prerequisites to make intentional alloys is to have clean and consistently homogeneous starting components. In the case of gold this requires breaking up of the naturally occurring gold-silver alloys into pure gold and silver (and/or copper). Later the components can be analyzed, e.g. by the touchstone (Eluère 1986) or by assaying (Cramer and Gellert 1746, Bugbee 1948, Proska and Ensslin 1964), and components in appropriate amounts may be weighed out for alloying. In this way refining of gold and its alloys and the intentional alloying are intimately connected and it was tried to find out from an increase in the copper content of prehistoric gold at what time refining and alloying began in prehistoric Europe (Eluère 1982, 1989).

On refining and purification of gold and silver there exists quite a literature from antiquity on to modern days, from *Agatharchides (200 b.c.), via Plinius, Mappae Clavicula, Roger von Helmarshausen, Georgius Agricola, Johann Andreas Crämer's/C.E. Gellert's "Anfangsgründe der Probierkunst", J.J. Berzelius'/F. Wöhler's oldest textbook on inorganic chemistry to T.K.Rose's and W.A.C. Newman's book "The Metallurgy of Gold", R.J. Adamson's "Survey on Gold Metallurgy in South Africa", H.Moesta's delightful booklet on "Erze und Metalle - ihre Kulturgeschichte im Experiment" to textbooks of metallurgy, like V. Tafel's "Lehrbuch der Metallhüttenkunde" and F.Pawlek's "Metallhüttenkunde" or more recent articles in Gold Bulletin.*

The basic principle in antiquity was always the same: Alloys to be refined were made into particles of large surface areas (by using dust or cut up sheet), since solid state reactions proceed via the surface. The alloys then were reacted with sulfur or chloride, or substances containing such elements, at higher temperatures. Silver forms a sulfide and a chloride; gold under these circumstances reacts rather little. Silver chloride or sulfide are separated from the gold by various methods and later reduced again to silver. The chloride method was reproduced successfully and described by Notton (1974). Modern methods by, e.g. chlorination or electrolytic refining are not discussed here (Rose and Newmann 1937, Adamson 1972).

J.A.Cramer's "Anfangsgründe der Probierkunst" (Beginnings of the Asasaying Art) of 1746 mentions the following processes for separating and refining gold and silver (citations in old German) (Cramer/Gellert 1746):

"XXVI Proceß: Das Gold vom Silber durch das Aqua regia ganz rein zu scheiden"
"XXVII Proceß: Das Gold vom Silber durch das Scheidewasser zu scheiden"
"XXVIII, XXIX and XXX Proceß: (To reclaim remaining silver from the earlier processes)
"XXXI Proceß: Das Gold durch das Cementiren fein zu machen (using rocksalt)"
"XXXII Proceß: Das Gold durch das Spießglanz von den anderen Metallen zu scheiden und zu reinigen (das Gold durch den Spießglanz zu gieben)"; (Spießglanz = antimony-sulfide)
"XXXIII and XXXIV" (Improvements of XXXII)
"XXXV Das Platzgold von den Salzen zu scheiden" (use of sulfur and sulfuric acid)
"XXXVI Silber und Gold aus der Krätze zu scheiden" (mechanical separation).

J.J.Berzelius in 1836 discusses the interesting aspect that gold and silver might be combined in nature following certain atomic ratios, but could not confirm this analytically. He already mentions: "*Der gewöhnliche Silbergehalt des aus goldführendem Sande ausgewaschenen Goldes beträgt ungefähr 8 bis 10 Prozent, ohne jedoch in verschiedenen Körnern an ein und derselben Stelle gleich zu sein*".

Berzelius (1836) states that before being refined, gold must be tested with a touchstone in order to add the proper amount of silver for assaying (3 times as much Ag as Au, called *"Quartierung"* or parting). The parting process for separation of silver from gold however yields only gold with "höchstens 23 Karat and 1o Grain" purity.

As other methods for purification and parting Berzelius (1836) lists:

2) *"Cementierung"* (with powder from fired bricks, vitriol and rocksalt)
3) *"Schmelzung mit Schwefelantimon"*
4) *"Schmelzen mit Bleioxyd und Schwefel"* wodurch man bleihaltiges Gold erhält, welches cupeliert wird".

and an interesting method:
5) *"Man cementiert in dünne Blättern ausgewalztes Gold mit Manganperoxid bei der Schmelzhitze des Goldes, worauf die Masse mit dem dreifachen Volumen pulverisierten Glases umgeschmolzen wird"* (Oxidation and fluxing of impurities).

Final quality testing of gold is done by fire assaying, by heating it in a flame (more than 1 % Cu causes a black coloration by copper oxides) and by density measurements. Silver alters the colour of gold and at about 20 % generates a whitish color with a green tint; at higher concentrations it loses this tint and becomes whitish. Copper turns gold alloys reddish (Raub 1940).

Copper oxides formed by heat treating an alloy with more than 1% copper in air (Raub 1940, Raub 1993) can be easily removed by leaching (Fig. 10). In antiquity solutions of acetic, oxalic or oxycarbonic acids occurring in nature (tartaric or citric acid), and rocksalt may have been used for this. Today hot diluted sulfuric acid or acidic salt mixtures ("dry acids") are applied for such depletion gilding ("Gelbsieden"). The process was similarily applied by the Indians in South America to gild (mis en couleur) their "Tumbaga" alloys. It is rarely discussed for European archaeological objects even though it is described in the oldest text-books on goldsmithing, e.g. Mappae Clavicula. It must be assumed that all gold alloy artifacts having more than 1% copper which have been heat treated in air, e.g. by melting, soldering, annealing, etc., and which today show a golden appearance, have been treated in such a way. This refers, for example, to coins produced by melting and casting as well as to soldered and granulated objects. In investigating such alloy artifacts this effect of an intentionally or by nature during storage produced copper depleted layer must be taken care of.

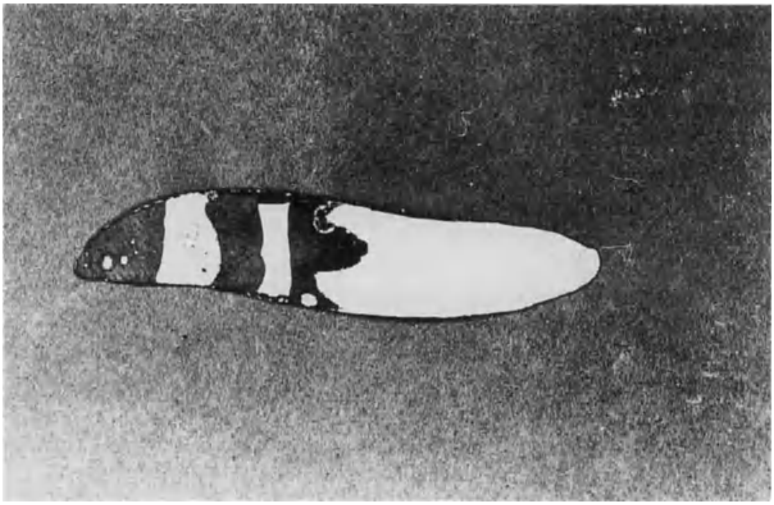

Fig. 10: Optical photograph of a tarnishing layer formed on a Au-Ag-Cu alloy (5.0 Cu wt%) partially leached in hot tartaric add (100g/l) + NaCl (20g/l); Magnification 1.8 x.

3. SILVER

3.1 GENERAL REMARKS

Silver, with a melting point of 960.5°C, and a boiling point of 1950°C has a density of 10.5 and a Brinell hardness near 25 HB. It is much more sensitive to chemical reactions than gold, e.g. dissolves oxygen especially in the liquid state, less in its solid form, forms a metastable oxide (decomposing at 180°C) and at normal temperatures a stable chloride and sulfide. It reacts with nitric acid (Scheidewasser). The most important ore is galena (Bleiglanz) containing between 0.03 to 1.0 % of Ag (Tafel 1927, Pawlek 1983). Copper ores nearly always have some silver and gold. The famous chalcopyrite in the Mansfeld Kupferschiefer shows 0.01 to 0.05 % Ag (Tafel 1927). Silver exists in the oxidation zone of ore bodies in the form of native silver (Haarsilber, gediegenes Silber). As the fable tells the rich silver ores of Freiberg in Saxonia were discovered in the 13th century by a find of native silver on a road. In the same area huge discoveries of native silver occurred: From Schneeberg one of nearly 20 tons is reported. From the beginning of the 19th century a medal from Freiberg is known, commemorating a discovery of 13 "centner" of native silver in one spot!

The concentration of silver in the earth's crust is 0.07 and in sea water 3 x 10^{-3} ppm (Pawlek 1983).

Until today silver has been produced mostly by variations of the classical cupellation process (Pawlek 1983), which quite similiarily, on an analytical scale, is used as "fire assaying" to determine the fineness of precious metal alloys. In this method first the metals are collected by melting the ore with lead on a scorifier, partially slagging the oxidic impurities and then oxidising the lead bullion and separating the liquid lead oxide - containing most of the oxidised impurities as plumbates - from the metallic silver on a cupel, which absorbs the lead oxide.

If sulfidic lead ore is used it is first roasted to remove the sulfur and later reduced by charcoal or coke in order to obtain lead. From the Mansfeld Kupferschiefer it was won by the tedious "Seigerarbeit" in which silver is distributed between copper and lead, preferentially joining the lead. From this it is finally extracted again by cupellation. Later processes for concentrating silver from its ores are amalgamation, cyanidation, the Parkes desilvering with zinc (suggested 1842 by Karsten, in 1850 industrially introduced by Parkes) and the Pattinson process of 1835, based on selctive crystallization and separation of lead and silver-rich crystals in cooling down a silver-rich melt. Today electrolytic refining of silver is the standard method for purification (Tafel 1927, Pawlek 1983).

3.2 BEHAVIOUR OF IMPURITIES DURING EXTRACTION AND MELTING

Silver obtained by cupellation nearly always contains traces of copper, gold, lead, zinc, nickel, antimony, tellurium, arsenic and bismuth. The latter oxidises less readily than lead and therefore remains with the silver till the last litharge is gone or absorbed by the test or cupel. It dissolves in the litharge (Bleiglätte) only near the end of the process and therefore its concentration in the silver (or the lead) depends on the process conditions, e.g. on the bismuth concentration of the hearth walls as well as on the oxygen partial pressure. On a cupel it produces an orange yellow ring around the silver bead (PbO is brown yellow). It is the only metal behaving like lead in cupellation. Badly cupelled silver may contain up to 0.16 % lead and the same amount of bismuth. This is the reason too why the bismuth concentration of antique silver may only be used as a rough kind of tracing value, since it decreases the more carefully and the more often silver is remelted. After introduction of the Parkes process bismuth values changed but nevertheless presented a problem, as in the Pattinson process, too. Today bismuth is precipitated by additions of alkali and alkaline earth metals (Na, Ca), forming intermetallics insoluble in the melt (Tafel 1927, Bugbee 1948, Proska and Ensslin 1964, Pawlek 1983).

Tellurium in silver too is rather dangerous, due to its embrittling of silver and it is very difficult to remove by cupellation. Later it was washed out by excessive additions of lead or by treatment with sodium carbonate or nitrate (oxidising alkaline flux). In this way about 60 % were fluxed with the PbO, 37 to 38 % were evaporated and 2-3 % still remained with the metal (Tafel 1927, Bugbee 1948, Proska and Ensslin 1964, Pawlek 1983).

As can be realized from above remarks, the amount of impurities in silver (and gold) strongly depends on the cupellation process and how often and under what conditions it was made. With the same ore supply different results may be obtained if cupellation conditions change.

The alloy mostly used in antiquity is based on the silver-copper system (Hansen and Anderko 1958). It shows partial solid solubility of silver in copper (max. 8 wt.%) and of copper in silver (max. 7 wt.%) and a low melting eutectic with 30 % Cu and a melting point of 779°C. This eutectic is used as a brazing solder from antiquity to modern times. The copper concentration of antique alloys varies a lot. For table ware it is mostly in the solid solution range below 10 %; for jewellery it may reach more than 30 %. Copper dilutes the silver, making it cheaper, but it as well hardens and strengthens it. In later times instead of copper zinc- and tin- containing brass as well as tin-bronze were used as alloying additions.

Silver-copper alloys tarnish even more then corresponding gold alloys do by heating in air (Raub 1940). This till today present problems and attempts are made to eliminate by additions of oxide formers, e.g. silicon, aluminium or phophorus (Rapson and Groenwald 1978).

Melting therefore had and has to be done under a charcoal cover, which was handled very well in antiquity. The best silver copper alloys up to today are produced in a coke furnace, due to its superbly reducing atmosphere.

During annealing in air the formation of copper oxides at the surface and their removal by pickling (surface enrichment or "Weißsieden") or reduction to copper in charcoal may be the cause for weird metallurgical effects, seen in archaeological samples: Enrichment or depletion of copper on the surface, oxidic commas, silver-rich cores or blistering of surface layers (Raub 1990).

This short note wants to point out that the antique metallurgical colleagues possessed a tremendous wealth of knowledge, obtained by experience. They had at least similiar amounts of knowledge as we in the meantime learned from science. But one should never forget what the Hoovers wrote in their "De Re Metallica": *"Science is the base upon which is reared civilization of today, and while we give daily credit to all those who toil in the superstructure, let none forget those men who laid its firm foundation stones"* (Hoover and Hoover 1950, p. XIV).

Acknowledgement

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Chapter 4

INDUSTRY IN CELTIC OPPIDA - ASPECTS OF HIGH TEMPERATURE PROCESSES

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ABSTRACT. The late Iron Age (3rd to 1st century B.C.) is characterised by a high industrial standard. The ability to invent new products or techniques largely depended on the transfer of techniques already in use to new areas of production. The close contact between different craftsmen encouraged the fast exchange of experiences and promoted the invention of new techniques. This development was favoured by the settlement structure of the oppida (Celtic towns). The organisation of the oppidum enabled the specialized craftsman to earn his living without doing additional farming. The scale of industrial production in Celtic oppida is very unusual. Major changes can be observed mainly in metal working, but also in other industries such as woodworking or pottery production.

1. The oppida civilisation

The 2nd and 1st century B.C. is characterised by a large network of settlements in Central Europe (Collis 1984). They were widely distributed in an area bounded by the Pyrenees, the Mediterranean

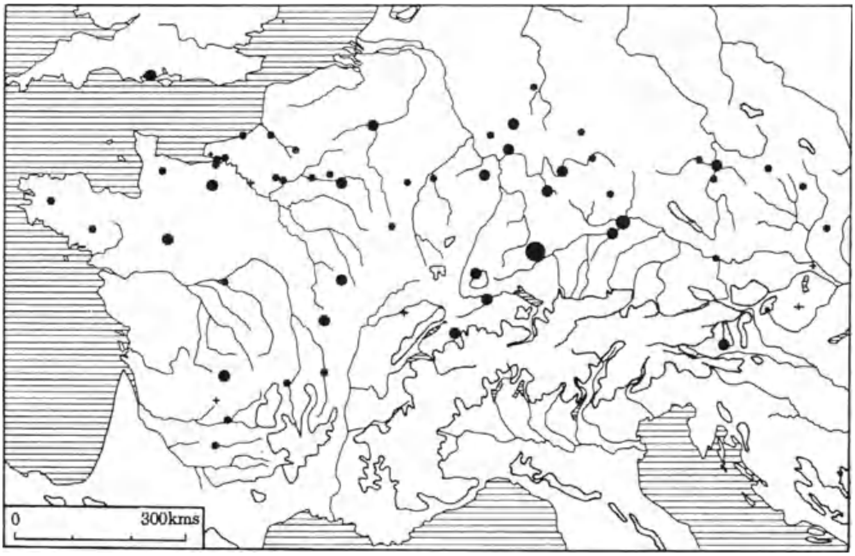


Fig. 1: Distribution of the oppida civilisation: Fortified sites over 30 hectares (after Collis 1984).

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 261–272.

Time B.C.	Period	Settlement patterns	Crafts
1000	Hallstatt B	Late Bronze age hillforts	*Extended wood- and bronze metal working*
750	Hallstatt C		*First iron working*
600	Hallstatt D	Local power concentrations "Fürstensitze"	*Gold and metal working. Wheel turned pottery (local)*
480	Latène A		
420	Latène B1	Celtic migrations	
	Latène B2		*Extended production of wheel turned pottery*
260	Latène C	New settlement structures	
200-120		Beginning of the oppida	*Fast development of industry: iron, glass, gold*
120	Latène D		
80-15		Decay of the Celtic world	

Fig. 2: Development of crafts in central Europe during the first millennium B.C.

zone of Gaul, the Alps, the Hungarian Plain and by the southern rim of the North European Plain (Fig. 1).

These sites were named "oppida" by the Roman historians. Oppidum means a town, especially in the sense used by Gaius Julius Caesar for defensive sites (52/51 B.C). An oppidum is characterised as a regional urban centre with a town wall, a minimum size of about 25-30 hectares and a structured settlement area. The structures within the town area are a result of social developments. We find enclosures which are attributed to landowners, farmers, houses of artisans or traders along the street, as well as public buildings. Various factors were responsible for the functioning of the oppida system: local concentrations of political power, a specialization of the craft and a well developed trading system. Characteristic features of the system are local trade, trade between the oppida and external trade with the Mediterranean areas. Foreign trade created a merchant class, industrial overproduction and an accumulation of wealth by the social elite. As late Celtic trade used a monetary system, the production of precious metal for minting played a central part in the oppida civilisation.

The development of the crafts during the 1st millennium B.C. was correlated to social developments (Fig. 2). There was a first industrial boom when local centres were established in the Late Hallstatt era (Hallstatt D). The hillforts of the elite were characterised by a high standard of

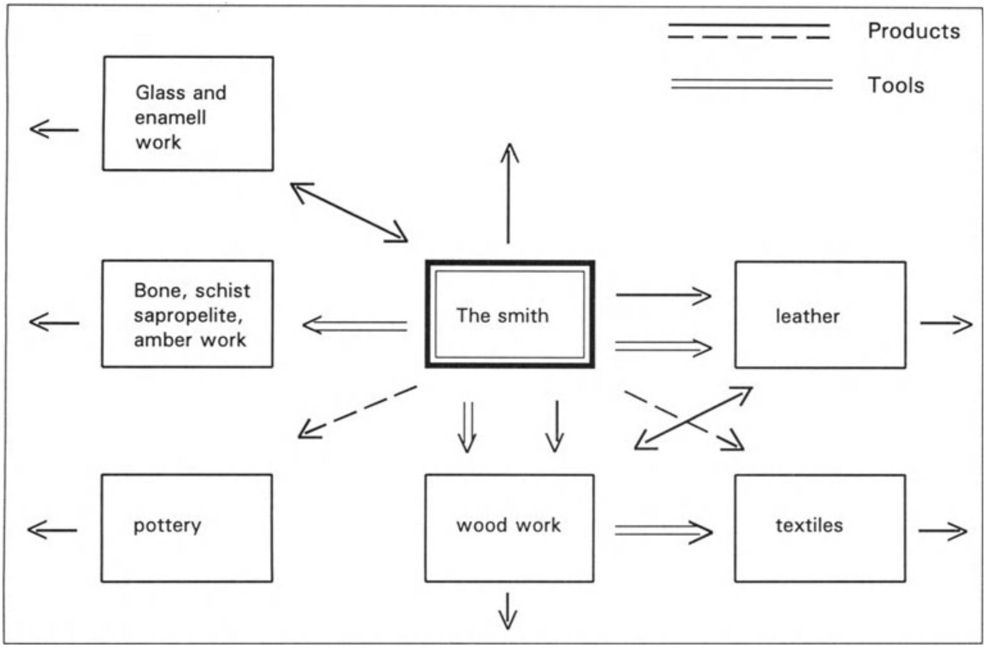


Fig. 3: The role of the smith in late Iron Age industry.

metal working and an extensive manufacture of gold jewellery. Moreover wheel-turned pottery appeared for a short time in a few places like the Heuneburg near Hundersingen in Southwest Germany. These abilities, however, were lost again as soon as the respective sites were destroyed or abandoned in the early 5th century B.C..

In the late Iron Age, industrial production appears with an unusual abundance of iron tools and products. The industrial structure is mainly based on the central position of the smith (Fig. 3). The experienced iron smith produced objects and special tools for his own requirements as well as for other craftsmen. The situation in the oppidum facilitated a close cooperation with the other craftsmen. Tools made by the smith could easily be modified, embellished or perfected on the request of the other craftsmen. This close contact between different craftsmen encouraged the fast exchange of experiences and promoted the invention of new techniques.

2. Settlement structures in the Celtic oppidum of Manching

The Celtic oppidum of Manching, near the modern town of Ingolstadt and south of the river Danube in Southern Bavaria, plays a prominent role in the discussion of Celtic town structures. Since 1955, systematic excavations have been conducted in Manching by the German Archaeological Institute. Despite the rather large scale of these excavations, only a relatively small part of the total area of the oppidum has so far been scrutinized (Fig. 4). Nevertheless these excavations have brought to light essential parts of a densely populated settlement (Krämer and Schubert, 1971). Estimates

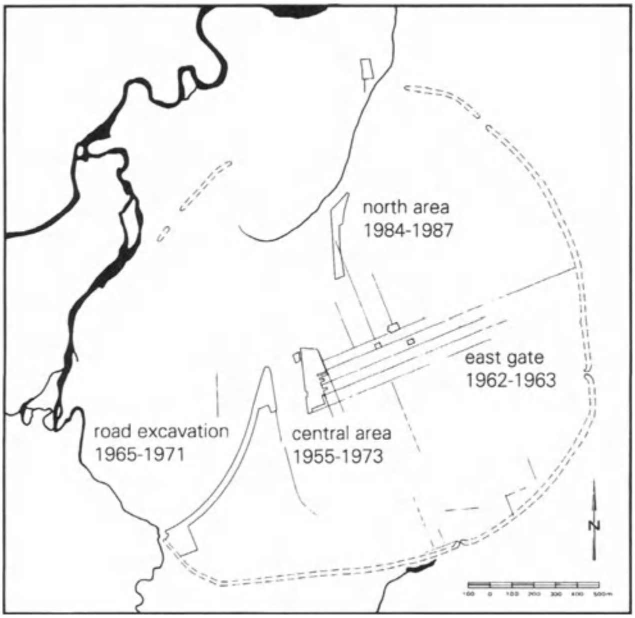


Fig. 4: Excavated areas in the Celtic oppidum of Manching.

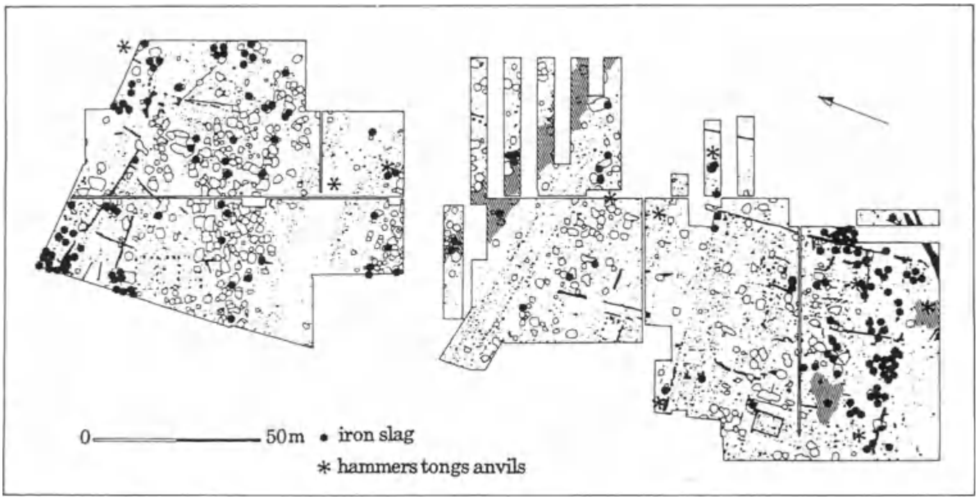


Fig. 5: Excavations in the central area (1955-1961) of Manching: remains of iron working. The concentration of iron slags in the south (right side of the map) is clearly correlated with the borders of an enclosure (after Jacobi 1974).

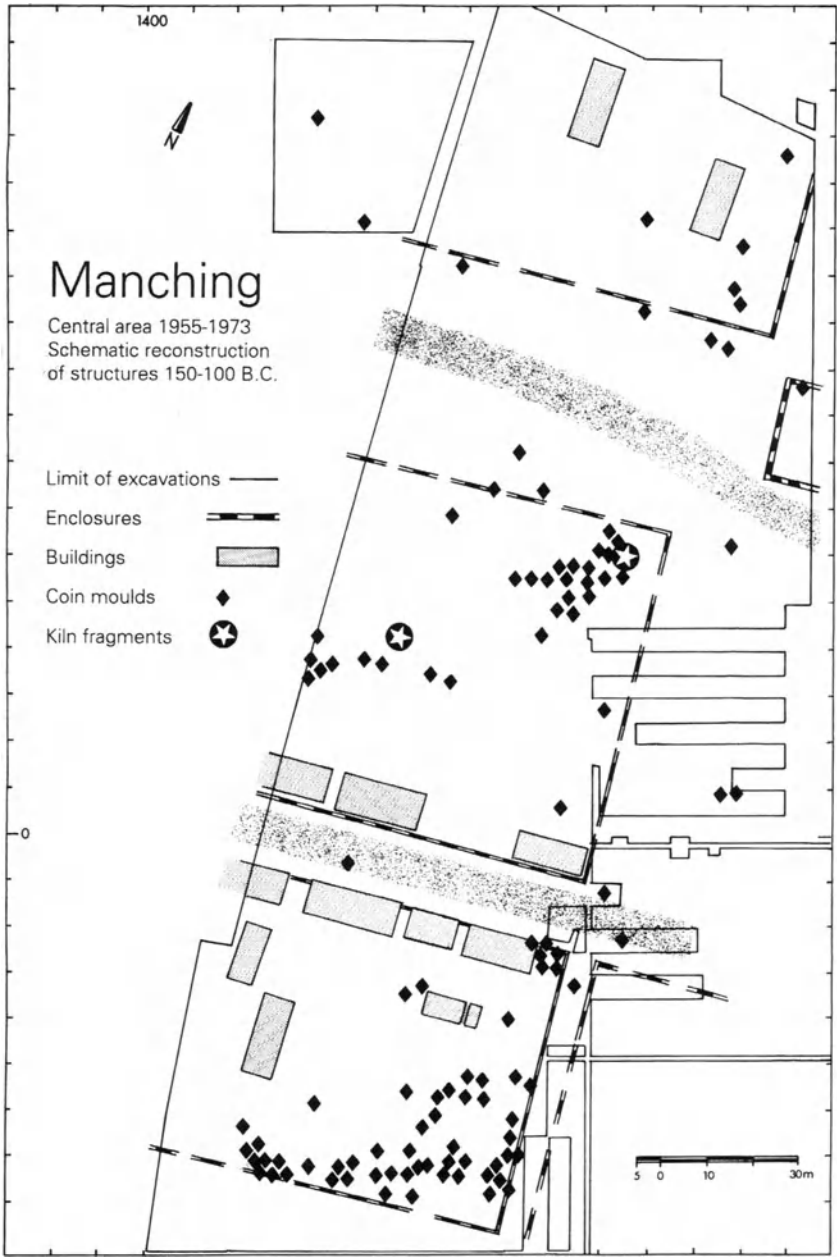


Fig. 6: Excavations in the central area of Manching: remains of precious metal working. The distribution of coin moulds and the site of the furnace used for gold making are indicated. The different areas were probably not in use simultaneously. The enclosure in the south of the excavation area dates back to the 2nd Century BC.

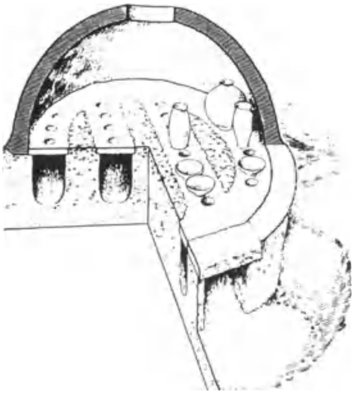


Fig. 7: Reconstruction of a Celtic pottery kiln.

based on the number of excavated animal bones (remains of slaughtering) indicate that the population was between 5000 and 10000 people in the heyday of the settlement. The settlement was divided into quarters enclosed by fences or palisades. The analysis of various groups of finds shows that there were mainly two different types of quarters, one of predominantly agricultural and one of predominantly industrial use (Gebhard, 1993, Figs. 80 and 88).

Remains of the working of bronze, iron and precious metals, especially of gold, have been found. However, iron working was predominant (Fig. 5). Intensive iron work is proved in the north and in the south of the central excavation area, for instance by finds of iron slags, hammers, tongs, and anvils. In the south, a high concentration of such items has been found close to the borders of an enclosure built in the late 2nd century B.C.. The northern part of this enclosure was a built-up area, while the southern part was not developed, presumably because of the risk of fire arising from the furnaces.

Indications of gold and silver melting are concentrated in two regions of the central excavation area (Fig. 6), which are defined mainly by the distribution of coin moulds. The distribution is

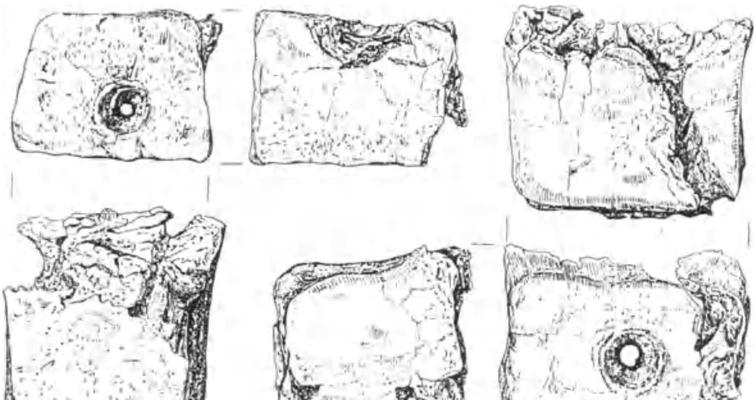


Fig. 8: Tuyères for bronze melting hearths. Scale 1:6.

significant compared to the waste distribution in the central excavation area (Gebhard et al. 1991). The unique find of furnace fragments with gold and silver traces, datable to the 2nd century B.C., proves that the concentration of coin mould fragments coincides with the location of the melting furnaces.

A comparison with the distribution of iron slags and nozzles of iron working furnaces shows that iron working was clearly concentrated in the southern enclosure in the same area where the gold was processed. In the middle part of the central excavation area there are two other areas of high concentrations of coin moulds and furnace fragments. These indicate gold working in a second enclosure. Here the buildings are in the southern half of the area and the working places are in the northern half. Remains of ironwork could be found here as well.

3. Relationship between different techniques

A study of the find distributions shows that a connection between iron working and precious metal working is likely. This relationship can be explained if one considers the necessity of the transfer of technical skills between the different crafts. The kilns and furnaces used for firing pottery, for iron working and for the melting of precious metals appear of particular interest in this context. Therefore excavated furnace structures have been studied, of which there are very few, and material from destroyed furnaces, i.e. wall fragments and tuyères. In this investigation X-ray radiography was used for the detection of metal inclusions and the metal composition of the inclusions found were analysed using the energy-dispersive X-ray spectrometer attached to the scanning electron microscope (SEM/ED-XRF). The analysis of the ceramic material by Mössbauer spectroscopy, thin section microscopy and X-ray diffractometry is very useful for reconstructing the temperatures that were reached during the firing process (cf. the article by Gebhard et al. in this volume).

The construction of the furnaces is mainly determined by the requirements of controlling the temperature or atmosphere. Kilns for advanced pottery making have to be built according to two aims mainly (i) a good control of the kiln atmosphere to produce reproducibly oxidized or reduced wares; and (ii) to reach sufficiently high temperatures without the use of bellows, which was necessary because of the long duration of the firing cycle. The Celtic pottery kiln fulfilled both conditions in a perfect way (Fig. 7). It was divided into two superimposed chambers. The main chamber holding the pottery was built as a dome above a firing chamber which was separated from the main chamber by a grid made of loam or clay. The small air volume of the dome with a diameter of about 1 m prevents heat loss, and the separate firing chamber facilitated the control of the air supply during the firing process. Firing was possible from one or two sides through a short tunnel. This construction provided a good control of the desired kiln atmosphere. The pottery products of the late Iron Age are excellent in material, shape, and the colours achieved by reducing or oxidizing firing.

Most furnaces used for metallurgical processes other than iron smelting were much smaller than the pottery kilns. They were not dug into the earth and usually destroyed completely after becoming useless. Thus fragments of such furnaces have to be used to reconstruct the original shapes and size. The most common remains of furnaces are tuyères made of clay. They were exposed to high temperatures during the use in the furnaces. At points of extremely high temperatures, the clay surface became vitrified. Two types of tuyères were used for melting bronze (Figs. 8 and 11 a-b). They consist of massive clay bricks with a tube canal inside. One type has a hemispherical cavity, obviously destined to support the crucible. The clay was mixed with organic temper and was reduced during the melting processes. The front end with the nozzle pointing toward the furnace has a partly

Fig. 9: Vitrified inner part of a furnace for precious metal working with gold and silver inclusions and rests of the nozzle. Scale 2:3.

vitrified surface. In most tuyères found the tube canal is blocked by vitrified clay and the tuyère must thus have become useless.

Typical tuyères for iron working are made in the shape of tubes (Fig. 11 d). The clay is strongly tempered with sand and mainly oxidized. These tuyères were probably used on an open hearth. The last type of tuyères or wall fragments could be connected with precious metal working. As yet, two sites with fragments of precious metal furnaces have been discovered in Manching (Fig. 6).

All fragments were studied by X-ray radiographs, which reveal metal inclusions in the glass matrix of the side directed towards the furnace chamber. There are two wall fragments with nozzles, each of them totally vitrified on one side. The X-ray radiograph (Fig. 9) of one of these fragments reveals two separate clusters of mainly gold and mainly silver inclusions, respectively. Presumably these were caused by a second nozzle on the opposite side which blew metal dust from the coin mould in the centre of the furnace. The second fragment could be used for the reconstruction of the side of the furnace. It can be completed to a brick of about 22 x 10 x 7.5 cm (Fig. 11 c). The shape is very similar to the tuyères used in bronze work. Another fragment from the same furnace can be identified as part of the bottom. It has a rectangular shape and is completely covered by spots of metal inclusions, mainly of silver. Different types of metal inclusions sampled from the bricks have been analysed by SEM/ED-XRF. The metal inclusions consist of a variety of gold-silver alloys as well as pure silver and gold (Fig. 10). These analyses correspond to the variety of gold-silver

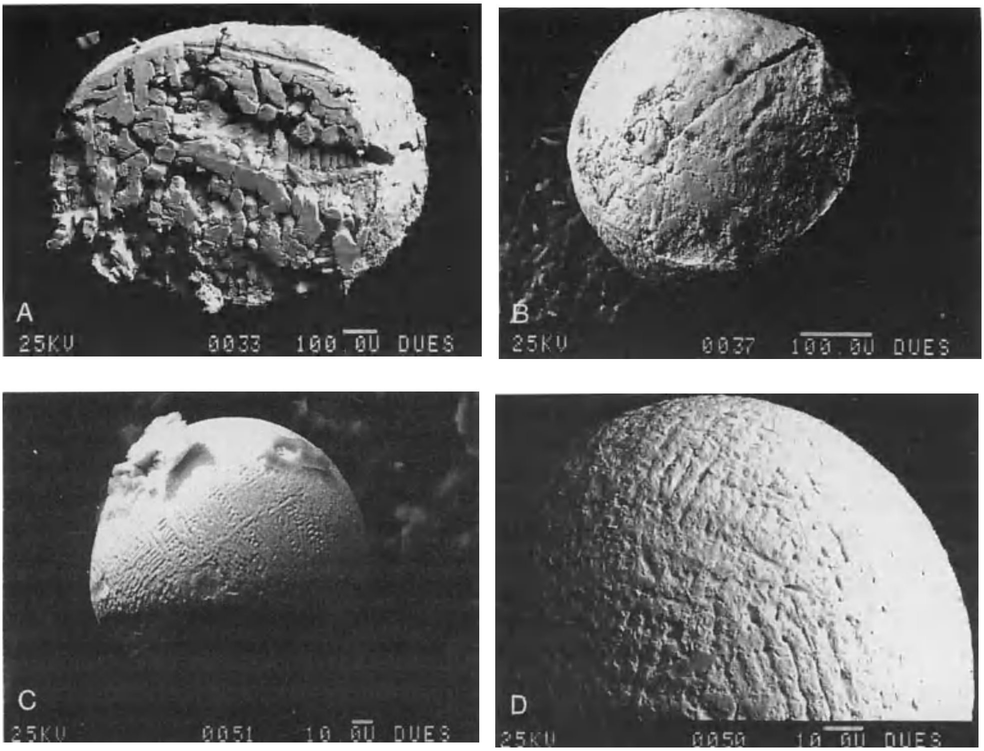


Fig. 10: Metal inclusions from furnace fragments. a) Section of an Ag-droplet with dendritic structures (∅ 1x0.8 mm; mainly Ag). - b) Flat bottom of an Ag-Au droplet (∅ 0.5 mm; 60 % Ag; 40 % Au). - c) Au droplet with regular dendrites and flat bottom (∅ 0.12 mm; 97.5 % Au; 1% Ag; 1,5 % Cu). d) Surface detail of an Au droplet (∅ 0.15 mm; 96.5 % Au; 1 % Ag; 2.5 % Cu).

alloys found in the coin moulds. The information obtained from the furnace fragments allows a reconstruction of the furnaces used in precious metal working: Between two opposed bellows there must have been a rectangular chamber of not more then 22-25 cm in width. This size fits quite well with the size of the coin moulds that were used for the melting of coin blanks. The largest coin moulds measure from 14x14 cm up to 17x17 cm. All coin moulds used in these furnaces have been exposed to strongly reducing conditions during their use (cf. Gebhard et al., this volume). Thus there must have been a cover on the top, probably a removable plate that facilitated reloading the furnace with charcoal. Analyses of the coin moulds and furnace fragments show that very high temperatures of more than 1000 °C have been reached in the centre of these furnaces.

Fig. 12 summarizes the firing techniques used in late Celtic industry. Craftsmen in the oppida

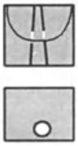
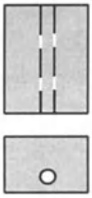
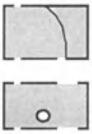
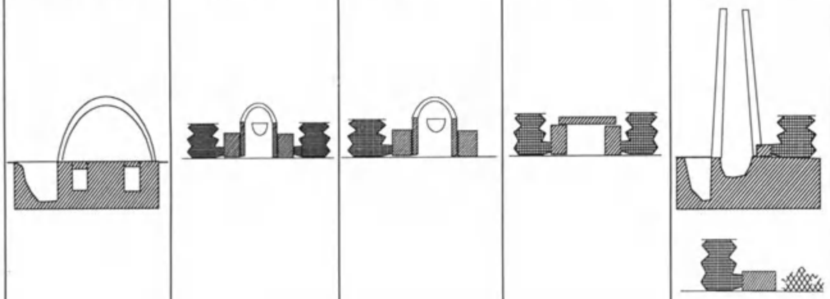
tuyères	scheme	clay	∅ nozzle	work
a) big square type with hemispherical cavity	furnace ⇑ bellow  >10 cm; front 16 cm; 13 cm	organic temper fired in reducing atmosphere.	2 cm	melting of *bronze* and *(?) glass.*
b) big square type and	furnace ⇑ bellow  18.5 cm; front 13-15 cm; 17-21 cm	organic temper fired in red. atmosph., vitrified surface, few metal inclusions.	1.3-1.5 cm	melting of *bronze* *(?) glass.*
c) square type	furnace ⇑ bellow  ~7.5 cm; front ~10 cm; 22 cm	mineral temper oxidized on bellow side, vitrified surface on furnace side, metal inclusions (Au, Ag).	1.5 cm	melting of *gold* and *silver* .
d) tube type	furnace, hearth ⇑ bellow  >15 cm; front ∅ 6 cm	mineral temper mainly oxidized, contains iron slag on hearth side.	2.0 - 2.4 cm	working of *iron.*

Fig. 11: Types of tuyères found in Manching.

were well experienced in handling temperature and furnace atmosphere. This was achieved by special design schemes. Furnaces for extremely high temperatures, necessary for iron and gold melting, were sustained with bellows. Kilns without bellows were used in pottery production. The highest temperatures had to be reached for the production of iron. Since bronze working is not very popular in Manching it can be assumed that the experiences from iron smelting formed the basis of the gold melting process. The manufacture of glass and ceramic wares was mainly related to metallurgy by the use of similar firing techniques. So far there is no archaeological evidence on the construction of the furnaces which the Celts used for glass making. The typical glass composition has a melting point of about 1050 °C. Therefore it seems likely that the furnace construction was similar to that used for metallurgical purposes.

The glass industry yields a final aspect which has to be considered in this context of the tradition of craftsmanship. Manching was one of the very few Celtic centres of glass industry. It was specialized in the difficult production of jointless glass bracelets from 260 to about 40 B.C. (Gebhard 1989, Gebhard et al. 1989). During this time the craftsmen had to hand down two secrets: that of

	Pottery	Bronze	Glass/ Enamel	Gold/ Silver	Iron
temperatures	850-950 °C	800-1000 °C	~1050 °C	1100-1250 °C	1250-1350 °C
process		melting (secondary)	melting (secondary)	alloying	iron ore reduction
kiln atmosphere (cf. ceramic)	reducing oxidizing	reducing	reducing oxidizing?	reducing	reducing
kiln design	2 chambers	bellow(s)	bellow(s)	bellows	bellows



making the shape and that of colouring the glass. It is likely that the tradition of making the shape was interrupted once, namely at the end of the 2nd century B.C.. But it is very remarkable that the cobalt blue glass was manufactured to the same formula without interruption for one and a half centuries. This is a fine example for the effective tradition and continuity of production techniques in prehistoric times.

4. Conclusions

The development of crafts during the first millennium B.C. is embedded in a complex process of social and economic changes. The new settlement structures favoured a close contact between specialized craftsmen. The smith has a central position in late Iron Age industry. The gold melting process is influenced by techniques used for bronze and iron work. Gold melting was therefore probably done by the iron working smiths. There was probably no continuous supply of raw gold and no continuous requirement for gold melting. The same craftsmen may therefore intermittently have melted gold between their iron working. The strong tradition in craftsmanship, for which glass making is only an example, guaranteed of the constant quality of the melting process.

The technical standard of the late Iron Age is related to the formation of the Celtic towns. Like in medieval times, the town was a centre which promoted the development of industry. Since the Celts had contacts to the Greeks and Romans, it is possible that some techniques were influenced by these connections. However, products like the glass bracelets, the swords and many others are singularly Celtic. Roman authors often report the high quality of Gaulish, that means Celtic, industry. Hence it is highly probable that many of the Celtic techniques, e.g. alloying gold in coin moulds, were originally Celtic inventions.

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Chapter 4

COIN MOULDS AND OTHER CERAMIC MATERIAL: A KEY TO CELTIC PRECIOUS METAL WORKING

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ABSTRACT. Coin moulds from the Celtic oppidum of Manching together with fragments of precious metal melting hearths used there and some reference materials were studied by various scientific methods to determine the metallurgical processes used to produce the blanks from which Celtic gold coins were struck. The methods used were optical and scanning electron microscopy, electron microprobe analysis, X-radiography, neutron activation and X-ray fluorescence analysis as well as ^{57}Fe Mössbauer spectroscopy. Combined with the archaeological evidence, the results give a rather detailed picture of the construction and operation of the Celtic gold melting hearths used to produce the coin blanks. These ideas have also been tested successfully in a field experiment.

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1. Introduction

The reconstruction of the metallurgical processes used in Celtic times for the manufacture of gold objects must be largely based on the excavation of archaeological sites, and on the scientific analysis of the gold and other objects. The present investigation deals with the techniques used in the production of gold coins, which were produced on a large scale in Celtic Europe. These coins were struck with bronze or iron dies from blanks of the proper weight by melting gold particles or pieces, usually mixed with some copper or silver. For the melting of such blanks, the Celtic craftsmen used flat clay plates with small circular or square depressions on the upper side (Fig. 1) . The use of these coin moulds was wide spread throughout the Celtic oppidum civilization, and even in peripheral areas like southern Poland. Maier and Neth (1987) have listed 46 sites in Central and Western Europe where coin moulds have been found; about half of these sites are oppida. The connection of these early examples of industrial ceramics with precious metal metallurgy is fully confirmed by gold and silver inclusions which can often be seen even with the naked eye on the surface of the coin moulds and fragments of hearth lining.

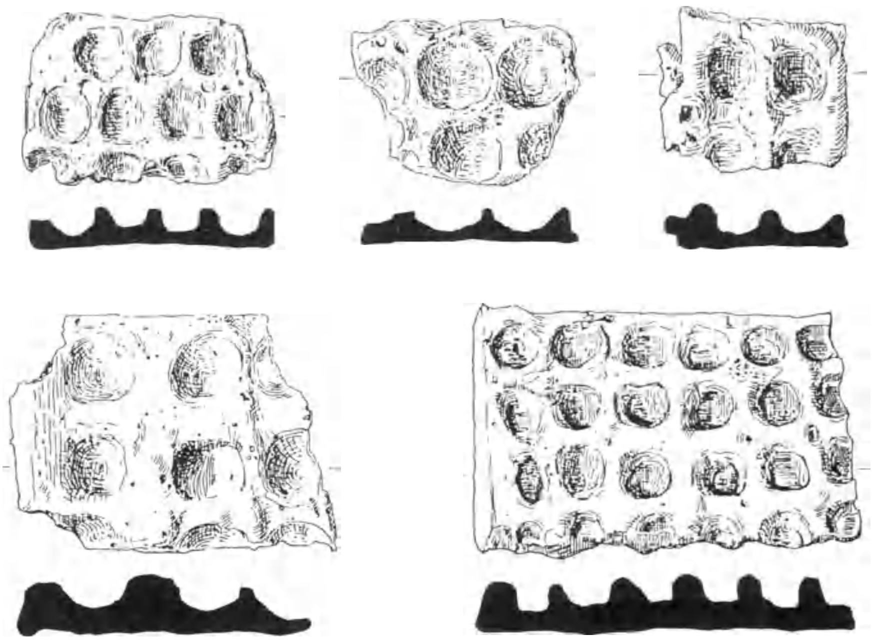


Fig. 1: Some coin moulds from the oppidum of Manching. (From Kellner 1990).

Metallurgical studies of the microstructure of Celtic gold coins have shown (Lehrberger and Raub this volume) that the raw materials for the coin blanks were heated to or above the point of fusion of the respective alloy rather than being merely sintered, for which significantly lower temperatures would have been sufficient (Raub this volume). Since many Celtic gold coins contain only a few percent of silver or copper (Lehrberger this volume), melting required that a temperature of or even exceeding 1000 °C be reached, if only briefly. This, as well as the archaeological evidence (Gebhard this volume, Industry in Celtic Oppida), suggests that the hearths were fired with charcoal and operated with bellows to supply the air required for obtaining these high temperatures. In fact, a number of tuyères (Fig. 1) used in such hearths has been found. These finds, and other hearth remains mainly excavated in the Celtic oppidum of Manching, bring the reconstruction of Celtic precious metal melting hearths within reach (Gebhard ib.).

Although several studies of the ceramic material and the metal inclusions of coin moulds have become known (Jansová 1974, Tournaire et al. 1982, Raub and Fingerlin 1984, Maier and Neth

Table 1. Studied specimens of technical ceramics and mudplaster from Manching and methods applied in the present investigation. Samples studied by a method are marked (x), samples not studied are marked (-). The inventory numbers (Inv.No.) are those of the excavation records (Krämer and Schubert 1970), the Garching numbers (Gar.No.) pertain to our internal laboratory reference system.

Inv.No.	Gar.No.	Material	NAA	TSM	MOS	XRR
1962/432-171	19/200	mudplaster	x	-	x	x
1962/433-171	19/201	mudplaster	x	-	x	x
1962/222-162	19/202	mudplaster	x	-	x	x
1963/1017	19/203	mudplaster	x	-	x	x
1963/1048	19/204	mudplaster	x	-	x	x
	19/438a	tuyère (cold end)	x	x	x	x
	19/438b	tuyère (hot end)	x	x	x	x
	19/439a	tuyère (hot end)	x	-	x	x
	19/439b	tuyère (cold end)	x	-	x	x
1956/163	19/441	coin mould	x	x	x	x
1961/159	19/442	coin mould	x	x	x	x
1974/1523	19/443	coin mould	x	x	x	x
1974/1585	19/444	coin mould	x	x	x	x
1956/475	19/607	coin mould	x	x*	x	x
1959/169	19/608	coin mould	x	x*	x	x
1956/163d2	19/609	coin mould	x	x*	x	x
1956/108	19/610	coin mould	x	-	x	x
1956/605	19/612	coin mould	x	x**	x	x
1956/684	19/613	coin mould	x	-	x	x
1959/301b	19/614	coin mould	x	x**	-	x
1959/217	19/615	coin mould	x	-	x	x
1960/18	19/616	coin mould	x	-	-	x
1962/323	19/617	coin mould	x	-	-	x
1974/2179	19/618	coin mould	x	-	-	x
1962/227	19/619	coin mould	x	-	-	x
1974/1722	19/754	coin mould	-	x**	-	x

* polished thin sections
** polished sections

1987), no attempt has been made at a systematic scientific analysis to extract all the available information on the melting techniques used in Celtic times (Tylecote 1962, Castelin 1960, 1965). The present study deals with the analysis of both coin moulds and ceramic material from Celtic precious metal melting hearths. From this point of the view material studied comes from the Celtic oppidum of Manching, south of the Danube and east of the modern town of Ingolstadt. Large scale excavations conducted at this site from 1955 to 1987 have brought to light many remains of Celtic precious metal working. As has been described in more detail by Gebhard (this volume, Industry in Celtic Oppida), coin moulds were found mainly in the middle and in the southern region of the central excavation area. Fragments of a hearth used for coin production were also found in the middle of the excavation area.

Table 1 gives an overview of the specimens studied and the methods applied. In addition to 18 coin moulds, tuyères and five samples of mudplaster from the wattle and daub walls of the remains of excavated houses were studied, the latter because they could possibly be representative of local clay materials. Neutron activation analysis (NAA) has been used to characterize the clay from which the ceramics were made by their major and trace element contents. Optical thin section microscopy (TSM) gives information on the mineral content of the ceramic material. Scanning electron microscopy (SEM) provides further information on details of the structure of the ceramic material and reveals how the metal inclusions found in the coin moulds are embedded into the largely vitrified ceramic matrix, while X-radiography (XRR) turned out to be a convenient, non-destructive method for studying the distribution of gold inclusions below the surface of the coin moulds. Energy dispersive X-ray fluorescence analysis (ED-XRF) performed in the scanning electron microscope yielded information on the alloy composition of these inclusions. Finally, Mössbauer spectroscopy (MOS) provides information on the chemical and physical state of the iron in the ceramic material, and thus indirectly on the hearth atmosphere and the temperatures to which the coin moulds were exposed during the gold melting process.

Most of these methods require substantial amounts of sample material, which limits the number of specimens that can be studied: For NAA about 100 mg are needed, for Mössbauer spectroscopy about 200 mg from each of the studied layers of a coin mould, and much more is required for preparing thin or polished sections. Therefore smaller fragments of coin moulds can often not be analysed by all the methods.

2. Metal inclusions in coin moulds

Sometimes small spherical grains of precious metal are visible on the surface of the coin moulds but, more often, these metal inclusions are hidden in the clay matrix. In order to make a survey of such inclusions non-destructively, X-radiographs were made of about 150 fragments of coin moulds from Manching with a commercial X-ray tube operated at a voltage of 60 kV. Owing to the strong X-ray absorption of gold and other metals, these radiographs show the metal inclusions as dark spots. Fig. 2a shows an example of a radiograph obtained by putting an as-found fragment of a coin mould on X-ray film and illuminating it from above. The dark dots represent noble metal inclusions. The big dark mass on the right side is an inclusion of magnetite and fayalite from an iron silicate slag (cf. section 5). X-radiographs were also made of the polished sections used in the microscopic studies (Figs. 2b-d). These specimens were 3 mm thick slices cut from the coin moulds. Figs. 2c-d, in particular, show the high density of precious metal inclusions in the sides of the pits and on the ridges between the pits.

A microscopic examination of the radiographs allows to study the number, size distribution and

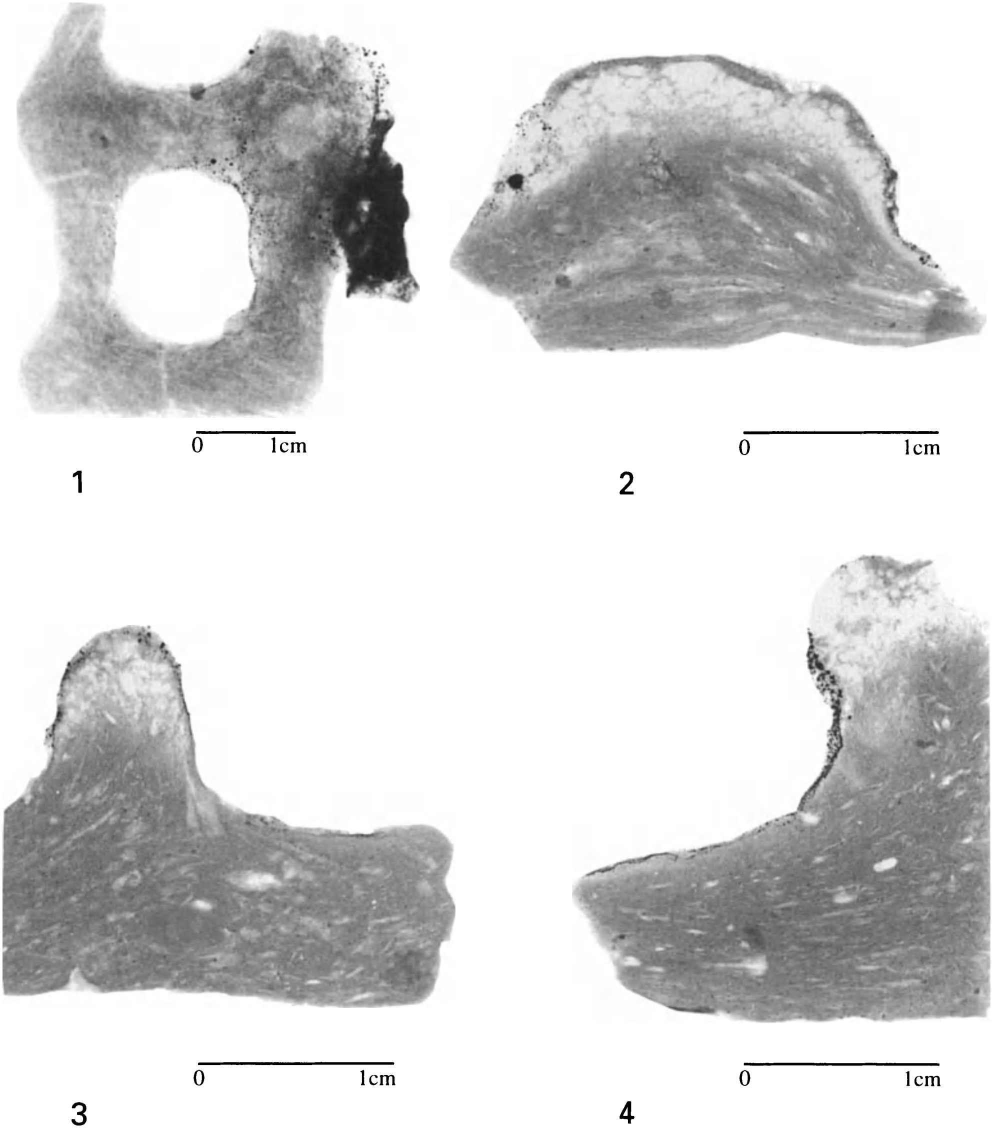


Fig. 2: X-radiograph of the as-found coin mould fragment 1956/475 (a) and of 3 mm thick sections from coin moulds 1956/605 (b), 1959/301b (c) and 1956/684 (d).

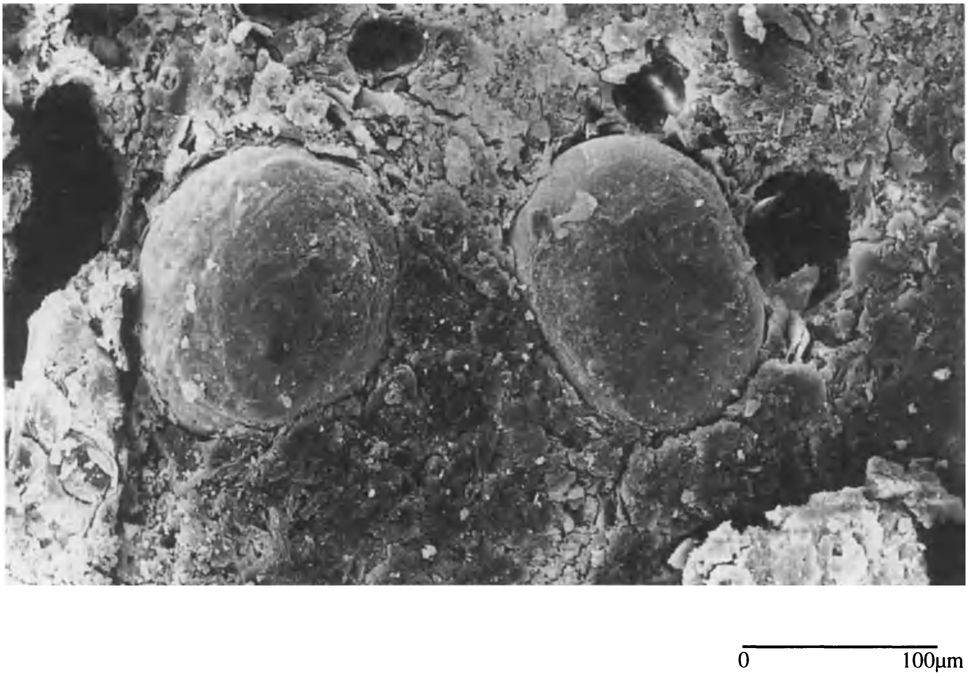


Fig. 3: Scanning electron micrograph of the surface of coin mould 1974/1722 showing two precious metal droplets embedded into the vitrified ceramic material.

morphology of the inclusions. A preliminary evaluation shows that most of the inclusions are smaller than 0.3 mm. About 40 % of the coin moulds studied were found to contain a high density of inclusions, mainly in the walls of the pits. The abundance of such metal inclusions suggests that the gold dust melted in the coin moulds was not or, at best, very loosely compacted before the melting process. In about 10% of the coin moulds no precious metal inclusions were observed, while the remainder had small to moderate precious metal contents. Most of the precious metal inclusions are not on but below the upper surface of the coin moulds. In most cases this surface is vitrified because of the high temperatures sustained during the melting process.

A study of the surface of the coin moulds by scanning electron microscopy (SEM) revealed that the vitrified zone of the ceramic material has typical hot tears. These are best developed where metal inclusions are found at the surface. The metal inclusions form rounded droplets, which are often slightly flattened. Normally only about one third of a droplet protrudes from the ceramic surface while the rest has sunk into the vitrified mass. This can be seen from Fig. 3, which also shows that the surface of the metal inclusions protruding from the ceramic surface has no intrinsic structure visible on a scale resolved with the SEM.

Energy dispersive X-ray analyses (ED-XRF) performed in the scanning electron microscope reveal a broad spectrum of different precious metal alloy inclusions in the coin moulds. Au-Ag-Cu alloys with Au contents between 55 and 80 wt. %, Ag contents from 15 to 33 wt. % and Cu contents

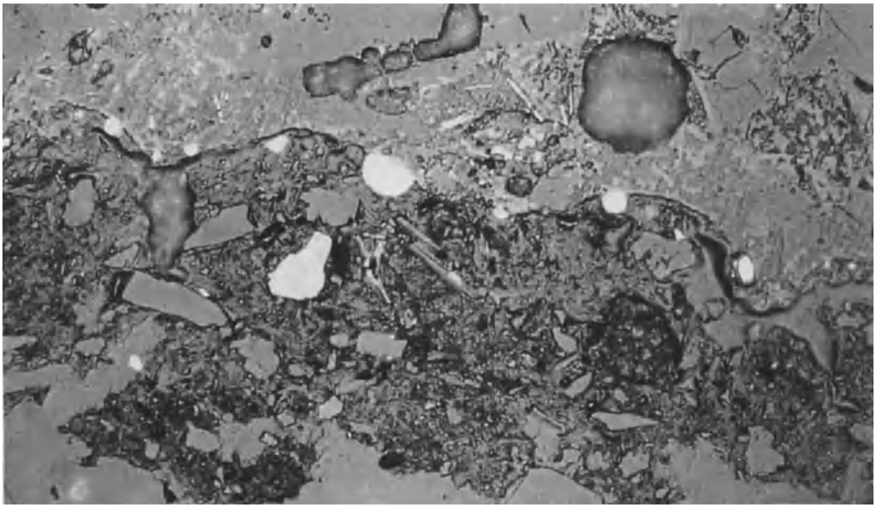


Fig. 4: Optical micrograph of a polished section of coin mould 1974/1277 showing the vitrified surface layer and the large number of precious metal droplets (light spheres) that have sunk into the molten ceramic surface and accumulated at the boundary between the molten and the solid region.

from 4 to 15 wt. % are predominant. A few of the analysed droplets were found to be pure silver, which indicates that pure silver was deliberately added to the gold alloys. An important result of ED-XRF is the detection of metallic tin and tin-copper bronze inclusions in the coin moulds. In the vicinity of the tin-bearing inclusions one also observes the formation of needle shaped crystals in the vitrified matrix. These crystals have been identified as tin oxide (cassiterite) needles formed by the oxidation of tin originally contained in the bronze, while the copper was completely incorporated into the Au-Ag-Cu alloy of the coin blanks. The occurrence of tin oxide and of bronze inclusions in the coin moulds is taken as an indication that bronze rather than pure copper was used as a source of copper in making the desired gold alloys.

3. Optical microscopy

In the interpretation of these micrographs, results from a continuing study of pottery from the oppidum of Manching (Bott et al. 1994a, 1994b) have been of assistance. One group of the pottery sherds from Manching is characterized by the presence of large amounts of quartz and muscovite. Another is rich in quartz, muscovite, plagioclase, microcline and biotite. Graphite ware, which is frequently found in Manching, often belongs to this type of ceramics, but additionally contains graphite flakes.

The thin sections of the tuyères 19/438 show that there is a difference between the front end directed towards the hearth and the rear end directed towards the bellows. In the rear end, which did not get very hot during use, muscovite is abundant like in many pottery sherds. Quartz, plagioclase and microcline are also found to be present. At the hot end, vitrification is obvious, and only very big muscovite flakes have survived even in part.

A similar situation is found in the coin moulds. Here the thin sections clearly show the vitrification of the upper zones, which have a thickness of 1-5 mm and were exposed to the highest temperatures during the melting process. Only the coarser quartz grains resist the fusing of the silicate minerals. Both the thin sections and the polished sections of the coin moulds show that the metal inclusions sink down from the upper face of the coin mould into the molten ceramics till they reach the boundary of the non vitrified zone and come to rest in this position. The lower parts of the coin moulds were exposed only to much lower temperatures. There muscovite is still present, but less abundantly than in the rear part of the tuyère or in some other ceramics. A typical feature of all coin moulds examined is the presence of quartz grains with strikingly sharp edges, which suggest that these grains are the result of a deliberate crushing of larger quartz pieces. Presumably this quartz was added on purpose as a temper. Whether this was done to produce particularly temperature resistant ceramics or for a different as yet unknown reason, requires further clarification, since it might give interesting insights into the technical skills of the Celtic craftsmen.

Occasionally, grains of garnet are found in the thin sections. Garnets can be associated with sands found in the Manching area, which may have been used as temper. The presence of garnets is of some interest because the Mössbauer spectra also show the presence of a mineral which, on the basis of its Mössbauer parameters, can be identified as a garnet, presumably an almandine with a non-ideal composition (cf. section 5).

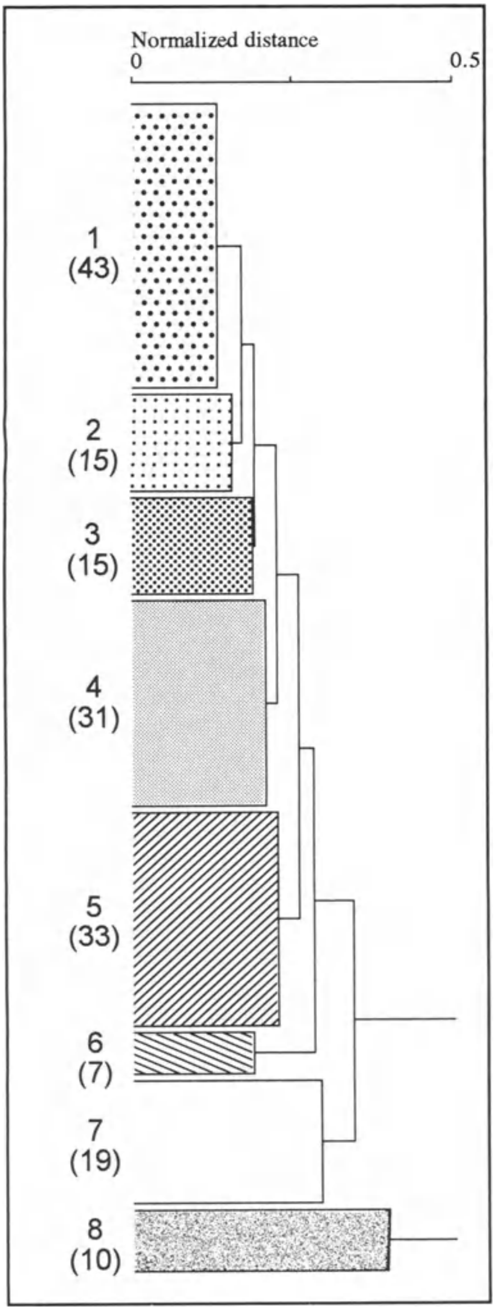
X-radiographs like the one shown in Fig. 2a were used to select the sites for the cutting of the coin moulds for the preparation of polished sections. Slices of about 3 mm thickness were embedded into epoxy resin and then polished like normal ore samples. These polished sections have been studied in reflected light in the polarization microscope. These investigations showed metal inclusions at the surface of the coin moulds, but also many inclusions which have sunk into the vitrified zone (Fig. 4). The polished sections are presently being used to make grain size analyses of the metal inclusions using an automated counting system.

4. Neutron activation analysis

By neutron activation analysis both the trace element content as well as the concentrations of some major elements of clays and ceramics can be determined with high accuracy and without interference from the major elements normally making up ceramic materials, like Si, Al, or Mg, since these barely become radioactive during neutron irradiation. The trace element contents contain information on the provenance of the clay and temper used for manufacturing the ceramics. Even if the source of the raw materials cannot be identified, a classification of ceramic artefacts according to their trace element contents often yields archaeologically meaningful information.

In the present study, 17 coin moulds and two tuyères have been analysed so far. For these specimens, the concentrations of three major (K, Ca, and Fe) and 17 trace elements have been determined in duplicate samples against a standard for which the element concentrations are known. Even though care has been taken to use only material from the bottom of the coin moulds, the analysis is hampered by the fact that even this material is contaminated with traces of gold and silver, which both become strongly radioactive during neutron irradiation, thus rendering the determination of other trace elements difficult, though not impossible.

The compositions of the coin moulds become meaningful only when they are compared with these from other Celtic ceramics, both from Manching and from other locations and, if possible, with local clays. Since the origin of the clay used in Manching in Celtic times has not yet been discovered, five samples of mudplaster from the remains of wattle and daub walls of Celtic houses excavated



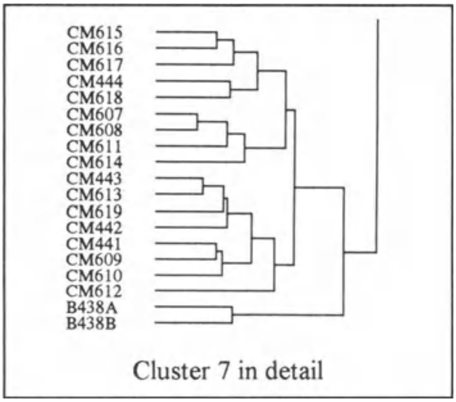


Fig. 5: Dendrogram of the neutron activation data of technical ceramics as well as wheel-turned and coarse pottery from Manching and Bohemia. Eight groups or clusters have been distinguished. Only the group containing the technical ceramics is shown in detail. The other groups are represented by blocks. The number of sherds in each group is given in parentheses.

in Manching were included in the analysis as specimens of a local clay, though none of these mudplasters was used for making pottery (Bott et al. 1994a, 1994b). Further, several soil samples collected at the excavation site have been analysed. These results were compared with the element contents of nearly 200 pieces of wheel-turned pottery from Manching and Bohemia, which have recently been measured in the course of a comprehensive investigation of Celtic pottery involving more than 500 samples. This study shows that different wares were produced from the same raw materials, and that the composition of wheel-turned pottery can be considered as representative for the raw materials used for pottery production in Manching (Bott et al. 1994a, 1994b).

The results of the cluster analysis of the logarithms of the element concentrations by the average linkage method (Fahrmeir and Hammerle 1984) are shown in Fig. 3 as a block dendrogram, in which the normalized euclidian distance in concentration space is a measure of the dissimilarity of individual specimens or clusters of specimens. A small normalized distance means a high degree of similarity, and vice versa. The aim of such an analysis is to establish meaningful groups of materials, with similar element contents within each group and sufficiently different element contents between the individual groups, and to draw archaeologically meaningful conclusions from such a grouping. Despite a certain arbitrariness inherent in the subdivision of the set of specimens into groups, the analysis allows one to identify several clusters which appear meaningful.

These are shown in Fig. 5 as blocks whose individual members are not given for the sake of clarity. Of the total of 183 specimens used in this analysis, 13 have been suppressed in Fig. 5 because they did not fall into any of the recognized clusters. None of the omitted specimens is a coin mould or a tuyère. Also it is important to note that the concentrations of gold and silver, with which the coin moulds were contaminated during their use or when they were formed from clay in the workshop, have not been used in the cluster analysis.

Group 1 in Fig. 5 contains 43 sherds of wheel-turned ware, five of these from misfired vessels. Because the latter are certainly of local production, this group is considered as representative for the trace element content of ceramics made in Manching. Groups 2 and 3 contain only 15 samples each. Group 4, with 32 sherds found in Manching, is considered as locally made rather than imported ware owing to the archaeological typology of its members. Group 5 contains wheelturned ware found in Bohemia and is large enough to be considered as statistically relevant. Group 6 contains seven specimens of coarse ware also from Bohemia.

Group 7 contains all the technical ceramics studied in the present context. This group is certainly distinct from the other groups of ceramics, but rather inhomogeneous, as is shown in the insert in Fig. 5. The most obvious feature of the technical ceramics is a high Ca content of between 4 and 11 % and occasionally even as high as 20 %. However, the cluster analysis yields practically the same grouping if it is run without the Ca data. The material of the tuyères is somewhat different from that of the coin moulds, mainly on account of its low Ca content of about 1.5 %. This is about the normal value for pottery from Manching. An effort was made to study the hot and cold end of the tuyères separately. For tuyère 19/438, the two ends yielded very similar results (Fig. 5), but the hearth end of tuyère 19/439 had an extremely high content in elements like Mn and Fe, presumably because of a contamination acquired during use or manufacture. Lesser, but still enhanced contents of these elements were also observed at the rear end. The data for tuyère 19/439 have therefore not been included in the dendrogram. The investigation of more tuyères is required before an explanation of the origin of this contamination can be suggested. An eighth group (Fig. 5) comprises the samples of mudplaster from the wattle and daub walls and the soil samples collected at the excavation site in Manching. This group is again quite inhomogeneous. The soil samples are somewhat different from the mudplaster, but both are substantially different from both the household ware and the technical ceramics. Obviously, quite different materials were used for building wattle and daub walls on the one hand and for making ceramics on the other.

A more important conclusion in the present context, however, is that different raw materials were also used for the manufacture of household pottery and for making the technical ceramics, i.e. primarily coin moulds, but presumably also the tuyères and perhaps the whole hearths. The reasons for this are not yet understood, but may lie in the properties of the materials, of which the Celtic craftsmen appear to have had quite a good knowledge.

5. Mössbauer spectroscopy

Mössbauer spectroscopy with the 14.4 keV gamma rays of ^{57}Fe is a convenient method for studying the chemical and physical state of iron, which usually is present in percent concentrations in clays and ceramics (Wagner et al. 1986). For recording ^{57}Fe transmission Mössbauer spectra like those shown in Figs. 6-14, the 14.4 keV gamma rays emitted after the radioactive decay of the ^{57}Co source isotope to ^{57}Fe are allowed to pass through an absorber also containing ^{57}Fe, a stable iron isotope occurring in natural iron with an abundance of 2.2 %. In such an absorber the gamma rays can induce transitions of the ^{57}Fe nuclei from the groundstate to the 14.4 keV state, i. e. they can be resonantly absorbed, if their energy coincides with the excitation energy. In practice, the intensity of the gamma rays passing through the absorber is measured as a function of the velocity with which the source is moved with respect to the absorber. By means of the Doppler effect, this movement gives rise to small shifts of the energy of the gamma rays emitted by the source. The resonance absorption pattern of the absorber can thus be scanned by varying the velocity. The sensitivity of Mössbauer spectra for the solid state properties of the absorber material results from the fact that hyperfine interactions between the ^{57}Fe nuclei and their electronic environment split and shift the resonance line in a way that allows conclusions to be drawn, for example, on the oxidation state of iron, on the symmetry of the environment of the iron atoms, and on the magnetic properties of iron compounds. Since the hyperfine patterns of the various iron-bearing mineral phases usually present in ceramics are known, Mössbauer spectroscopy allows one to identify these mineral phases even in complicated mineral mixtures. An advantage of the Mössbauer method, for instance over X-ray diffraction, is that natural iron contents of about one percent are sufficient for obtaining good Mössbauer spectra without interference from the major mineral phases that do not contain iron. Moreover, the iron yields informative Mössbauer spectra even in cases where X-ray diffraction would fail altogether, for instance if iron is present as very small oxide particles or in a vitrified silicate matrix.

There are three types of hyperfine interactions, which give rise to different features in the Mössbauer spectra (Gütlich et al. 1978): The electric quadrupole interaction splits the Mössbauer line into a doublet of two lines which usually have the same intensity. The magnitude of the splitting, Q, is a measure for the deviation of the electric charge distribution around the iron nuclei from cubic symmetry. Owing to its half-filled 3d shell, Fe^{3+} usually exhibits smaller quadrupole splittings (0.3 to 1.5 mm/s) than Fe^{2+} (1 to 4 mm/s). The second type of hyperfine interaction, the isomer shift S, is also of electrostatic origin and causes a shift of the whole Mössbauer pattern. When the spectra are measured with the standard sources of ^{57}Co in a rhodium matrix, the centres of gravity of the Mössbauer patterns of Fe^{3+} in oxides and silicates exhibit isomer shifts between +0.1 and +0.4 mm/s, while Fe^{2+} has shifts between 0.8 and 1.2 mm/s. The isomer shift and quadrupole splitting together therefore usually allow an unambiguous determination of the oxidation state of iron in such systems. In magnetically ordered materials, e.g. in ferro- or antiferromagnets, one observes a magnetic hyperfine interaction, which splits the Mössbauer line into a six-line pattern. From the

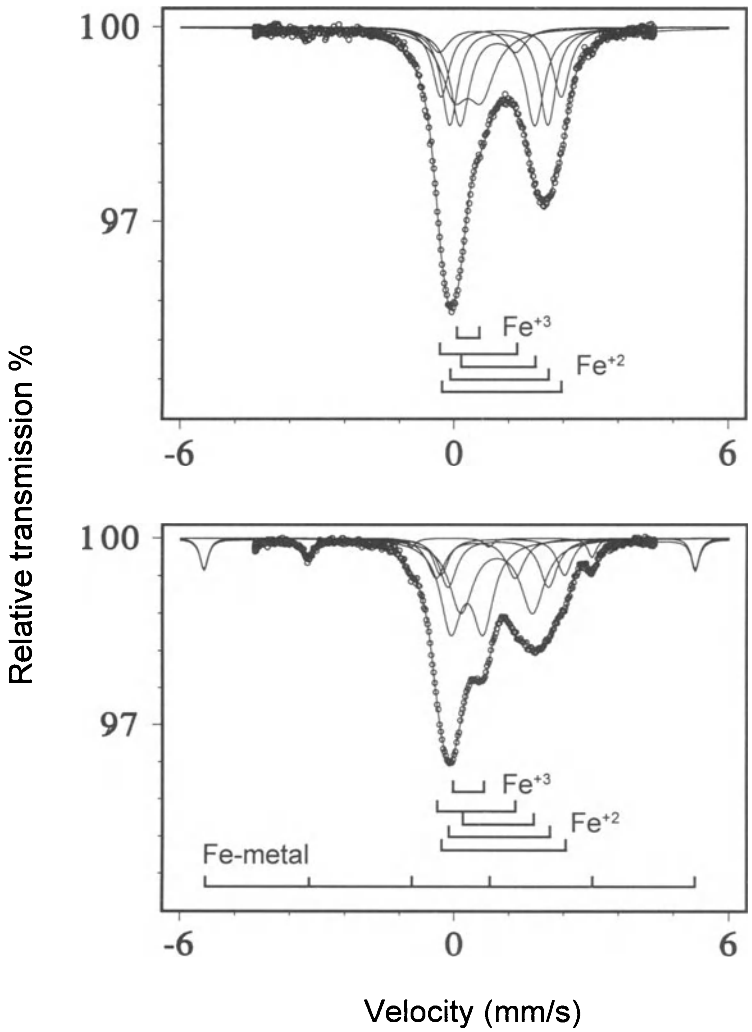


Fig. 6: Mössbauer spectra of the upper surface (upper spectrum) and the core (lower spectrum) of coin mould 19/608 measured at room temperature with a source of ^{57}Co in Rh. The individual superimposed hyperfine patterns (quadrupole doublets and magnetic sextets) are indicated by bar diagrams.

magnitude of the splitting one obtains the magnetic hyperfine field, B, produced by the atomic electrons at the nuclear site. Such sextets are, for instance, observed in metallic iron or in hematite. Very small particles of magnetically ordered materials, however, give rise to superparamagnetism, a feature that often has a profound influence on the Mössbauer spectra of ceramics: In very small particles, which usually consist of a single magnetic domain only, the direction of the magnetization may flip rapidly owing to thermal stimulation. As a consequence of these so-called superparamagnetic fluctuations, the magnetic hyperfine field at the nucleus also changes its direction. When the rate of the fluctuations becomes sufficiently fast, the magnetic hyperfine splitting of the Mössbauer spectra collapses and the spectra become single lines or quadrupole doublets (Mørup et al. 1980). The Mössbauer patterns of hematite particles with diameters below about 10 nm, for instance, show the superparamagnetic collapse of the magnetic hyperfine pattern already near or above room temperature (Kündig et al. 1966). To observe the magnetic hyperfine splitting in such materials, one has to cool the absorbers. At the temperature of boiling liquid helium (4.2 K), the superparamagnetic relaxation will usually be sufficiently slow even for the smallest hematite grains present in ceramics to show the typical magnetic pattern with a hyperfine field of about 52 Tesla by which it is easily identified. Superparamagnetism can therefore be used to obtain information on the size distribution of iron oxide particles in ceramics (Gangas et al. 1973, Wagner et al. 1992).

The Mössbauer spectra of ceramic materials usually are a superposition of the Mössbauer patterns of the various iron-containing phases present. The typical changes in the Mössbauer spectra when clays are fired have been studied in some detail (Wagner et al. 1988, Wagner et al. 1994). In unfired clay minerals the iron may be either trivalent or divalent (Coey 1980; Murad and Wagner 1991). In technical clays, some iron is usually present in form of oxides, mainly as hematite and more rarely as magnetite, or as oxyhydroxides like goethite or ferrihydrite. When such clays are fired in air, the oxyhydroxides start to transform into hematite at about 400 °C. Such hematite often consists of small particles which show superparamagnetic behaviour in the room temperature Mössbauer spectra. The clay minerals undergo dehydroxilation between about 300 and 500 °C. This usually goes along with an increase of the quadrupole splitting of the Fe^{3+} in the clays, which may reach values as large as 1.5 mm/s (Murad and Wagner 1989, 1991). Above 800 °C the layer structure of the clay minerals breaks down altogether and the iron initially contained in the clay minerals tends to form hematite, except in clays that are rich in calcium, which causes the formation of gehlenite, $Ca_2[(Al,Fe)_2SiO_7]$ (Maniatis et al. 1981). Above about 1000 °C, vitrification sets in and the hematite tends to dissolve in the glassy matrix. Firing in reducing atmospheres, as are often encountered in pottery kilns and are also expected in the hearths studied in the present work, leads to the formation of divalent iron, mainly in the form of minerals which have but rarely been identified. A compound that seems to play an important role in this context (Bott 1992) is the spinel hercynite, $FeAl_2O_4$. Hercynite is known to form from oxides of iron and aluminium in a reducing CO/CO_2 atmosphere at temperatures near 1000 °C (Kunnmann et al. 1963). When ceramics that were first fired in a reducing atmosphere are fired again in an oxidizing environment, the iron in the Fe^{2+} containing minerals transforms into hematite. On the other hand, later hematite formed by oxidizing firing can be transformed into Fe^{2+} containing minerals by firing in a reducing atmosphere (Bott 1992, Bott et al. 1994a).

In the case of the coin moulds, the microscopic studies have already shown that the upper faces are vitrified (cf. sections 2 and 3), obviously because they had to sustain higher temperatures than the inner and bottom parts. For this reason, samples for Mössbauer spectroscopy were taken separately from the vitrified upper surface, from the core, and from the bottom of each of the studied coin moulds. Mössbauer spectra were measured at room temperature (RT) and in many cases also at 4.2 K with sources of ^{57}Co in Rh, which were kept at the same temperature as the absorber.

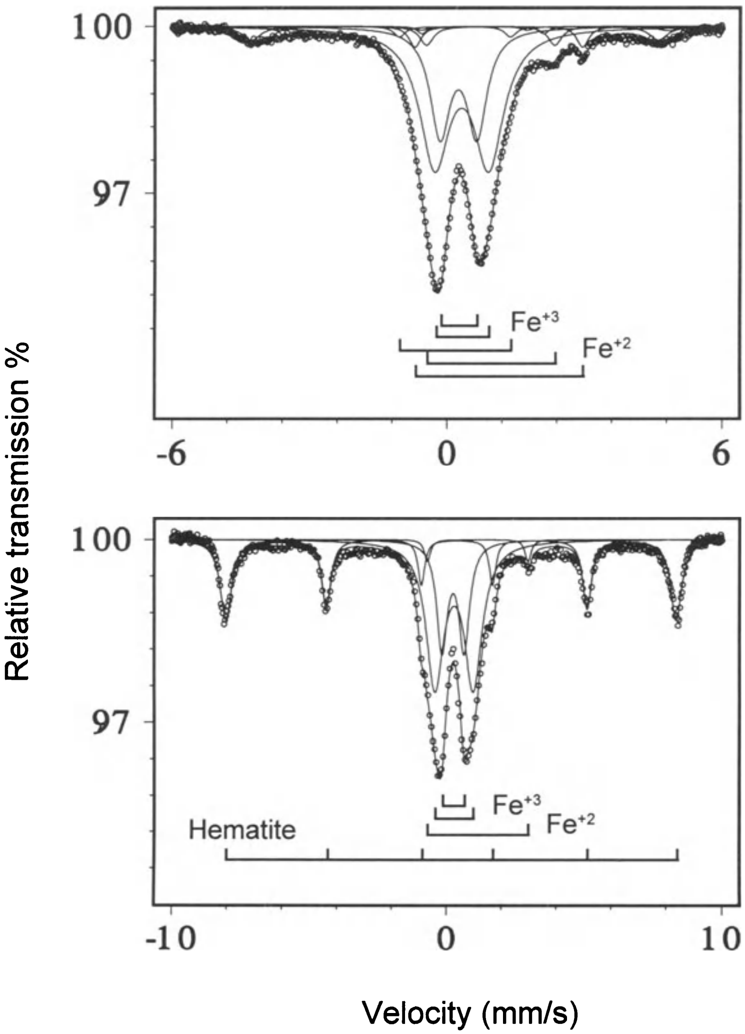


Fig. 7: Like Fig. 6, but for the bottom part of coin mould 19/613 and for the same sample after firing in air at 800 °C for 48 hours. Note the different velocity scales of the two spectra.

Figs. 6 and 7 show spectra that are typical for the surface, the core and the bottom parts of coin moulds. The vitrified surface usually contains very little Fe^{3+}. Most of the iron is divalent, which corroborates the idea that the hearth atmosphere was strongly reducing due to charcoal covering the coin mould while the hearth was fired. The Fe^{2+} Mössbauer patterns are rather broad and can be approximated with three or four quadrupole doublets. The divalent iron may be dissolved in the glassy part of the ceramic material or it may form a separate mineral phase. The core of coin mould 19/608 (Fig. 6) also contains only very little trivalent iron, albeit somewhat more than the surface. The pattern of Fe^{2+} is broader and more structured than that of the surface. It is very similar to the Mössbauer spectra observed for synthetic hercynites (Bott 1992). Indeed the formation of hercynite ($FeAl_2O_4$) at temperatures above 900 °C under reducing conditions is conceivable (Kunnmann et al. 1963). Mössbauer patterns like that of the core of coin mould 19/608 have also been found in pottery sherds fired in reducing kiln atmospheres (Bott et al. 1994a, 1994 b, Wagner et al. 1986, 1988, 1994). However, not all coin moulds have cores like this. In many cases Fe^{3+} prevails in the cores of the coin moulds, although Fe^{2+} always dominates in the surface layers. The spectra then are rather similar to the typical spectra of the bottom layers, in which trivalent iron usually dominates, as in the bottom of coin mould 19/613 (Fig. 7).

The Mössbauer spectrum of the core of coin mould 19/608 (Fig. 6) exhibits another feature that has been found to be quite frequent in the surfaces and the reduced cores of coin moulds, namely the presence of metallic iron, which is easily recognizable in the Mössbauer spectra by its six-line magnetic hyperfine pattern with a hyperfine field of 33.0 T. The formation of metallic iron by reduction of hematite during the firing of ceramics in a reducing atmosphere above about 950 °C is well known (Wagner et al. 1988, 1988/89, Bott 1992). The surprising feature is that metallic iron has survived two millennia of ground burial. This can only be explained by a tight enclosure of the iron in the ceramic matrix. Metallic iron is practically absent in the surface layer of coin mould 19/608, perhaps because the iron dissolved in the vitrified silicate matrix as Fe^{2+} during firing. It is improbable that it was oxidized during burial, because no hematite or oxyhydroxide is observed in the spectrum of the surface layer.

The presence of metallic iron in coin moulds could also be attributed to iron particles inadvertently mixed into the clay from which the coin moulds were formed. If this mechanism could be proven, it would indicate a close relation between the melting of gold and the working of iron in the Celtic workshops. In this context it is worth mentioning that the metallic iron particles that give rise to the iron component in the Mössbauer spectra can hardly exceed diameters of about 0.03 mm, since the 14.4 keV gamma rays would be too strongly absorbed in larger particles. Iron filings incidentally mixed into the clay in the workshop would therefore need to be rather fine particles in order to be seen in the Mössbauer spectra. Presumably the iron particles giving rise to the magnetically split spectra have sizes of several tens of nm only. A lower limit to their size is set by the fact that the spectra show a magnetic splitting at room temperature. For particles smaller than about 10 nm superparamagnetism would be expected to manifest itself in the room temperature Mössbauer spectra (Mørup et al. 1980, Boudart et al. 1977). These considerations suggest that the metallic iron seen in the Mössbauer spectra was indeed formed in situ by reduction of oxides during firing.

Coin mould 19/607 (Fig. 8) is a case where all three layers have been largely reduced, showing that the hearth atmosphere was reducing everywhere and that even the bottom got hot enough for iron reduction, which requires temperatures above 800 °C. Metallic iron is present in the surface layer and in the core, with more in the latter. The absence of iron in the bottom part indicates that the temperature was insufficient for iron oxide reduction in the gold melting hearth. Oxidation during burial is quite improbable, since the bottom part contains hardly any hematite or oxyhydride,

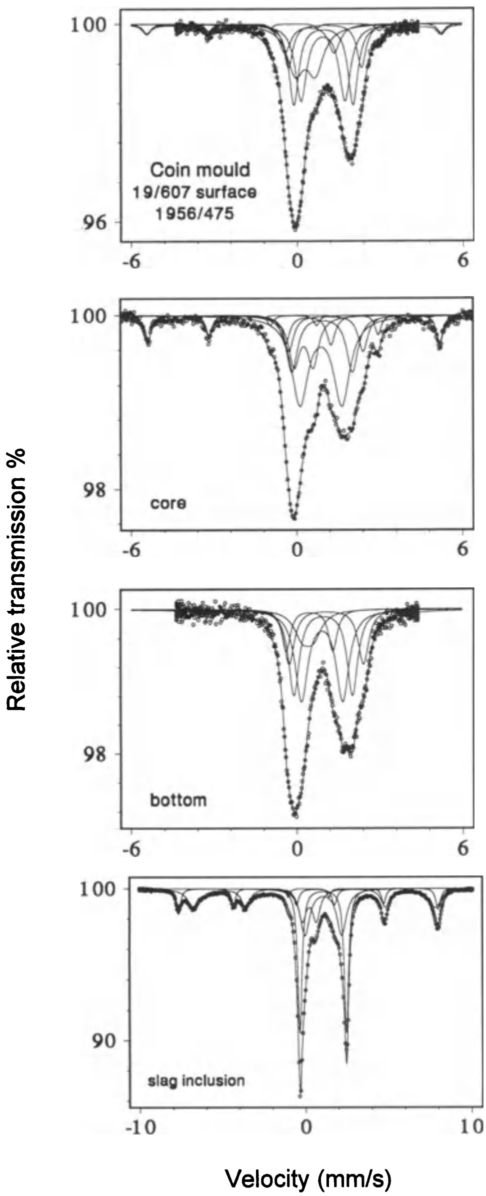


Fig. 8: Room temperature Mössbauer spectra of the surface, the core and the bottom of coin mould 19/ 607. The spectrum of a slag inclusion is also shown.

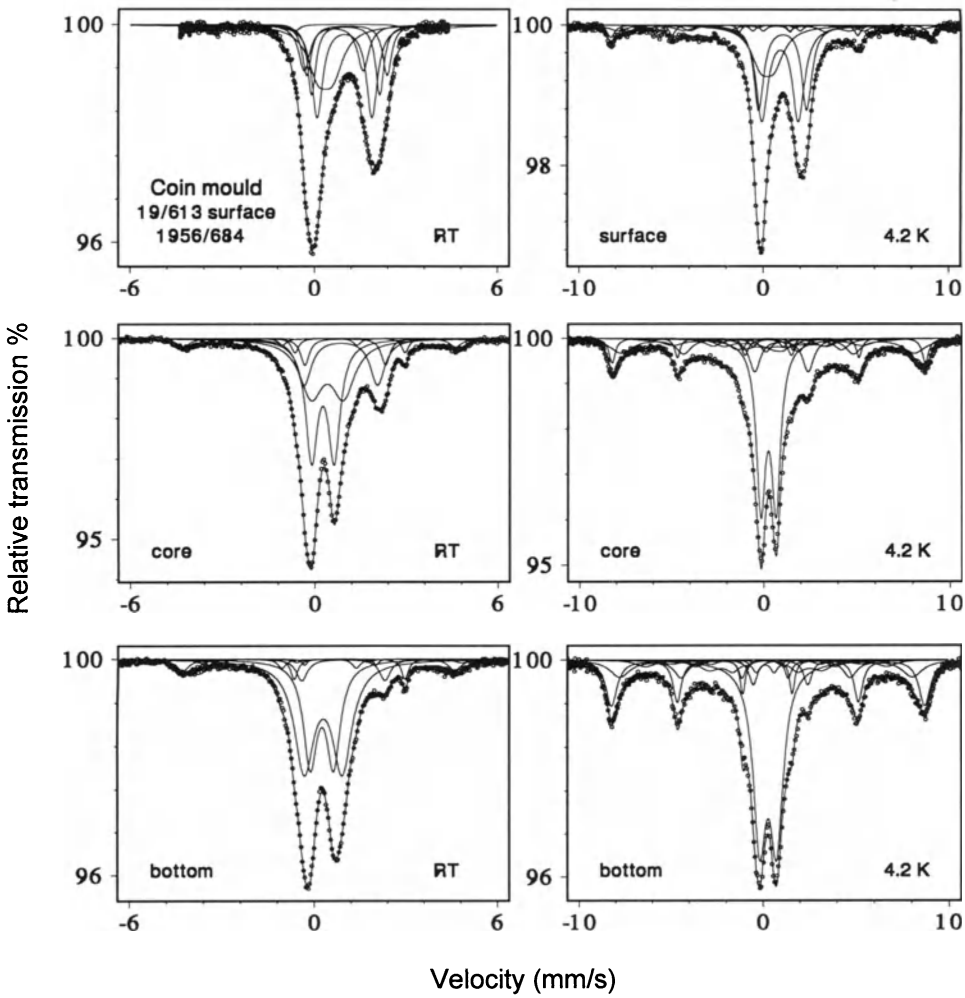


Fig. 9: Mössbauer spectra of the surface, the core and the bottom of coin mould 19/613 measured at room temperature (left) and at 4.2 K (right). The source was at the same temperature as the absorber. Note the different velocity scales for the room temperature and the 4.2 K spectra.

which could be the product of iron oxidation. This also speaks against the idea that the metallic iron dust or filings were accidentally mixed into the clay of the coin moulds when these were manufactured in the workshop, since such iron should also have found its way into the bottom of the coin mould. The fact that metallic iron is quite frequent a feature in the spectra of coin moulds also argues against an accidental contamination.

In coin mould 19/607, however, another interesting feature was observed: In the surface layer a nodule consisting of magnetite and fayalite, Fe_2SiO_4, of a total weight of about 700 mg was found. This nodule can also be seen in the X-ray radiograph of this coin mould reproduced in Fig. 2a. Magnetite and fayalite are minerals that are typically found in copper and iron working slags (Rüffler 1991). It is improbable that these minerals were formed in situ in the coin mould. More probably, iron slag was accidentally mixed into the clay from which the coin mould was formed, or adhered to the mould during handling in the workshop. It may be too early to take this as a definite proof that iron or copper working and gold smelting were performed in the same workshop, but it is at least a serious indication.

In the room temperature Mössbauer spectrum of the bottom part of coin mould 19/613 (Fig. 9) the magnetic hyperfine pattern of hematite is nearly absent. This means that the trivalent iron that gives rise to the Fe^{3+} quadrupole doublets is either contained in the silicate matrix of the (perhaps already partially disintegrated) clay minerals, or present in the form of iron oxide particles that are small enough to exhibit superparamagnetic Mössbauer spectra. The latter should exhibit magnetic hyperfine patterns when the superparamagnetic relaxation is blocked at 4.2 K. This is indeed the case for part, but by a long way not for all, of the Fe^{3+}, as can be seen in Fig. 9, which shows spectra taken at room temperature and at 4.2 K for the surface, the core and the bottom of coin mould 19/613. The values of the Mössbauer parameters for these spectra are compiled in Table 2. In this case Fe^{3+} dominates in both the core and the bottom, but Fe^{2+} is slightly more abundant in the core than in the bottom. In the surface there is no magnetic hematite component visible at all in the room temperature spectrum. At 4.2 K about 20 % of the spectral area shows a magnetic splitting, part of this with a wide distribution of hyperfine fields indicating impure or badly crystallized hematite with particle sizes well below 10 nm. When a sample from the bottom of this coin mould was fired in the laboratory at 800 °C in air for 48 hours, it exhibited a narrow, well-defined hematite pattern already at room temperature (Fig. 7), showing that the small hematite particles have now grown together to larger ones. The fact that the same process had not taken place already during the use of the coin mould in the gold melting hearth shows that the temperature reached in the core and at the bottom of coin mould 19/613 remained well below 800 °C, while the temperature on the surface rose to about 1000 °C. This appears possible only if the temperature required to melt the gold was maintained only for a short time.

It is worth noting that the divalent iron in the surface of the coin mould does not split magnetically at 4.2 K, while in the core about half of the Fe^{2+} splits at 4.2 K with rather small hyperfine fields, as are not unusual for Fe^{2+}. This supports the notion that the divalent iron in the surface layer is dissolved in the glassy matrix, while the divalent iron in the core is contained in separate iron-rich minerals like hercynite, whose 4.2 K Mössbauer spectrum is magnetically split at 4.2 K with a hyperfine field of 12.3 T for the main component (Bott 1992).

The room temperature Mössbauer spectra of the core and the bottom part of coin mould 19/613 (Fig. 9) also contain a weak but clearly visible component of divalent iron with a very large quadrupole splitting of 3.61 mm/s and an isomer shift of 1.18 mm/s with respect to the ^{57}Co:Rh source (Table 2). These parameters are practically identical with those found previously for divalent iron in garnets like almandine (Amthauer et al. 1976, Murad and Wagner 1987). The presence of a small number of garnet crystallites has also been observed in the thin sections of the coin moulds

Table 2. Mössbauer parameters for the surface, the core and the bottom of coin mould 19/613 measured at room temperature and 4.2 K with the source of ^{57}Co in Rh at the same temperature as the absorber. B, Q, S, W and A are the magnetic hyperfine field, the electric quadrupole splitting, the isomer shift, with respect to a source of ^{57}Co in Rh, the full linewidth at half maximum, and the relative intensity of the individual components in the Mössbauer spectra. The subscripts "mag" and "magDis" refer to magnetic components and components with a distribution of hyperfine fields, respectively.

Gar No	Fe	B (Tesla)	Q (mm/s)	S (mm/s)	W (mm/s)	A (%)
19/613 RT						
surface	Fe^{+3}	-	0.47(6)	0.36(2)	0.86(5)	26.0
	Fe^{+3}	-	1.93(1)	0.63(2)	0.43(6)	14.2(3)
	Fe^{+2}	-	1.80(1)	0.99(1)	0.43(7)	28.5(6)
	Fe^{+2}	-	2.23(2)	1.02(1)	0.32(4)	16.8(3)
	Fe^{+2}	-	2.63(2)	1.06(1)	0.34(4)	13.3(2)
	Fe^{+2}	-	3.60	1.18	0.39	1.2
core	Fe_{mag}	45.5-47.6				9.8(1)
	Fe^{+3}	-	0.74(1)	0.27(1)	0.48(1)	34.8(1)
	Fe^{+3}	-	1.05(2)	0.41(1)	0.91(8)	30.4(2)
	Fe^{+2}	-	2.40(2)	0.85(1)	0.58(5)	16.7(2)
	Fe^{+2}	-	2.63(2)	0.99(1)	0.34(9)	5.8(1)
	Fe^{+2}	-	3.59(1)	1.15(1)	0.28(4)	2.5(1)
bottom	Fe_{mag}	45.5-47.6				14.9
	Fe^{+3}	-	0.75(1)	0.26(1)	0.54(1)	31.0(3)
	Fe^{+3}	-	1.24(3)	0.30(1)	0.77(6)	46.8(3)
	Fe^{+2}	-	2.69(6)	0.99(3)	0.4(1)	4.2(1)
	Fe^{+2}	-	3.61(1)	1.16(1)	0.27(3)	3.1(1)
19/613 4.2K						
surface	Fe_{magDis}	14.7-50.0				15.6
	Fe_{mag}	53.7(8)				5.8(2)
	Fe^{+3}	-	0.70(6)	0.25(2)	1.3	20.1(1)
	Fe^{+2}	-	1.97(2)	0.95(1)	0.72	33.4(1)
	Fe^{+2}	-	2.59(1)	1.08(1)	0.6	25.1(1)
core	Fe_{magDis}	23.1-49.0				28.2
	Fe_{mag}	52.4(3)				7.6(1)
	Fe^{+2}_{mag1}	11.7				8.1(1)
	Fe^{+2}_{mag2}	8.9 -				7.2(1)
	Fe^{+3}	-	0.82(1)	0.27(1)	0.6	36.3(1)
	Fe^{+2}	-	1.75(6)	0.99(3)	0.72	3.6(1)
	Fe^{+2}	-	2.87(2)	0.96(1)	0.72	9.0(1)
bottom	Fe_{magDis}	18.7-49.0				32.4
	Fe_{mag}	52.5(4)				20.0(1)
	Fe^{+3}	-	0.92(1)	0.28(1)	0.86	43.6(1)
	Fe^{+2}	-	2.95(2)	0.95(1)	0.54(5)	4.0(1)

(cf. section 3). This garnet component is visible in the Mössbauer spectra of the core and bottom parts of most coin moulds, but it is absent or at best very weak in all surfaces. The reason for this is that the garnet disintegrates between 900 and 1000 °C. This can be seen in Fig. 10, which shows the Mössbauer spectra of a mudplaster from Manching, which is rather rich in garnet. The presence of this garnet component is a typical and rather unique feature of clays and ceramics from Manching.

In the untreated mudplaster, 20 % of the spectral area of the iron is attributable to the garnet phase, the remainder being trivalent iron. After heating in air at 900 °C for 48 hours the area of the garnet is still 13 %, but after heating to 930 °C for the same time it has fallen to 3 % (Fig. 10). The garnet component thus provides a temperature probe: If it is still present, the sample cannot have become hotter than about 950 °C. Whenever the temperature got much higher, the garnet will no longer be present. For a more precise temperature determination, the influence of the time of heating must be studied more carefully, but even now one can conclude from the presence or absence of the garnet that the coin moulds were heated above about 950 °C on the surface, while the core and bottom remained well below that temperature.

In Fig. 11 the Mössbauer spectra of the front and rear end of tuyère 19/438 (cf. Table 1) are compared with the spectra of the surface and core of two more coin moulds (19/441 and 19/609), which are similar to those of coin mould 19/613. The rear end, which was directed towards the bellows and must have been cooler than the front end directed towards the interior of the hearth, contains mainly trivalent iron, albeit with a noticeable contribution of divalent iron. Its Mössbauer spectrum is very similar to that of the cores of many of the coin moulds, e.g. 19/441 and 19/609 (Fig. 11). Presumably the divalent iron present in all these cases is not a product of reduction of originally trivalent iron. Presumably spectra like those of the rear end of the bellow tube represent the original distribution of divalent and trivalent iron in the clay used for making both the bellow tube and the coin moulds. The bellow tube, through which air was blown, was certainly exposed to oxidizing conditions. From laboratory firing experiments with clays containing divalent iron one knows (Murad and Wagner 1989) that divalent iron in clays gets oxidized already on heating in air to about 500 °C or even less. If divalent iron has survived in the rear end of the bellow tube, this part of the tube cannot have become hotter than about 500 °C. By analogy, one concludes, that the core and bottom parts of those coin moulds that exhibit spectra like those of the cores of 19/441 and 19/609 also have not gotten any hotter.

The hot end of the bellow tube contains only trivalent iron, with a noticeable fraction of hematite that is magnetically split at room temperature. This spectrum is reminiscent of that of the bottom of coin mould 19/613 after laboratory firing in air at 800 °C (Fig. 7). Presumably, the front end of the tube indeed reached a temperature in this region. With the air from the bellows giving rise to oxidizing conditions, hematite was therefore formed. Part of this hematite has sufficiently large particle sizes to give a magnetic Mössbauer pattern at room temperature.

These ideas are supported by experiments in which a sample from the bottom of coin mould 19/613 was refired in the laboratory in air at increasing temperatures. The Mössbauer spectra measured at room temperature and 4.2 K after each refiring step (Fig. 12) confirm that the small divalent fraction originally present has disappeared after firing at 500 °C. (The spectra of samples fired at 300 and 500 °C are not shown in Fig. 12). After firing at 800 °C, the spectrum is very similar to that of the hot end of the bellow tube. Practically all the iron is hematite, but much of it as particles so small that superparamagnetism prevails at room temperature. The magnetic splitting is fully developed only at 4.2 K but with broad, asymmetrical lines typical for small and impure hematite particles. Hematite that is magnetically split at room temperature continues to develop at higher firing temperatures, showing that the hematite particles grow in size. On firing at 1000 °C, the magnetic pattern dominates already at room temperature. However, even at 4.2 K a very small Fe^{3+}

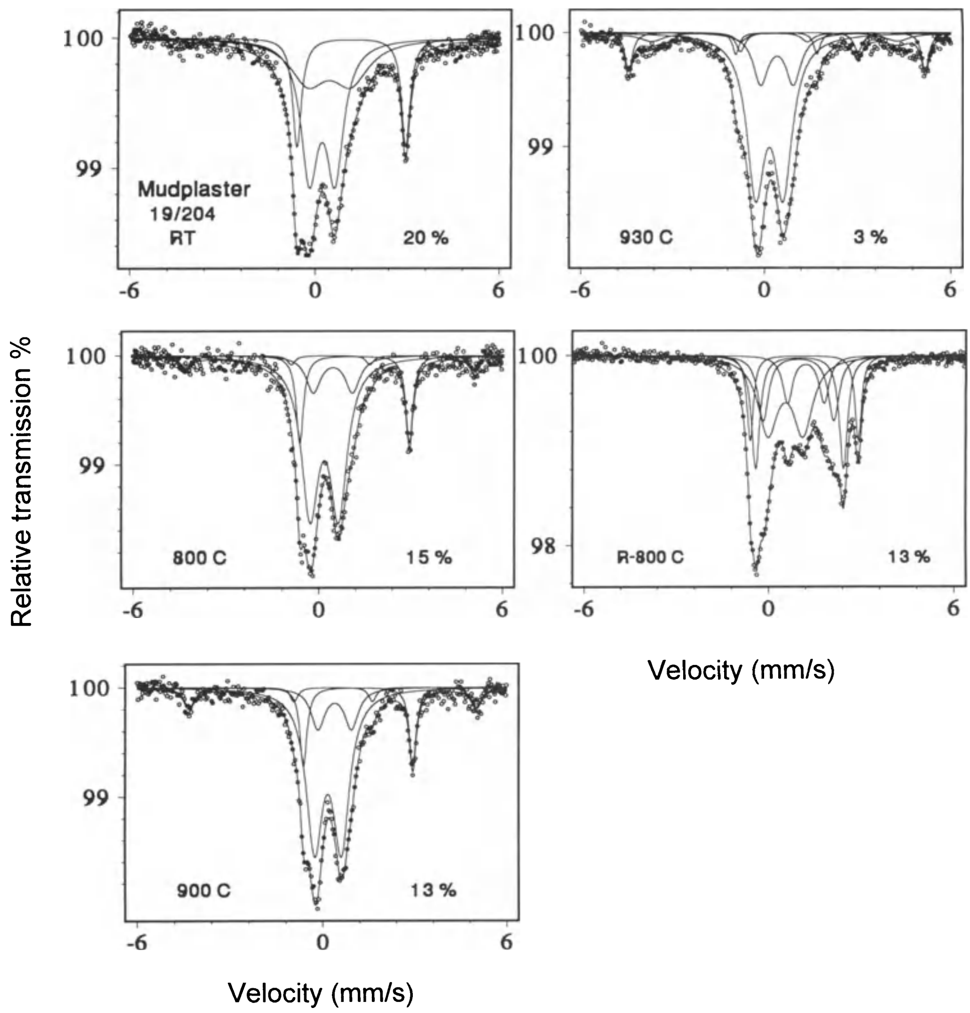


Fig. 10: Room temperature Mössbauer spectra of mudplaster 19/204 (cf. Table 1) as found (top) and after labortatory firing in air at 800, 900, and 930 °C (below and right). The percentage of the garnet quadrupole doublet in the spectral area is given in the figures. A spectrum recorded after reduction for 3 hours at 800 °C is also shown. The percentage of the garnet quadrupole doublet is unchanged by the reduction.

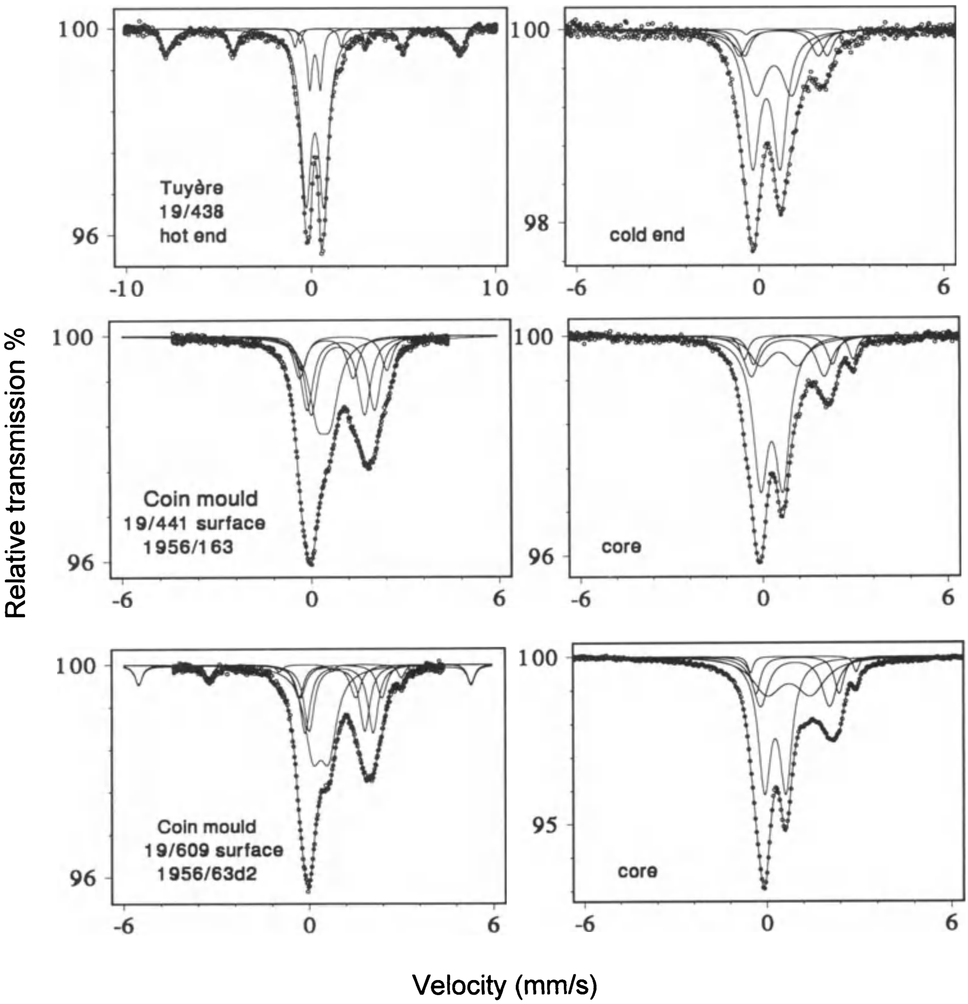


Fig. 11: Comparison of the room temperature Mössbauer spectra of the hot front and the colder rear end of the tuyère 19/438 with the spectra of the surface and core of coin moulds 19/441 and 19/609. Note the different velocity scales.

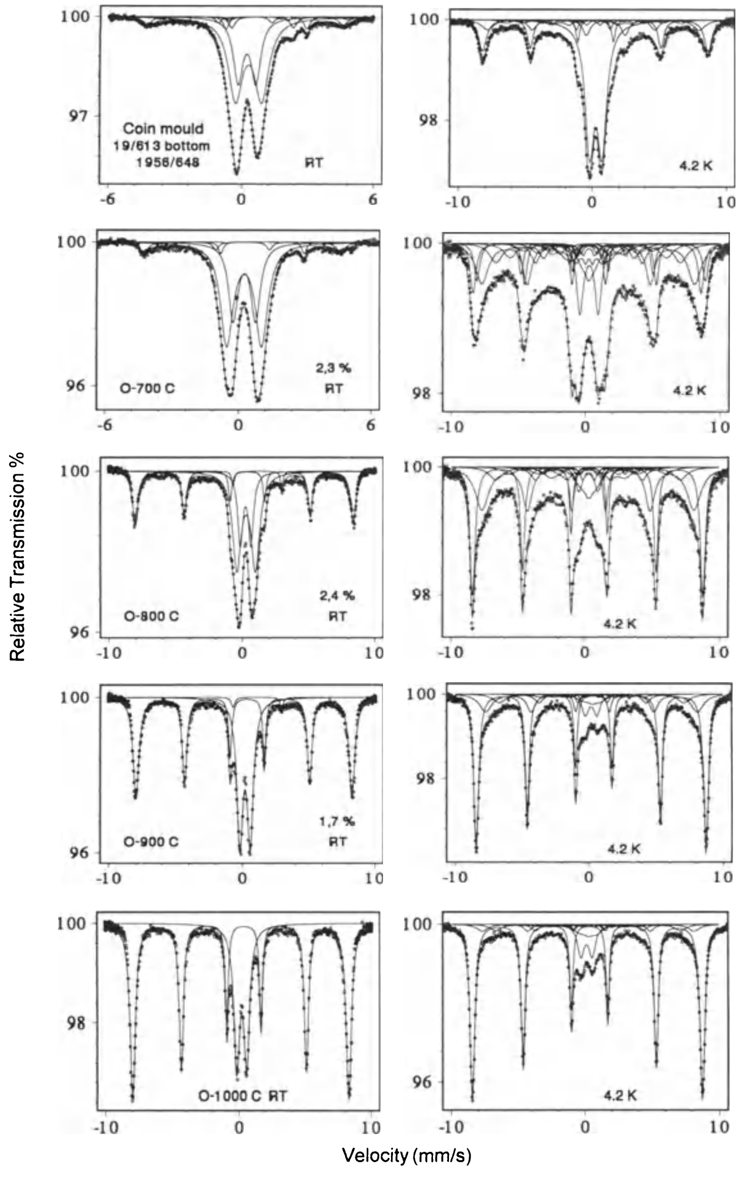


Fig. 12: Mössbauer spectra of a sample from the bottom part of coin mould 19/613 after labratory refiring in air at the temperatures given in the spectra. Spectra taken after heating at 300 and 500 °C are not reproduced. On the left side the room temperature spectra are shown, on the right side the corresponding spectra measured at 4.2 K. The percentage amount of the garnet phase serving as a temperature indicator is given for the room temperature spectra. At 4.2 K the garnet exhibits a complicated magnetic hyperfine splitting (Murad et al. 1987) and therefore cannot be seen in the spectra.

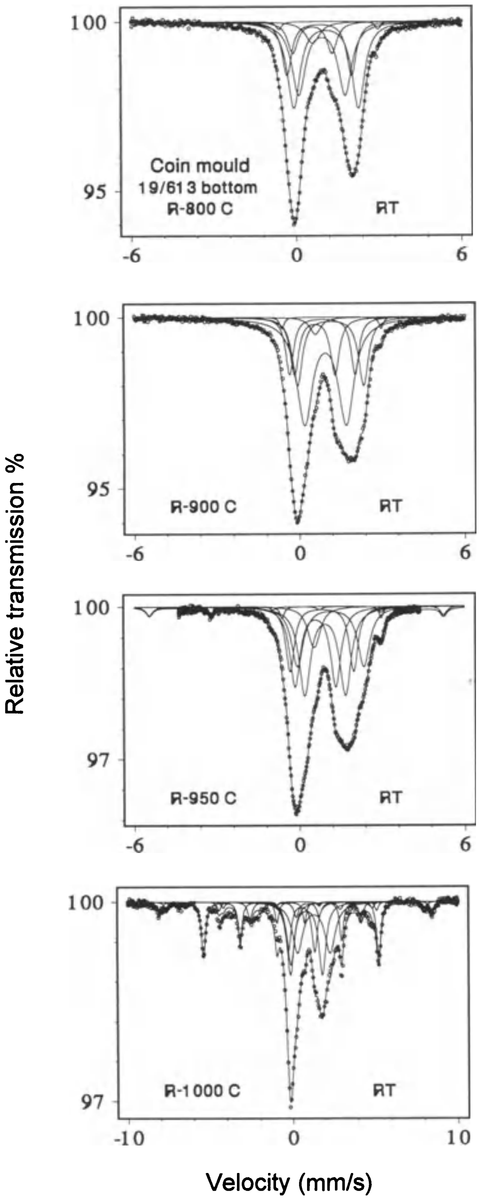


Fig. 13: Room temperature Mössbauer spectra of a sample from the bottom part of coin mould 19/613 refired under reducing conditions at the temperatures given in the spectra. Note the different velocity scales.

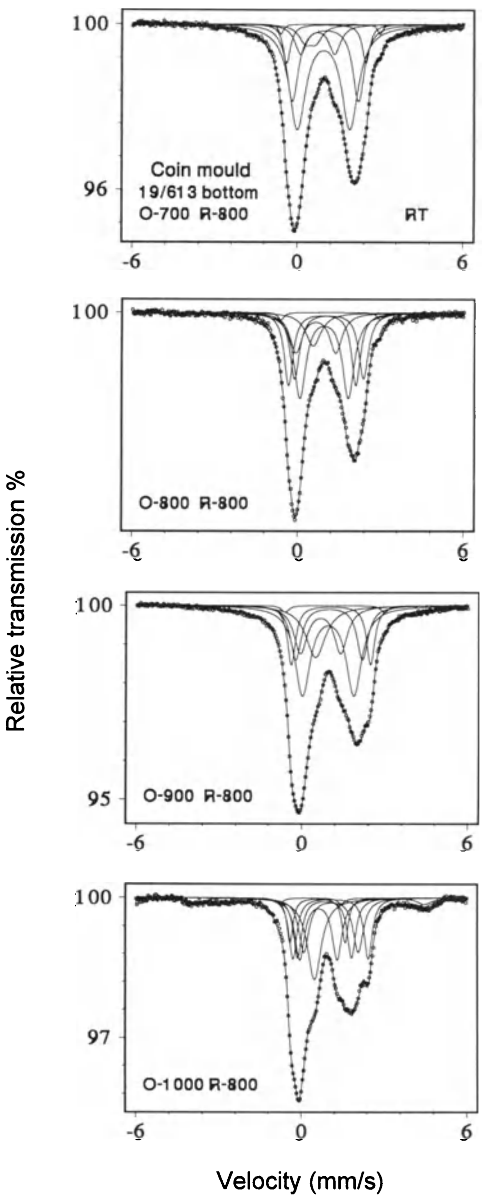


Fig. 14: Room temperature Mössbauer spectra of a sample from the bottom part of coin mould 19/613 refired under reducing conditions at 800 °C for 3 hours after a preceding refiring in air at increasing temperatures given in the spectra.

quadrupole doublet remains. It should be stressed that in this case vitrification with iron dissolved in the glass matrix obviously does not take place, since trivalent iron in the glass matrix would not be expected to show magnetic hyperfine patterns at room temperature. The weak garnet doublet makes up 2.3 % of the spectral area after firing at 700 °C, and still 1.7 % after firing at 900 °C, but it is gone after firing at 1000 °C. This once again shows the suitability of the garnet component as an indicator of the firing temperature. One should note, however, that the garnet doublet cannot be seen at 4.2 K since at this temperature almandine is magnetically ordered and the complicated magnetic hyperfine pattern (Murad and Wagner 1987) is too weak to be observed in most cases. For the strong garnet component in the mudplaster, however, the magnetic hyperfine splitting at 4.2 K was observed.

A sample from the bottom part of coin mould 19/613 was refired in the laboratory under reducing conditions produced by heating it together with charcoal in a closed quartz vessel (Fig. 13). Already after such a reducing firing at 800 °C the iron has practically all become divalent. The spectra change but little on firing at higher temperatures, except for the formation of metallic iron, which sets in at 950 °C and has become quite strong on firing at 1000 °C. The shape of the divalent pattern, which consists of a superposition of several quadrupole doublets, changes somewhat with the firing temperature, reproducing shapes also found in the coin moulds. It is interesting to note that the result of refiring a sample from the bottom of coin mould 19/613 under reducing conditions at 800 °C after a previous laboratory firing in air at various temperatures up to 900 °C always yields similar final products, irrespective of the temperature of the preceding oxidizing firing (Fig. 14). The reducing firing at 800 °C always produces practically only divalent iron, only the lineshapes depend slightly on the temperature of the preceding oxidizing firings for reasons that have not yet been clarified.

Many of the conclusions drawn from the Mössbauer data are still tentative. Further experiments will certainly answer some of the open questions. Even now, however, it has become clear that Mössbauer spectroscopy is capable of revealing many interesting features of the ceramic materials that would otherwise pass unnoticed. A point of major interest is the temperatures which the coin moulds attained during the melting of gold. There is little doubt, and here Mössbauer spectroscopy confirms the conclusions drawn from the microscopically observed vitrification and from metallurgical arguments on the melting points of the produced noble metal alloys, that the upper surfaces of the coin moulds reached temperatures exceeding 950 °C. The temperatures attained by the cores and the bottom parts of the coin moulds are more difficult to assess. The most appealing interpretation of the Mössbauer data is that those coin moulds which still exhibit a major amount of trivalent iron in their cores and bottoms do so because the clay (of which we unfortunately do not have an unfired representative, since the mudplaster (19/204) cannot be considered as a reliable model material) contained predominantly trivalent iron, which is the rule for practically all pottery clays.

The atmosphere in the hearth must always have been reducing, as is to be expected in the presence of charcoal at the temperatures prevailing in the hearth. The maximum temperature to which the cores and bottoms of the coin moulds still containing Fe^{3+} were exposed therefore cannot have exceeded 600 °C, since at higher temperatures the Fe^{3+} would have been reduced to Fe^{2+}. Coin moulds with cores and bottoms containing mainly divalent iron must then have become hotter, i.e., hot enough for a virtually complete reduction of the Fe^{3+} to Fe^{2+}. The presence of metallic iron in the cores of some coin moulds shows that these must have become hotter than about 900 °C. The generally observed absence of metallic iron in the bottom layers indicates that these never got hot enough for reduction to metallic iron to take place. The reduced state of the iron in the bottom layer and in the surface of the coin moulds shows that after the gold melting process the coin moulds were allowed to cool at least to below about 400 °C before they were taken out of the hearth, since else the surfaces would exhibit an oxidized layer, as do many pottery sherds from Manching (Bott et al., 1994a, 1994b) and elsewhere (Wagner et al. 1986, 1988, 1992, 1994).

6. Conclusions

The scientific study of the ceramic materials connected with the production of gold coins in the Celtic oppida is still going on. This report reflects the present state of knowledge, but it already permits a tentative description of the way in which the coin blanks were produced.

The coin moulds, filled with appropriate amounts of gold grains or dust, with added silver, copper, or bronze were covered with charcoal, perhaps with charcoal that was already glowing. The hearths were rather small with a section of about 25 x 25 cm (Gebhard 1994). Whether the coin moulds were also sitting on beds of charcoal is doubtful. The fact that the bottoms never show signs of having become hotter than the cores might argue against this. Air was blown from one or, more probably from two opposed tuyères sideways and above the coin mould into the bed of charcoal. In this way the temperature of about 1000 °C needed for gold melting was attained. This high temperature was reached only on the upper surface of the coin mould. Owing to the abundance of hot charcoal, the hearth atmosphere was reducing throughout the firing cycle and throughout the hearth. The intense heat that caused the upper faces of the coin moulds to vitrify was maintained only briefly, otherwise the cores and bottoms of the coin moulds would have become hotter than they actually did. From the Mössbauer data for many of the coin moulds one concludes that the hearth must have been allowed to cool under reducing conditions. If it had been opened before the temperature had fallen below about 400 °C, the divalent iron in the ceramic material would again have oxidized to trivalent iron. During this cooling process, the temperature must have fallen so rapidly that the oxidized bottoms and cores of the coin moulds did not become hotter than about 600 °C by heat conduction from the top.

These notions on the production of Celtic gold blanks are precise enough to be field tested in a reconstructed hearth. A first experiment of this kind was recently performed by the authors and succeeded in the melting of pure gold ingots of the size used for Celtic gold coins. During this experiment, the temperatures in the upper surface layer, in the core and in the bottom layer of the replica coin mould were measured by thermocouples. The results confirm the conclusions from Mössbauer spectroscopy that only the uppermost part of the coin mould reached temperatures near 1000 °C, while the core and the bottom reached temperatures between 400 and 800 °C only. Further field experiments planned for the future will also aim at producing fired coin moulds, which can then be subjected to a comparison with the ancient specimens.

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Chapter 4

GOLD ANALYSIS: FROM FIRE ASSAY TO SPECTROSCOPY - A REVIEW

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ABSTRACT. Analytical methods and techniques for the determination of gold contents are employed in the exploration and evaluation of gold deposits, grade control in primary and secondary production, the assaying and hallmarking of gold and its alloys in jewellery, and in the study of coins, archaeological finds etc. and in provenance studies.
The methods range from those known since antiquity (e.g. fire assay, touchstones, specific gravity measurements) to modern spectroscopic (emission, absorption, induced coupled plasma etc.) and non-destructive fluorescence (X- and gamma-rays in the widest sense) and radioactive (neutron activation) techniques. The review includes an extensive list of references.

1. Introduction

The analysis of gold from ores to artifacts requires a variety of techniques unique to this paramount precious metal. In terms of concentration, several orders of magnitude have to be bridged. Obviously, no general method is capable of covering this whole field. Thus any review has first to define the various analytical applications. Apart from wide concentration ranges, the determination of gold contents - especially in objects of archaeological value - is only too often restricted to non-destructive methods. This additional requirement adds a further dimension (and restriction) to the list of available methods.

Any discussion and review of analytical techniques for the determination of precious metals - and gold in particular - has to differentiate between the following fields of application:

- Techniques used in exploration and evaluation of gold deposits,
- Analytical methods required in control of primary and secondary gold production,
- Characterisation of high-grade gold and its alloys, including provenance studies.

Following this sequence, the paper will discuss the methods specific to the various fields of application.

2. Exploration and evaluation of gold deposits

The concentration range likely to be encountered in these applications extends from ca. 0.05 ppm to above 50 ppm (1 ppm = 1 g/t).

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 303–315.

2.1 FIELD METHODS

As kown by every prospector looking for placer gold, the panning dish or *batea* is a powerful analytical tool, provided the operator has sufficient experience not to lose any material during the concentration process. If sampling is based on a defined volume or weight of material (e.g. using buckets of known volume), quite reliable quantitative gold determinations are possible in the field. Where the panning operation can be carried on until "nuggets" (normally only tiny grains) are isolated from associated heavy mineral particles, a so-called grain-size chart is a very useful aid. It helps to find the relation between particle size and weight. The following six classes (in miner's terminology *colours*) of grains, recommended by Utter (pers. communication) are (Table 1):

Table 1. Grain size table giving the relation between gold particle size and weight.

Group or Colour	Size (in mm)	Average Weight (in mg)
0	0.062 - 0.125	0.02
1	0.125 - 0.25	0.09
2	0.25 - 0.5	0.98
3	0.5 - 0.8	2.54
4	0.8 - 1.0	8.18
5	1.0	16.45

After completion of the panning operation, sorting and counting the gold grains, the final step in grade determination is performed as illustrated by the example in Table 2. Assuming a total sample weight (prior to panning) of 8.8 kg, the following gold grains are supposed to have been isolated:

Table 2. Example for a calculation of the total gold content of a sample from colour and number of grains.

Colours	Number of Grains	Total Weight
0	8	8 x 0.02 = 0.16
1	1	1 x 0.09 = 0.09
2	1	1 x 0.98 = 0.98
4	4	4 x 8.18 = 32.72
		Sum = 33.95

The deposit thus sampled and evaluated has a gold content of: 33.95 mg/ 8.8 kg = 3.85 mg/kg = 3.85 g/t.

Another method of determining the gold content in bulk samples is the treatment of the concentrate with mercury. The resulting gold amalgam (more correctly gold/silver amalgam) is decomposed by heat, preferably by distillation to recover the mercury and to avoid the highly toxic effects of mercury vapour. Purification of the recycled mercury is carried out in the field by dissolving the mercury in nitric acid and precipitating the metallic mercury from its nitrate solution by inserting copper rods, as witnessed by the author in Brazilian gold exploration camps.

The modern method of BLEG-sampling (Bulk Leach Extractable Gold) uses soil samples of 2 to 5 kg which, after leaching with cyanides, enable the prospector to determine the gold contents in the pregnant solutions by spectroscopic methods, e.g. atomic absorption spectroscopy (AAS). The method is very sensitive and able to detect gold anomalies well down into the ppb-range. As many samples are normally analysed during an area survey, the accuracy of the single determination needs not to be very high. Therefore, simple equipment which can be operated in a field-site laboratory is quite adequate (Lehne: pers. communication).

During the last, and until the beginning of the present century, a knowledge of blow-pipe techniques was mandatory for mineralogists and prospectors. With only a few pieces of equipment and some basic chemicals qualitative and even reliable quantitative determinations could be carried out under virtually any conditions everywhere. The subject was a major teaching topic at many mining academies with Freiberg/Saxony taking the lead, where C.F. Plattner (1835) published his famous book, which went through numerous editions and was based on several earlier publications by Berzelius and especially Harkort. However, Plattner's *"Probierkunst mit dem Löthrohre"* covered a much wider field of applications and was based on extensive personal experience. His quantitative analysis of gold ores in the field was a short-cut, fire assay technique (cf. below), producing tiny gold beads which were often too small to be weighed (on a small collapsible field kit balance); they were measured with a special ruler (Fig. 1) which enabled direct correlation of bead diameters with weight; (cf. Krug 1914).

Plattner's book had many successors, e.g. Frick and Dausch (1932) and Henglein (1962). Hardly any books have appeared on this subject in recent years. During the era of spectacular gold discoveries in the New World, this useful method was not only propagated, but even extended in the USA (Brush 1890).

2.2 LABORATORY METHODS

Turning from analytical field techniques to laboratory methods, the foremost place is taken by fire assay. Known, perhaps, since the 4th millenium B.C., this versatile procedure - essentially a laboratory scale pyrometallurgical extraction of gold with lead as collector, subsequent oxidation of the resulting lead-bullion button by cupellation,

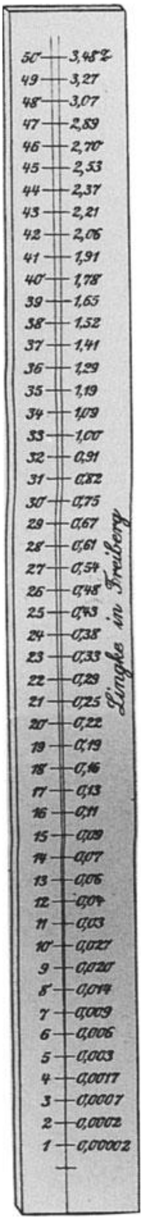

Fig. 1: Ruler used to determine the weight of gold beads. From Plattner (1835).

and isolation of a bead with all the precious metals originally contained in the sample - is still used worldwide for the analysis of high- and low-grade materials. In connection with exploration and evaluation, gold contents below even 0.5 g/t in waste dumps etc. are just as amenable to this method as all types of primary ore.

The history and development of fire assay through the ages is a subject which would merit a monograph of its own. We not only have detailed descriptions of this technique from such renowned authors as Biringuccio (1540) and Agricola (1556), but many less well known writers have also given prominence to the subject and have made contributions; cf. the impressive list of early books on assay methods, including many editions of the so-called *"Probierbüchlein"* (Booklet on Assaying), collected by Annan (1960). Good reviews of early assay practices applied to precious metals were given by Oddy (1983) and Nriagu (1985).

Sampling of material from surveys, exploration campaigns and producing gold mines for fire assay requires practices set out in relevant guide-lines, e.g. by Lüschow (1980, 1989). A representative sample of gold ore is one which attempts to eliminate the "nugget effect". If, for example, a sample is supposed to contain the metal in a concentration of ca. 4 g/t, the gold is most probably not distributed homogeneously in the rock or sediment matrix. No matter how small, the particles in gold-ore specimens have a definite size. Thus, the larger the sample weight, the more representative it is with regard to the statistical distribution of grain size groups (or *colours*). However, for routine analysis a sample weight has to be chosen which can be handled with respect to crucible size, laboratory furnace capacity, time of processing etc.). A sample weight of 25 g is a good compromise (Bachmann 1992). With the hypothetical gold concentration mentioned above (4 g/t), fire assay will give a bead containing 0.1 mg of gold (+ silver + platinum group metals, if present). This is a bead weight which can still be weighed on a normal analytical balance, though a micro-balance is sometimes preferable. Another method to obtain beads which can be weighed with sufficient accuracy - particularly when the gold content is unknown - is the intentional addition of silver to the assay charge.

Fire assay by lead collection and followed by cupellation gives a metallic bead containing all the precious metals contained in the sample analysed; gold and silver with high accuracy and with some restriction most of the platinum group metals as well. If gold and silver have to be determined, they have to be separated from each other by nitric acid, leaving the gold unaffected and bringing the silver into solution in which it can be analysed by conventional methods (titration etc.); the gold residue can be weighed. Complete solution of the cupellation bead - preferably after being milled into a thin strip to increase its surface area - is the mandatory preparation for most spectroscopic methods, e.g. atomic absorption spectroscopy (AAS).

The numerous text- and handbooks on gold analysis cover many analytical procedures as derived from practical experience. Emphasis can either be placed on the determinations of low gold concentrations, e.g. in ores, sweeps (i.e. gold-containing non-metallic materials, such as dust, slags, slurries), or on richer materials. Virtually every aspect of assay techniques is covered in the comprehensive, critical and up-to-date books by Chemikerausschuß (1964), Beamish (1966), Beamish and Van Loon (1972, 1977), Lenahan and de Murray-Smith (1986) and Stoch (1986).

Though fire assay still counts as a universal and reliable analytical method - particularly in the analysis of low-grade materials - it has occasionally received critical comments, recently by von Hase (1989) and Gasparrini (1993). Minor systematic errors are still under investigation. Small losses through volatilisation during smelting and/or cupellation have always been taken into account by renowned laboratories. A laboratory manual, issued 80 years ago by the Deutsche Gold- und Silberscheide-Anstalt (1914), gives sets of data for *Kupellenzug* (i.e. cupellation losses) - varying with the gold-silver ratio in the samples to be analysed - which have to be added to the final results.

An interesting, highly sensitive combination of precipitation of gold with lead sulphide, followed by cupellation and subsequent fusion of the bead in borax to remove any associated silver was published by Haber (1927) in his paper on the sensational proposal to repay the German war debts after World War I by the recovery of gold from seawater. Haber (1927) claims a high accuracy for his method with a limit of detection near 1×10^{-10} g of gold.

Low gold concentrations in solutions can also be determined by colorimetry of intensively coloured gold compounds, like Purple of Cassius, gold complexed with hydrazine sulfate etc. (v.Philipsborn 1953, Haber 1927).

3. Control in primary and secondary gold production and recovery

With gold contents from below 5 to above 5000 g/t, the analytical methods employed by gold mines (primary production) and recycling plants (secondary production) are not very different from those already dealt with in the previous sections, especially where laboratory methods are concerned.

The South African Chamber of Mines has developed a portable, battery-operated X-ray fluorescence (XRF) gold analyser (Jörn 1993) equipped with a radioactive cadmium source. This instrument is capable of detecting gold contents in ores as low as 1 g/t at a distance of 2 to 6 centimetres from the rock face with a measuring time of about 1 minute. The penetration depth of the emitted gamma-rays is 25 millimetres. The instrument is used for routine grade control in underground mines.

A further improvement in "on site" gold analysis was recently reported also from South Africa (Anonymous 1993). Detection limit for this advanced XRF-spectrometer, named "Goldstream" and introduced by the Western Deep Levels Mine near Johannesburg for routine production control, is as low as 0.05 g/t. This, however, can only be achieved with measuring times of 30 minutes. No further technical details of this portable instrument are as yet known.

4. Gold and gold alloys

With a concentration range of ca. 10 to 100 % gold, the analytical methods for metallic materials have to be divided into destructive and non-destructive techniques.

4.1 DESTRUCTIVE METHODS

Here, too, fire assay is the most prominent technique. Metallic samples, such as ingots, semifinished products, coin blanks and minted coins, metal artifacts, gilded surfaces etc. are normally high in gold. Here the strength of fire assay lies not so much in the concentration of low gold contents in the collection step, but more in the elegant and efficient removal of impurities, e.g. base metals. The importance and reliability of fire assay was convincingly pointed out by Evans (1992), Deputy Warden of the London Assay Office, which is part of the Goldsmiths' Company. In the United Kingdom, fire assay has been in use for hallmarking objects made of precious metals since 1238. For accurate determinations sample weights of only 50 to 250 mg are recommended. According to Evans (1992):

"Fire assay is the only method capable of meeting UK legal requirements for gold."

However, fire assay is not non-destructive, though in classical assaying, the gold prill, isolated by the assaying processes (smelting or fusion with lead and cupellation) is physically present after weighing, i.e. no loss in precious metals is incurred. Spectroscopic methods, which require very little material (in most cases a few milligrams of homogeneous material) have augmented or even substituted fire assay in many laboratories. But even the removal of samples of only a few milligrams in weight is often not acceptable when valuable objects have to be characterised. In these cases, absolutely non-destructive approaches have to be taken. It is, therefore, a question of where to draw the line between destructive and non-destructive methods: a better classification criterion would be: Methods without loss of sample material, no matter how small, and others.

Spectroscopic analyses are very sensitive and thousands of museum objects have been analysed by emission spectroscopy and other spectroscopic methods. The removal of tiny amounts of material was generally acceptable. The most impressive summary of analytical data on archaeological gold objects is listed in the book on prehistoric gold finds from Europe by Hartmann (1970). Further studies along this line include investigation of a pre-Hispanic gold chisel by AAS, microprobe, microhardness and metallographic examination by Scott and Seeley (1983). A paper by Otto (1939) stands out as perhaps the first critical examination of prehistoric gold objects from Germany by ESA.

Sampling of precious museum objects for analysis requires precaution; some of its aspects are discussed by Pernicka (1989). Preparation of solutions of gold samples for those analytical methods requiring liquids, like AAS and ICP, was described by Scott (1983).

Though wet chemical analyses of gold coins are rarely carried out these days, it is of historic interest to appreciate the skill with which an elaborate procedure for coin analysis was developed and performed at the beginning of this century by the former German Technische Reichsanstalt (Mylius 1911).

Probably even older than fire assay is the use of touchstones for the identification of gold and its alloys. The comparison of standards with unknowns is the basic principle of working with touchstones: The trace of a streak of a gold alloy of unknown composition on the smooth surface of a black siliceous schist - i.e. a touchstone - is very characteristic of the particular alloy producing this streak. It can either be compared with streaks of standards or attacked with acids of varying concentrations. A weak acid will remove low carat gold alloys, while high-gold alloys are more resistant. Skilled operators can thus distinguish between a large number of jeweller's alloys quite easily. The papers by Ahlberg et al. (1976a, 1976b), Eluère (1985, 1986) and by Moore and Oddy (1985) give good summaries and describe very early examples of touchstone application.

A method of analysing streaks from samples by microchemical methods was developed and advertised not only for nearly all the base metals, but also for precious metals as well by

Ballczo and Mauterer (1979). However, this approach has failed to establish itself as an alternative to other techniques.

4.2 NON-DESTRUCTIVE METHODS

The answer to the question, "Who performed the first truly non-destructive precious metals' analysis?" is Archimedes, who investigated the crown of Hieron II. of Syrakus (306 - 213 B.C.). The loss of weight observed after immersion of the gold/silver crown in water could be directly related to the alloys's composition. It is the merit of Oddy (1972a, 1972b) and his coworkers (Oddy and Hughes 1972, Oddy and Schweizer 1972, Oddy and Blackshaw 1974, Oddy and Munro-Hay 1980) that the specific gravity method was critically assessed, compared with other methods, and tested on series of coins. The specific gravity method is used to an increasing extent to augment other non-destructive approaches, especially XRF, in coin characterisation. Though problematic in its application to ternary alloys, it is a reliable and informative method when binary alloys of gold with silver or copper have to be dealt with. Modern electronic balances and the use of liquids with high density, e.g. perfluordecaline, $C_{10}F_{18}$, d = 1.942 gcm^{-3}, increase the accuracy of the specific gravity method significantly.

The most versatile method in non-destructive precious metals analysis is X-ray fluorescence spectroscopy (XRF), which has as its main disadvantage the very low depth of penetration of X-rays into the sample matrix. In other words, exact analytical data obtained by XRF are restricted to surface layers often only a few micrometers thick. If this limitation is borne in mind, and if calibration is based on a sufficiently large number of accurate standards in combination with physico-mathematical interelement corrections, XRF is unsurpassed in reliability, speed and specimen protection. XRF and NAA (neutron activation analysis) as strictly non-destructive methods have been employed in many research projects on gold coins, jewellery etc.; either alone or in combination with other techniques to verify or to critically assess the XRF-data.

Papers published during the last twenty years of non-destructive analytical methods include:

- Araujo et al. (1993): Comparison of energy-dispersive XRF- with PIXE (proton-induced X-ray emission)-results,
- Bodenstedt (1976, 1981): Studies of electron coins from Phokaia and Mytilene, employing XRF, NAA, specific gravity determinations and radiography (to check coins for voids and inclusions),
- Capello et al. (1973): Use of NAA to determine gold, silver and copper in ancient and rare coins,
- Cesareo and von Hase (1973): Radio-isotope XRF of ca. one hundred Etruscan gold objects from burials,
- Coleman and Wilson (1972): NAA of Merovingian gold coins from the Sutton Hoo ship burial,
- Cope (1972): NAA and mass spectrometry of a Roman aureus,
- Cowell (1977): Energy-dispersive XRF of Celtic and late Roman coins,
- Darling and Healy (1971): Study of Greek gold-silver-copper alloys by XRF, radiography, hardness tests, microprobe etc.,

- Demortier (1984a, 1984b, 1984c, 1986, 1989, 1992a, 1992b) and Demortier and Hackens (1982): Numerous studies of ancient jewellery, brazing alloys, copper-gold-cadmium solders etc., mostly by PIXE,
- Fabris and Treloar (1980): Comparison of XRF- and AAS-analyses of gold objects from Sarawak/Malaysia,
- Ferreira and Gil (1981): PIXE of 18th to 19th century gold coins,
- Gillies and Urch (1985): Investigation of a pre-Columbian tumbago pectoral disk (tumbago = gold-base metal alloy) by XPS (X-ray photoelectronic spectroscopy),
- Gordus and Gordus (1974 and 1980): NAA of gold impurities in silver coins and art objects from several eras and many countries,
- Klockenkämper et al. (1990): XRF of German gold coins from the late 19th to the early 20th century,
- Kowalski and Reimers (1971, 1972): NAA, XRF and specific gravity measurements of medieval gold coins,
- Love et al. (1980): XRF, SEM (scanning electron microscopy) and scanning electron Auger spectroscopy of ancient gold coins and their modern copies,
- Mommsen and Schmittinger (1981): High-energy PIXE employed for analysis of ancient gold and silver coins,
- Oddy and La Nice (1986): XRF of Byzantine gold coins and jewellery,
- Piette et al. (1986): PIXE of gold solders, brazing alloys and various artifacts,
- Radcliffe et al. (1980): Coin analysis by differential absorption of gamma-rays,
- Reimers et al. (1977): Gamma-ray activation analysis and its advantage compared with NAA for the analysis of precious metal objects, including coins,
- Schweizer and Friedmann (1972): Comparison of NAA, XRF and wet chemical methods for determination of gold and silver contents in coins,
- Voûte (1985 and 1991): XRF of Celtic gold coins,
- Wilde and Paschmann (1989): Microprobe analysis of ancient Indian gold coins,
- Ziegaus (1991): XRF of Celtic gold coins.

All the papers cited refer to laboratory examinations. Modern concepts and miniaturisation of components have resulted in the design and development of mobile XRF-units. These can be brought to museums and art collections rather than vice versa, thereby eliminating the worries and refusals of curators etc. who have strong objections to seeing valuable objects removed from their collections. Results of an on-site analytical programme, including investigation of Roman gold artifacts, have recently been published (Bachmann 1993).

5. Provenance studies

Analyses of gold artifacts have occasionally been aimed at localising the source of gold from which the object was made. These comprise, for instance, the analysis of platinum-group element inclusions. These data have rarely been conclusive, as shown by Meeks and Tite (1980). If trace elements are characteristic of types of gold from certain deposits, NAA is perhaps the most appropriate method to apply.

Recently, a new, highly sensitive and accurate method of gold fingerprinting by "laser ablation inductively coupled mass spectrometry" was developed by John Watling. So far, only press releases and reports by science journalists (Gooding 1993) give some information about this technique. A detailed publication is still lacking. Watling was successful in establishing the exact sources of gold stolen in Australia. He predicts that the precise trace element profile he is able to establish for any type of gold will also enable him to identify gold sources of early coinage and thereby get a more accurate picture of human movement, trade routes etc.

6. Outlook

Electrical conductivity and ultrasonic probes are modern developments that give accurate results when is comes to distinguishing between different metals and/or alloys, provided the measurements are based on calibration with standards of known composition. These methods have so far only been employed occasionally to detect frauds and falsifications, but they may eventually be useful in artifact analysis as well.

New methods of gold analysis will almost certainly be introduced in the future. Though each new analytical approach widens the range and offers new possibilities, they will, nevertheless, only be additions to established and irreplacable methods, such as fire assay, the most ancient, and still most universal technique in many fields of gold evaluation.

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Chapter 4

ON NON-DESTRUCTIVE ANALYSIS OF GOLD OBJECTS

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ABSTRACT. Fourtyfour massive and visibly plated Celtic gold coins deposited in the Basel Museum of History have been analysed by non-destructive ED-XRF (Energy-Dispersive X-Ray Fluorescence Analysis). The chemical composition of the mainly ternary alloys ranges from above 95 % down to below 20 % Au with silver prevailing over copper in all coins except Triquetrum types. Since silver can be analysed by either its low energy L-line, or its high energy, K-line with very different penetrating power, non-destructive studies can be made in the technology of surface treatment, i.e. plating and depletion gilding.

1. Introduction

Non-destructive analysis is of interest in several fields of materials science, e.g. in forensics, questions of authenticity, but also in archaeology/archaeometry. The term "non-destructive" seems to be self-explanatory, but is in fact used inconsistently. It is defined here in its strict sense: an analytical technique is non-destructive, when neither sub-samples have to be taken, nor detectable alterations are induced. Thus, no polishing, drilling, scratching must be performed.

If a scientific analysis of an archaeological object has to be executed, at least three main reasons exist to do it in a non-destructive way:

1. Objects of art, of value whatsoever, of cultural heritage must not be damaged by material analysis.
2. The selection of second-rate, or scrap objects for analysis may lead to biased results, and should therefore be avoided.
3. The examination of very small sub-samples - which would keep the object quasi-unaltered - has its specific problems, for sample size and representativity are correlated. The smaller a sub- or micro-sample is, the less representative are the analytical results obtained. An ideal would be to perform series of microanalyses on each object in order to measure the homogeneity, but this approach is seldom realized because of the effort needed.

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2. Analytical methods

Several methods of truly non-destructive bulk analysis exist, among which density determination, neutron activation analysis (NAA), X-ray fluorescence (XRF), X-ray diffraction (XRD) are the most wide spread.

2.1 DENSITY DETERMINATION

The determination of the specific gravity (density) of solids by immersion in liquids and buoyancy measurement is a fast method and quite reliable, provided that the object is heavy enough (1g or more), homogeneous and not porous. Since weighing an object before analysis is always a good practice, the density may be determined at the same time. If the elements present in a binary alloy are known, the average composition can be derived from the density. If, however, the alloy is ternary, or if the main components are not known, the chemical composition cannot be deduced from the measured density.

The density of gold objects gives on the other hand essential information on aspects of possible heterogeneity: a gold-plated coin will display a lower specific weight than its massive equivalent. Hence density is a useful information in numismatic studies. In combination with the calculated specific weight (based upon instrumental surface analysis, like XRF) the measured density may give clues to surface treatment of gold objects (Oddy and Cowell 1993), such as depletion processes and plating.

2.2 NEUTRON ACTICATION ANALYSIS (NAA)

Neutron activation analysis (Potts 1987) is a very sensitive analytical tool for certain elements, but not for all those relevant in e.g. numismatics. According to the elements present and excitation conditions, isotopes of long half life may occur, making NAA unsuitable for routine work. As with all other bulk chemical methods NAA is susceptible to sample heterogeneities, in that the analytical result will represent an average of the entire body, i.e. core and possible rim (e.g. corroded surface layer).

2.3 X-RAY FLUORESCENCE ANALYSIS (XRF)

X-ray fluorescence analysis has been in use for some 70 years, and is a versatile, sensitive and highly specific method for the bulk analysis of main components and trace elements in solids. All elements of the periodic system with Z ranging from 5 (boron) to 92 (uranium) are detectable with Wavelength-Dispersive XRF (WD-XRF), whereas Energy-Dispersive XRF (ED-XRF) covers the elemental range from Z = 11 (sodium) to 92 only (Bertin 1978, Potts 1987).

WD-XRF is a sequential technique, whereas ED-XRF is in principle simultaneous. This implies that in WD-XRF only elements which were a priori looked for are recorded, although an initial qualitative WD-XRF scan is, however, always available. In ED-XRF all main elements are detected, even the unexpected ones. A principal disadvantage of ED-XRF theoretically is the presence of diffraction phenomena which are a possible source of error in trace element analysis. Hence, careful background suppression by suitable primary filters is necessary. Another weak point of ED-XRF is its reduced sensitivity for certain elemental and concentration combinations: e.g. platinum as a trace element in a gold alloy is difficult to analyze for very low Pt-concentrations.

Both, WD- and ED-XRF are quantitative methods when the object is homogeneous, and when the surface is flat, clean, and free of corrosion layers. Archaeological objects seldom match these prerequisites, the analytical results are therefore considered to be qualitative, though counting statistics are excellent and relative errors for that reason small. Unfortunately, there exists no clear definition of "quantitative" and "qualitative" chemical analysis, because the accepted relative errors are concentration-dependent, and also a matter of tradition and agreement (Fig. 1). Thus the result of 1000 ppm silver in a gold alloy means that for a quantitative determination a relative error of 2 to 5% has to be expected, the "true" value being somewhere between 950 and 1050 ppm with a probability of 68%. In qualitative analysis this range is accordingly larger, namely 850 to 1150 ppm. High concentrations display their respective errors also. A reported concentration of 99.0% Au means that the "true" quantity is somewhere between 98 and 100%. This implies that a quantification of 99.99% Au is hardly possible by direct instrumental gold analysis.

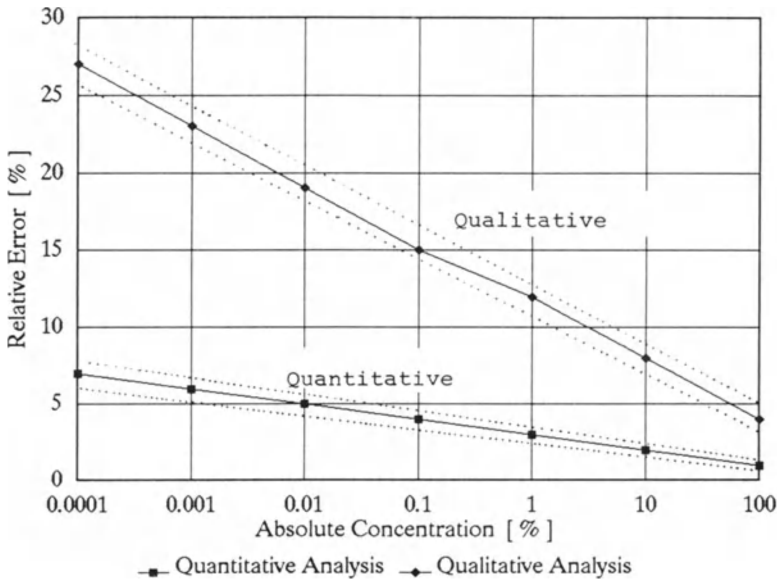

Fig. 1: Accepted relative error and absolute concentration, computed after Potts and Kane (1992).

Fortunately the determination of gold fineness to digits after the decimal point is not of importance in archaeometry; essential is the general description of the alloy, and the "fingerprint" of trace elements possibly linked with technological aspects and provenance.

With coins both techniques, WD- and ED-XRF, can be used. Since the diameter of gold and silver coins varies considerably, a minimum surface area for analysis (3 mm diameter) is defined here which fits the majority of specimens. If the spot size is too large, the sample holder will be analyzed as well; if it is too small, counting statistics will deteriorate. A special collimator was designed and built, which reduces the spot size to an ellipse of 2 by 3 mm and fits into the specimen chamber of the ED-XRF spectrometer, but not into the WD-XRF equipment. All analyses on coins were for that reason executed by means of ED-XRF, though it displays a lower analytical sensitivity than WD-XRF (Fig. 2).

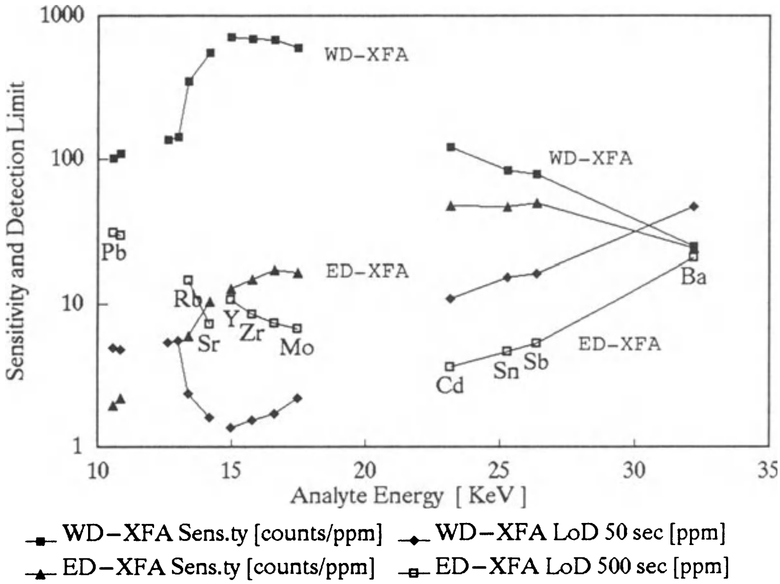

Fig. 2: Sensitivity - in terms of counts per concentration unit- and limit of detection (3 σ counting statistics) in wavelength- and energy-dispersive X-ray fluorescence. The same standard specimen (VsN) was used in a SRS-303 (WD-XRF) and a Spectrace-5000 (ED-XRF) and tested under "fair" conditions of comparison. The sensitivity of WD-XRF is for all tested elements better, but detection limits of the elements Ag, Cd, Sn, Sb are lower in ED-XRF under given analytical conditions.

Detection limits obtained this way are relatively low and may in favourable cases go down to 5 ppm (gold in silver).

A principal problem of XRF is the fact that X-rays are strongly absorbed by solid matter. XRF is therefore mainly surface analysis and susceptible to heterogeneities in direction of the specimen z-axis, i.e. depth. The critical thickness from which analyte X-rays stem is energy- and matrix-dependent. As a consequence the Kα radiation of silver may stem from a depth of up to 160μm (silver alloys), whereas the Lα radiation comes from a depth of at most 2 μm (in gold alloy as a matrix).

Whether K- or L-lines are used in metal analysis, depends largely from the specification of the instrument taken for analysis: in XRF the K-lines of Ag, Sn, Sb are prefered, in scanning microscopy or electron probe the L-lines are usually used. This implies that the analytically accessible depth profile is not only different from element to element, from matrix to matrix, but also from one instrument to another. The direct comparison of analytical data is as a consequence difficult and hardly possible when no information is given about the instrumental conditions involved.

Table 1. Calculated critical depth, from which 90 % of the analyte radiation stems (micrometre, programme AB V1 of Siemens Spectra-AT).

Analyte	Energy KeV	Gold alloy	Silver alloy	Bronze alloy
K-lines				
S	2.3	1	1	1 - 2
Fe	6.4	2 - 3	5 - 10	15 - 25
Cu	8.0	3 - 4	10 - 15	25 - 45
Zn	8.6	4 - 5	10 - 15	30 - 60
Ag	22.1	40 - 50	150 - 160	80 - 115
Sn	25.2	60 - 65	220 - 230	110 - 170
Sb	26.3	65 - 70	40 - 50	130 - 190
L-Lines				
Ag	4.2	1 - 2	1 - 3	1 - 3
Au	9.7	5 - 6	15 - 20	9 - 13
Pb	12.6	9 - 10	20 - 35	19 - 26

2.4 X-RAY DIFFRACTION (XRD)

Another non-destructive method of surface analysis is X-ray diffraction (Bish et al. 1989), which not only identifies mineral phases present at the specimen surface e.g. corrosion products on a coin, but is also able to give information about the last physical process involved in minting: cold working produces broad X-ray reflections where the $K\alpha_1/K\alpha_2$ doublets are not resolved. Tempering, on the other hand, improves crystallinity such that sharper reflections are observed, and the mentioned doublets are more or less resolved according to the diffraction angle (Fig. 3).

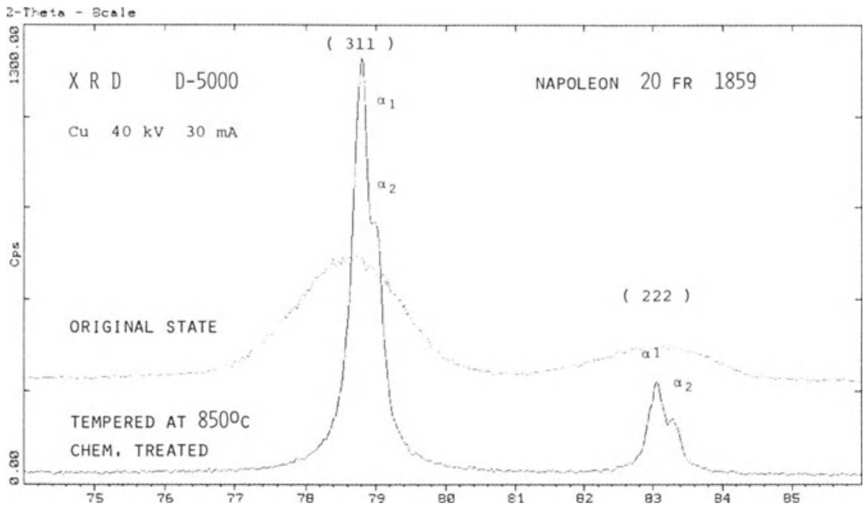

Fig. 3: X-ray diffractogram of a gold coin (Napoleon 20 Frs 1859). In its original state the coins displays the typical broad reflections of cold-worked noble metal, whereas the tempered and ammonia-treated coin shows the typical pattern of well-crystallized crystalline matter.

2.5 MATERIAL

All Celtic gold (N = 44), silver (N = 257) and bronze nominals (N = 403) deposited in the Basel Museum of History were analyzed by non-destructive ED-XRF. This work was part of an archaeometry programme supported by the Swiss National Foundation (grant Nr. 12-27858.89), by the Geochemical Laboratory and Archäologische Bodenforschung Basel-Stadt. A monograph on the subject has been accepted for publication (Burkhardt et al. 1993/1994).

Three contemporaneous Greek massive gold coins were kindly submitted for non-destructive analysis by a Swiss private bank (1 Philippou, 2 Alexandrou staters; Le Rider 1987, Price 1991).

Two Celtic rainbow staters were kindly supplied by Dr. G. Lehrberger from Technical University of Munich. These two gold coins had been sliced in Munich into segments in order to study the surface, and the interior as well (Lehrberger 1993).

Finally six Celtic, predominantly plated Philippou imitations from Tarodunum were used for comparison. Numismatic and analytical data on this complex are under preparation (Burkhardt and Dehn 1994).

3. Results

3.1 METROLOGY

Coin weight versus numismatic typology (Fig. 4) displays a clear decrease of the weight with time for all Philippou imitations ranging from full staters to quarters, the weight ratios (full-/half-/quarter-staters) remaining virtually constant.

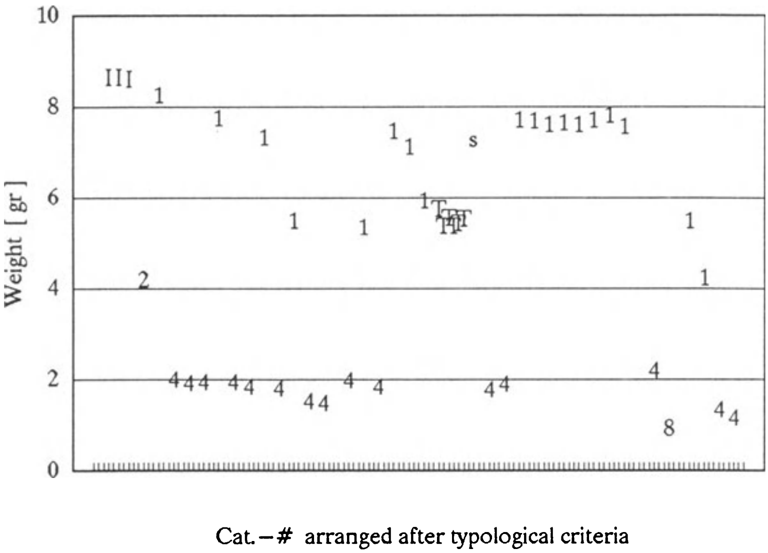

Fig. 4: The weight of Celtic and Greek nominals versus typology. The numbers refer to type of nominal: 1 = full stater, 2 = half, 4 = quarter; I = Greek Phillippou and Alexandrou staters; T = Triquetrum. For further numismatic information see Burkhardt et al. (1994).

The measured density, plotted the same way, shows a marked decrease with time (Philippou imitations), and also shows that macroscopically discernible plated specimens have a low density due to the bronze or iron core (Fig. 5). The possible density difference between massive and plated coins becomes, however, small for alloys with a low gold content. Hence clear evidence on plating is only given for coins with a high fineness.

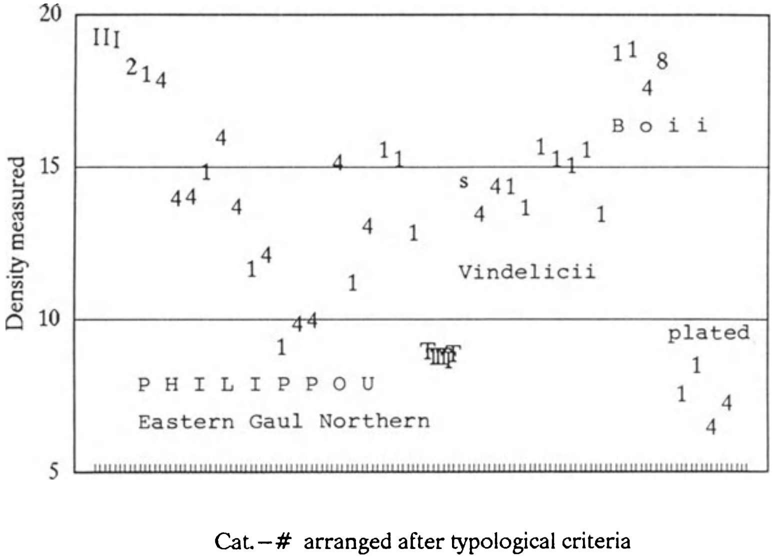

Fig. 5: The measured density of Celtic and Greek gold coins versus typology. For numismatic information see Burckhardt et al., 1993. The numbers refer to the type of nominal: 1 = full, 2 = half, 4 = quarter; I = Greek contempora - neous Alexandrou and Philippou staters; T = Triquetrum.

Since coin diameter and thickness remain virtually constant with time, one may assume that the size of mould and die were kept, but that the fineness of the alloy deteriorated.

Certain coins, like Triquetrum types, neither follow the Philippou metrology, nor do they have the same chemical composition.

3.2 CHEMICAL COMPOSITION OF GOLD NOMINALS

Fig. 6 gives an overview on the chemical main components of Celtic gold coins. In contrast to coined silver, a wide compositional field exists from a fineness above 95% Au down to below 20% without a marked frequency gap. Most alloys are ternary with silver and copper as main constituents. In most cases silver prevails over copper, except for Triquetrum types, which display a constant Au/Ag ratio of nearly 1, and a high, though varying, copper content.

The analysed contemporary Greek gold staters have a very high fineness of 99% gold and more and plot near the top of the ternary diagram in Fig. 6.

From the chemical analysis of the main components the density can be calculated, and compared with the measured one (Fig. 7). For approximately two thirds the correlation is high; for one third the calculated densities are much higher than the measured ones. One possible explanation is plating: since the bronze or iron core has a lower specific weight than the covering gold alloy, the experimentally determined average density is necessarily lower than the density derived from surface analysis. A second explanation is surface treatment, i.e. depletion on elements like copper and silver. Again, the calculated density will be too high, because of the surface analysis which finds too much gold.

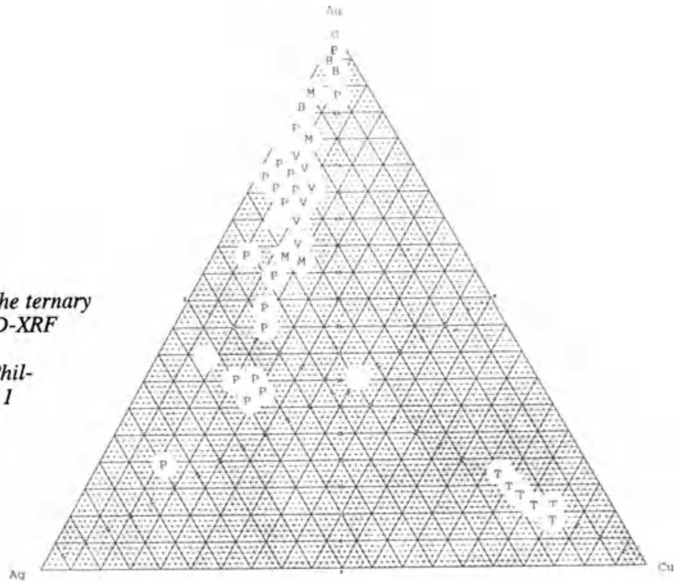

Fig. 6: Celtic gold coins, plotted in the ternary system Au-Ag-Cu. Non destructive ED-XRF analysis.
***B** = Boii; **G** = Greek Alexandrou, Philippou; **M** = rainbow staters Munich 1 and 2, averages of core and exterior; **P** = Philippou imitations; **T** = Triquetrum; **V** = Vindelicii; **Empty dots** = single coins of various origin; The dot size is larger than the estimated analytical 3 σ error.*

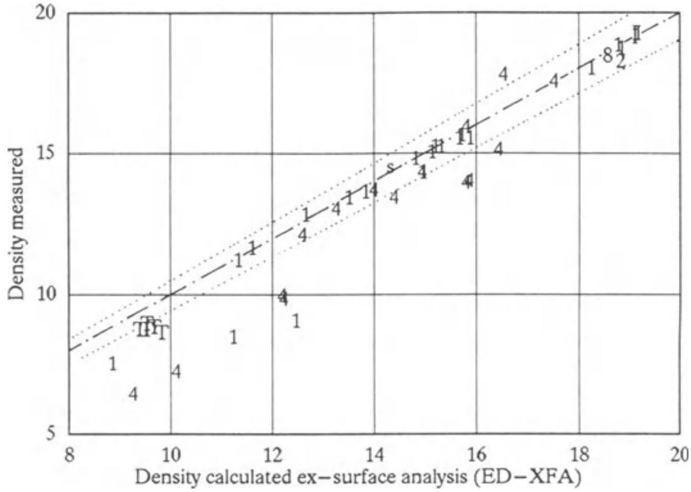

Fig. 7: Density measured and calculated from surface analysis by ED-XRF. The numbers refer to type of nominal: 1 = full stater, 2 = half, 4 = quarter; I = contemporaneous Greek Philippou and Alexandrou staters; T = Triquetrum.

Plating may be visible in many cases, especially when the plating is partially worn-off, but it needs not be visible always. From the 44 Celtic gold issues are four obviously plated (visible holes).

From 22 Philippou imitations four are visibly plated; from the remaining 18 pieces six display a calculated density which is more than 5% larger than the measured one. These coins are either plated or otherwise surface-treated, e.g. by a leaching processes (depletion gilding).

Depletion gilding is known from modern times, but is hard to prove from scientific analysis, when the object has to remain intact. By drilling holes, or by slicing an object the unaltered inner part becomes accessible - chemical analyses of core and exterior will be different, which has been proved with microprobe analyses by Lehrberger (1993). Two of his sliced gold staters have been analysed by the present author by ED-XRF; one (TU-M1) displays a very marked chemical difference between core and exterior (Tab. 2).

Table 2. ED-XRF of two staters (core vs. rim).

Average	wt.%	Ag	Au	Cu	Bi	Cr	Fe	Pb	Zn	Ag K/L	N
TU-M1	core	15.5	80.5	3.7	0.04	0.03	0.06	0.04	0.12	5.95	7
	rim	10.8	88.3	.66	0.03	0.00	0.11	0.02	0.07	29.5	6
TU-M2	core	28.3	55.7	15.6	0.05	0.11	0.04	0.11	0.05	5.51	7
	rim	30.2	56.9	12.2	0.06	0.03	0.51	0.06	0.06	13.8	7
Std-dev.											
TU-M1	core	.28	.34	.13	0.02	0.03	0.01	0.01	0.04	0.36	7
	rim	1.35	1.37	.04	0.02	0.00	0.02	0.01	0.03	9.65	6
TU-M2	core	.18	.13	.10	0.02	0.05	0.01	0.01	0.03	0.15	7
	rim	.92	1.00	.60	0.02	0.03	0.21	0.02	0.04	6.59	7

Stater TU-M1 which was shown to have an elemental zoning from the exterior to the core (Lehrberger 1993, microprobe) seems fairly heterogeneous also when analysed by means of a bulk chemical method, like ED-XRF. Stater TU-M2 which was considered to be rather homogeneous on the basis of microprobe analyses displays a weak heterogeneity only, when analyzed by XRF. Both coins are relatively poor in trace elements.

In contrast to microprobe analysis, where silver is generally analysed on the basis of its L-line (2.98 KeV), XRF prefers the K-Line because of its high energy of 22.16 KeV and penetrative power and lack of interference from other elements, e.g. Cd, Sn. As a consequence, XRF data of silver concern a considerably deeper part of the object than in microprobe analysis. One may expect also that from the intensity ratio of Ag K/L interesting insights are possible into the possible difference of depleted/plated exterior, and unaltered core (Fig. 8).

Repeated analyses of the unaltered core, and of the exterior of a plated stater display the same intensity ratio (Ag K/L), regardless the actual silver concentration (horizontal field representing the chemically unaltered gold alloy). Analyses of the exterior part, however, may show a strongly changing intensity ratio due to the small "critical thickness" from which the silver L radiation stems. It seems therefore that this intensity ratio makes a non-destructive insight into surface treatment possible: high ratios above 8 together with a marked difference in measured and calculated density are an evidence that surface alterations have occured, whereas a low ratio between 5 and 6 together with a density difference mean that the object is plated, but not chemically surface treated or altered by corrosion (burial).

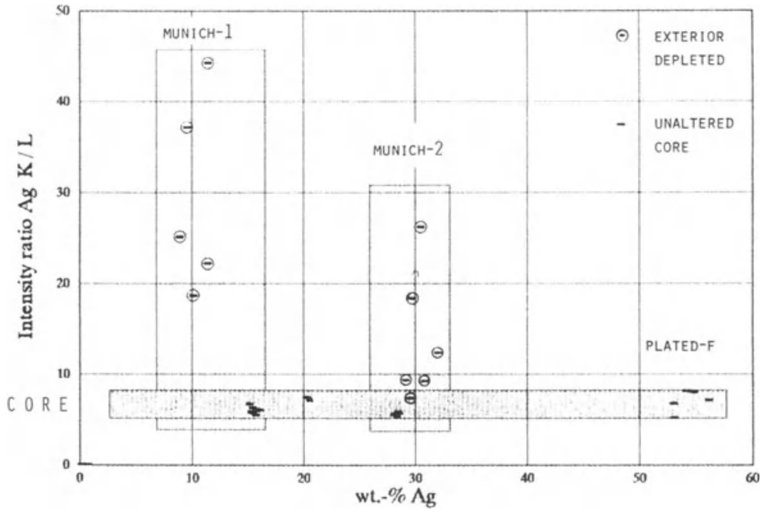

Fig. 8: Non-destructive information on the surface treatment of Celtic gold coins. The outside of a plated stater from Tarodunum (right) and the interior of two rainbow staters (Munich-1 and -2, left) have the same intensity ratio of Ag K/L: horizontal field "core". The exterior part of chemically treated staters TU-M1 and -2 display a largely varying intensity rario due to the shallow critical depth of the silver L-radiation (2.98 KeV).

These observations may be combined with results from X-ray diffraction. The few measurements executed so far on gold coins display broad reflections, typical for cold-worked metal (Fig. 9). Tempered silver or gold has very sharp diffraction peaks, where even the $K\alpha_1/K\alpha_2$ doublet is resolved at high diffraction angles (Fig. 3).

The combination of these different observations support the following assumptions about the technology of gold minting:

1. Flans of suitable size, but varying fineness are produced.
2a. The flans are struck without chemical treatment (assumed to have happened in two thirds of the studied Celtic gold coins).
2b. The flans become chemically treated, e.g. by boiling in ammonia, followed by striking which compacts the spongy Cu- and Ag-depleted, but gold-rich surface, or part of it. This procedure has possibly been followed in roughly 30 % of the studied coins.
3. An entirely different process is plating where the flan consists of bronze, or - seldom - iron, plated with the usual alloys made for minting.
4. Fire-gilding was not observed in the coins studied.

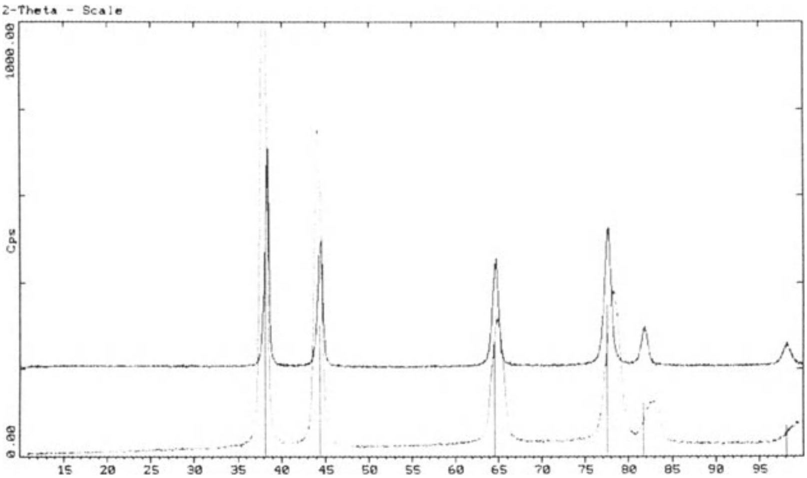

Fig. 9: X-ray diffraction pattern of two gold coins. Upper: Rainbow stater Munich-1, Lower: Napoleon 20 Frs 1859. Both patterns display the broad reflections which are typical for cold worked metals.

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Chapter 4

SOME EXPERIENCES WITH THE ANALYSIS OF GOLD OBJECTS

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ABSTRACT. A requirement for non-destructive analysis instigated several improvements to the XRF-spectrometer at the Swiss National Museum. To overcome problems with the surface enrichment of gold a method based on a combination of surface analysis with specific gravity was developed. Comparison with results published by Hartmann (1970, 1982) verified the practicality of the method. The analysis of several hundred Celtic gold objects has shown that objects with gold contents under 80% have in most cases been intentionally alloyed with silver and/or copper. The gold contents of coins and of other objects have different frequency distributions.

1. The spectrometer at the Swiss National Museum

Although parts of the X-ray-fluorescence (XRF) instrument at the Swiss National Museum have reached an age of over 30 years it is still in use. It is a wavelength-dispersive spectrometer, designed to work in air. The element range runs from Chromium (24) upwards. Recently it was fitted with modern measuring electronics sending their output to a computer. Because of its special properties, especially the unrestricted sample size, it is still needed. In the meantime, a modern spectrometer capable of measuring all elements from Fluorine (9) upwards has been acquired. The sensitivity of this new instrument is much higher and trace-elements are easier to detect, but the size of the samples is limited to a diameter of about 50 mm.

Although the basic principles of XRF have not changed with modern instruments, some reflections on analytical problems are still useful.

2. X-ray-fluorescence for non-destructive analysis

The basic principles of XRF-analysis in archaeometry are described by Banks and Hall (1963), Oddy and Hughes (1970), Schweizer (1970), Voûte (1981). In 1965 the laboratory of the Swiss National Museum was confronted with the need for non-destructive analysis of pewter. At that time the only possibility of performing real non-destructive analyses was to use the X-ray-fluorescence method. As the Museums' equipment, a Siemens Kristalloflex 4 with XRF attachment for measurements in air, could at that time only be operated with samples with a maximum dimension of about 25 mm the sample holder had to be changed. The drawer had to be removed, so that samples of all sizes could be accommodated. A shutter

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was needed for safety reasons. After this modification the objects could be placed on a plane with a slope of 45° to the horizontal.

An aperture of 8mm was chosen to obtain high intensities and good counting statistics. To comply with safety regulations a box lined with lead was placed around the sample holder and the X-ray tube. The shutter on the outlet of the X-ray tube was interlocked with the lid of the box.

With this construction the whole pewter collection of the Swiss National Museum as well as objects from many other collections, a total of over 1200 objects, were analysed.

In order to reduce errors caused by the varying shape and alignment of the objects the weight percentages were always calculated from relative intensities. Every object was checked with a binocular microscope in order to eliminate accidental measurement of solder or surface deposits.

Among the first gold objects examined at the Swiss National Museum, still using this first modification of the XRF apparatus, were the treasure of Erstfeld (7 torcs and rings, analysed in 1972) and the bowl of Eschenz (analysed in 1974) (Voûte 1991, Furger and Müller 1991).

The magnificient rings from Erstfeld were very delicate and constructed of several parts that could neither be separated nor were they rigidly fixed to each other. The rings were placed on an adjustable wedge and held with sectors of large cork rings as used in chemistry laboratories. All supporting parts were lined with velvet strips. It was improvised but it proved to be an excellent and very flexible mounting system. Any chosen measuring spot could be reached although it was sometimes difficult to make fine adjustments. As the quality of the measurements is strongly dependent on the surface of the measured spot, it is necessary to find a suitable site on the object. The Celtic rings were rather large, so it was possible to find measuring spots with ample diameter and having only a slight curvature in one direction.

In Table 1 the results from the Swiss National Museum for the objects mentioned (Voûte 1991) are compared with the results of Hartmann (1970, 1982). The analyses of Hartmann were obtained with an optical-emission spectrograph using small samples from the objects for analysis and the results should not have been unduly influenced by surface enrichment. The differences between the results of Hartmann (1970, 1982) and Voûte (1991) show that the Eschenz bowl and the rings from Erstfeld exhibit only minor surface enrichment. The parts liable to higher wear (closures) show a somewhat lower gold content and are consequently stronger.

3. Dealing with non-ideal surfaces

Very soon came the demand for the analysis of smaller objects like coins or fingerrings. The strongly curved or uneven surfaces brought new difficulties; similar problems arose with other material where a large enough area for measurement was not available. For this class of objects only semiquantitative analysis was possible.

The problem was partly solved by measuring with apertures of 1 to 2 mm. Similar apertures were used on the "milliprobe" built and used in Oxford (Banks and Hall 1963), but this instrument was specially designed for this purpose and had a high sensitivity owing to the use of a focussing spectrometer with a curved crystal (Banks and Hall 1963, Schweizer 1970). In the case of the Swiss National Museum the measurement time was of course much increased, but at least it was possible to obtain usable results.

Table 1. Comparison of the results of Eschenz and Erstfeld. Ha = Hartmann (1970, 1982). VT = Voûte (1991).

Object	Au %	Ag %	Cu %	Sn %	div. %	
Eschenz:						
Beaker	74.5	25	0.35	0.020		Ha4902
Beaker	76.3	23.3	0.4		0.2	Zn. sp Fe VT0534
Erstfeld 3192:						
Neckring (closure, mortise)	92.9	6ca	1.05	0.065		Ha4650
Neckring	93.0	6.60	0.40			VT0450
Neckring (closure, tenan)	86.5	12.8	0.7			VT0450
Erstfeld 3193:						
Neckring (closure, mortise)	94.2	5ca	0.73	0.022		Ha4641
Neckring	94.7	5.20	0.50			VT0450
Neckring (closure, tenan)	89.0	10.2	0.8			VT0450
Erstfeld 3194:						
Neckring (closure conus)	90.0	9ca	0.9	0.09		Ha4645
Neckring	93.8	5.95	0.25			VT0450
Erstfeld 3195:						
Neckring 2 Stierg.	93.2	6ca	0.76	0.092		Ha4646
Neckring	94.3	5.40	0.30			VT0450
Neckring (closure, tenan)	84.0	15.5	0.5			VT0450
Erstfeld 3196:						
Armring (closure, mortise)	89.6	10ca	0.38	0.021		Ha4648
Armring	94.0	5.70	0.30			VT0450
Erstfeld 3197:						
Armring (closure, mortise)	94.7	5ca	0.29	0.006		Ha4649
Armring	94.5	5.25	0.25			VT0450
Erstfeld 3198:						
Armring (closure, mortise)	89.6	10ca	0.31	0.053		Ha4647
Armring	94.5	5.20	0.30			VT0450

3.1 IMPROVING THE SPECTROMETER

In the course of the work with the XRF-apparatus some more shortcomings became evident, so several assessments and calculations were made. The following points were covered:

3.1.1 Detection limits had to be better even with low intensities

Because of the high absorption of the gold only a thin surface layer is measured. This thin layer yields a reduced intensity of fluorescent X-rays so the sensitivity for minor components is reduced. Improved detection limits are only possible by optimizing the instrument in other ways; reducing the background is one of the possibilities. The lowest intensity that can be measured has approximately the same value as the statistical variation of the background. In the original instrument the fluorescent rays first hit the analysing crystal and then passed through the Soller slit. By interchanging the crystal and the slit the X-rays hitting the crystal and producing background radiation are greatly reduced without changing the intensity of the measured line.

3.1.2 Precision on samples with non-ideal surfaces had to be improved

Perfect quantitative XRF-analysis requires samples and standards having the same surface quality in all respects. The measured surface has to be at exactly the same place and in the same plane. As the thickness of the measured layer is dependent on the material and the measured element, the angles of the incoming and the emergent radiation play an important role. Standard XRF-equipment uses flat specimens because they are the easiest to produce. The surface should be of such a quality that any unevenness is small compared with the penetration depth (less than $50\mu m$). In most cases the X-rays from the tube hit the sample at an angle of about 45° and the measured radiation leaves in a direction approximately perpendicular to the exciting rays ($\alpha = 90°$!). With many spectrometers the sample can be rotated in order to smooth texture effects or reduce the influence of inhomogeneities.

A closer view of the effects happening at the surface and in the surface layer shows that only the irregularities in the plane of the exciting and fluorescent X-rays have an influence. The unevenness in the other planes does not affect the path-lengths in the sample and therefore has no effect on the relative measured intensities of the elements. So rotation of the specimen is not needed as long as the sample is only structured in one direction.

As soon as the path lengths of the exciting and fluorescent rays are not the same at every point of the sample, the absorption-patterns of different energies will vary strongly. In the theoretical case of primary and secondary rays following opposite directions, the conditions are for all elements the same. This corresponds to an angle α of 0° in Fig. 1. It is clear that this setup cannot be arranged because the X-ray-tube would intercept the fluorescent radiation. Normally the angle between the two beams is about 90°. Calculations with a simulated gold/silver alloy showed that precision is greatly improved by reducing α to the smallest possible value (Fig. 1).

An α of 30° instead of 90° reduces the errors generated by a sample tilt of $\pm 15°$ from about 13% to about 2.5%. A striking aspect of this phenomenon is the strong non-symmetry of the curve at higher values of α. This means that a symmetrical relief on the sample's surface will not be fully compensated. At $\alpha = 30°$, however the curve is almost balanced.

The effect of an uneven sample-surface can be evaluated by measuring a flat sample under several tilt-angles to simulate the relief and comparing the results. This was done before and after modification of the spectrometer. The resultant errors are presented in Fig. 1.

3.1.3 Poor long-term stability due to atmospheric changes had to be improved

In order to minimize absorption changes, due to variations in atmospheric pressure or humidity, the path of exciting and fluorescent rays had to be evacuated. As many objects in museums cannot be put in a vacuum tank without provoking serious damage, a small path length of about 20 mm near the sample had to be left in air. Exciting and fluorescent X-rays pass through a vacuum-tight window of 0.1 mm Beryllium. The aperture of 4 mm is small enough to allow the choice of limited measuring spots, as well as giving enough intensity and compensating for inhomogeneities.

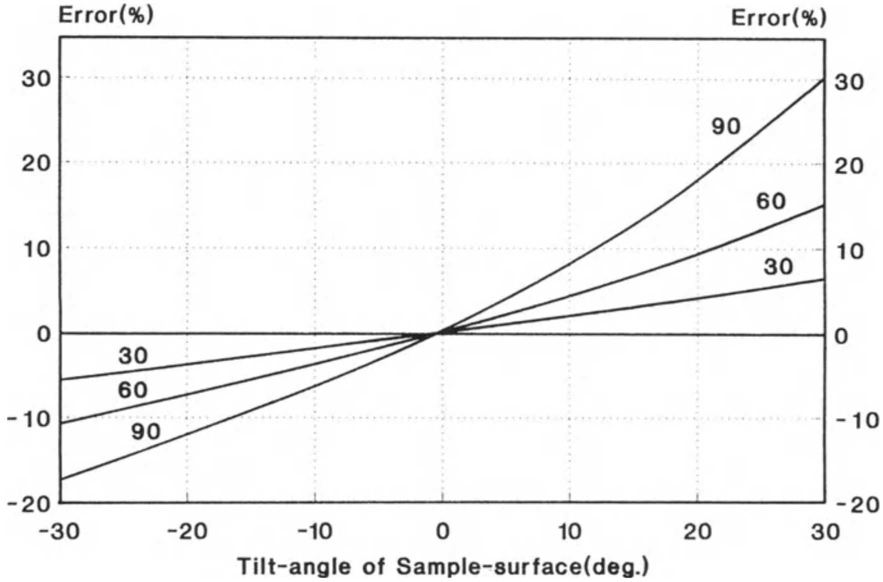

Fig. 1: Calculated error from tilt of sample surface at angles of 30°, 60°, 90° between exciting and fluorescent beam.

Since the above mentioned changes were made, it is possible to analyse almost all types of surface with the required precision. The alignment of the specimen is not critical and measuring spots can be choosen more freely (Voûte 1976).

4. Surface Enrichment

As the measuring equipment now functioned well, analytical problems caused by the samples themselves were the next challenge. Condamin and Picon (1964, 1965, 1970) and Oddy and Hughes (1970) have shown that surface enrichment is often encountered with archaeological objects of gold and other metals from excavations. In a thin surface layer the components of a gold alloy are leached according to their nobility. The result is a thin layer with a relative gold enrichment. In such a case just the layer analysed by XRF has changed by relative surface enrichment. On the other hand the enrichment layer represents only a very small fraction of the whole object.

4.1 SPECIFIC GRAVITY

As pointed out by Caley (1964) specific gravity gives information about the bulk composition of an object and the gravity determination is truly non-destructive. Coins are specially suited to this method. The specific gravity is measured by first weighing the object in air and then submerged in a fluid. It is very important that the fluid has excellent wetting properties. Oddy and Hughes (1970) and Oddy and Schweizer (1970) have developed standard methods to measure the specific gravity of coins. A high density liquid, perfluoro-1-methyl decalin with a density of 1.98 g/cm^3 was used to double precision. This fluid is rather expensive and it has to be often renewed to avoid errors due to contamination. The specific gravity was used directly to calculate the composition of the alloy. In case of binary alloys the results are very good. In the gold coins examined the copper content was lower than 1% so the gold content could be determined with an accuracy of about 0.5-1%.

High accuracy is achievable through working very carefully and eliminating or compensating for sources of error. At the Swiss National Museum a mixture of water with about 5% alcohol and some wetting agent is used. This mixture has excellent wetting properties and is very cheap and easy to renew. Cleaning and rinsing of the coins with water removes all traces of the measuring fluid after the measurement. If the coin has cracks or holes a prolonged stay in the measuring mixture is necessary, sometimes overnight, to get good wetting and filling of the cavities. Until the treatment is finished, small bubbles will emerge.

The balance used is capable of weighing with a precision of 0.1 mg. One side of the balance is shortened so that a small basket of platinum on a stainless steel wire can be suspended. The stainless steel wire has a diameter of 0.1 mm. In order to compensate for any surface tension effects on the suspension wire both weighings are made with the platinum basket submerged in the fluid.

A piece of spectrally pure gold is used as a standard. So that it would behave in the same way as a struck coin it was hit with a heavy hammer. The standard has a specific weight of 19.30 g/cm^3 (Caley 1964).

Using this standard to obtain a correction factor, the influence of any variation in the actual density of the fluid is eliminated. With this method the specific gravity can be measured with an accuracy of better than 0.01 g/cm^3 or in terms of gold-content 0.1% (if silver or copper is known).

As Celtic gold alloys may contain 30 to 100% gold, 0 to 70% silver and up to 50% copper it is not possible to determine the composition of these alloys from the specific gravity alone.

4.2 ENRICHMENT CURVES

In order to find a way to combine XRF-data with the measured specific gravity an attempt was made to describe the alteration of the surface composition of gold alloys during their stay in the soil.

In a triangular diagram where each point represents a distinct composition of a gold/silver/copper alloy, the pure metals are represented by the corners (Fig. 2). Due to surface alterations the composition of a binary gold/silver alloy measured by XRF will shift to a higher gold content. This means that the point on the gold-silver edge representing the original alloy will move nearer to the gold corner. The alloy gold/copper will do the same on the gold-copper edge. An alloy of silver and copper will change to a higher percentage of silver and thus move along the silver-copper edge towards the silver corner.

A set of enrichment curves must fulfill the above conditions. They will begin at the copper corner and end at the gold corner. Near the gold-copper edge they will run roughly parallel. With higher silver contents the curves will start more or less in the copper-silver direction and approach the silver-gold edge at the end.

The curves drawn at the Swiss National Museum and shown in Fig. 2 are such a set. Their usefulness was verified by practical experience.

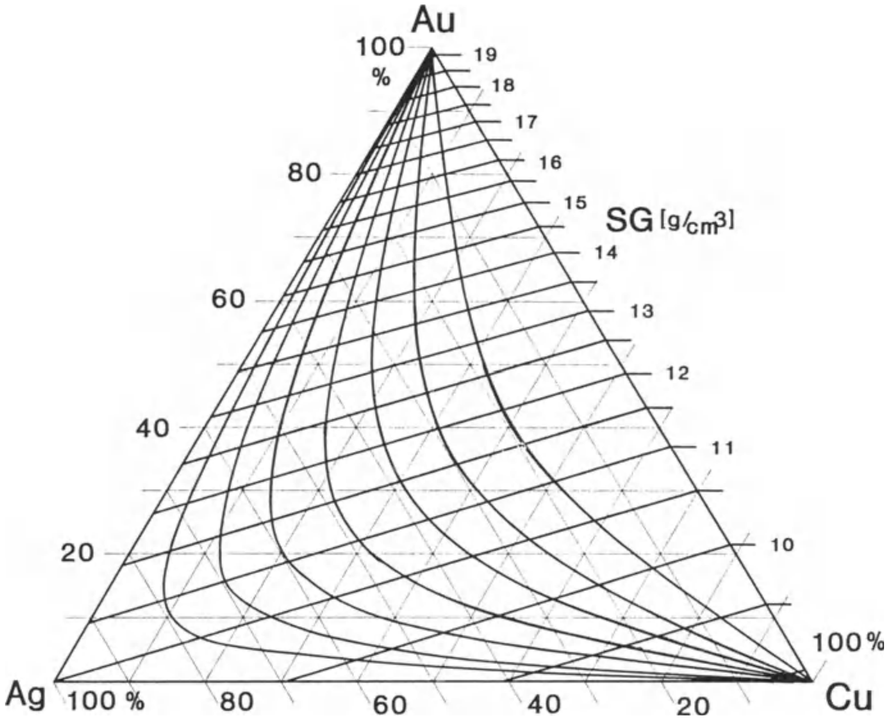

Fig. 2: Enrichment curves and specific gravity of gold alloys.

The lines of constant specific gravity are also included in the same diagram (Fig. 2) (Caley 1964, Oddy and Hughes 1970, Hughes and Oddy 1970, CRC Handbook).

During contact with the soil the surface of an object made from a given gold/silver/copper alloy will alter and the corresponding composition point will move along its curve. The final position of the composition point can be found from XRF-analysis. After moving back along the enrichment curve to its intersection with the measured specific weight line the original composition can be determined.

In reality the changing of the composition by surface enrichment does of course not travel along the whole curve. Surface enrichment is in most cases less than +5% gold with an upper value of about +20%. If it seems to be more than +10% one of the measurements may be faulty or the object has special properties. In such a case another check is advisable.

The curves are estimated and thus their shape is probably not quite correct but this produces in the worst case, with gold contents of, say, 50%, an error of not more than 0.5% in silver or copper. The error in the gold percentage is mainly dependent on the precision of the specific gravity measurement (Fig. 2).

5. Results

Some of the Celtic coins of the Swiss National Museum were analysed by Hartmann (1970, 1982) in 1964. The list in Table 2 compares the results with more recent measurements (Castelin 1985) including those of 4 coins from the excavations in Manching. There is no physical relationship between the two analytical techniques. In order to show the degree of surface enrichment the results of the XRF measurements at the surface are also listed. In most cases the results correspond very well. Only with Cat. Nr. 152 and Nr. 190 (for Ag and Cu) do the results show a higher deviation than can be expected from purely analytical errors.

Table 2. Comparison of recent results from the Swiss National Museum with results of Hartmann. Ha = Hartmann (1970, 1982). VT = Voûte (Castelin 1985, Voûte 1991); final = final result from XRF and specific gravity; Surface XRF = XRF analysis on the surface

			Au %	Ag %	Cu %	SG g/cm^3
Cat. Nr. Swiss National Museum						
152 Stater 7.797 g.	Ha		61.4	27.0		11.6
Bituriges Vivisci	VT	final	58.5	32.5	9.0	14.03
	Surface	XRF	62.0	30.0	8.0	
190 Stater 7.452 g.	Ha		51.3	40.0	8.7	
Incertaines de l'Ouest	VT	final	51.0	38.0	11.0	13.34
	Surface	XRF	53.0	36.7	10.3	
286 Stater 6.291 g.	Ha		64.6	29.0	6.4	
Ambiani	VT	final	64.0	29.0	7.0	14.61
	Surface	XRF	66.5	27.5	6.0	
890 1/4 Stater 1.849 g.	Ha		67.1	29.0	3.9	
Horgen-Unterentfelden	VT	final	66.0	30.0	4.0	14.88
	Surface	XRF	68.0	27.3	3.7	
902 1/4 Stater 1.760 g:	Ha		54.0	40.0	6.0	
Horgen-Unterentfelden	VT	final	52.5	40.5	7.0	13.58
	Surface	XRF	59.0	35.0	6.0	
1065 Stater 7.670 g.	Ha		54.6	35.0	10.4	
Regenbogen südlich	VT	final	53.0	35.5	11.5	13.49
	Surface	XRF	63.0	28.5	8.6	
Nr Manching						
M 1956/785 m2 Stater 7.919 g.	Ha		77.0	18.5	4.0	
	VT	final	77.3	18.5	4.2	16.05
	Surface	XRF	78.7	17.3	4.0	
M 1956/785 m3 Stater 7.507 g.	Ha		67.0	32.5	0.64	
	VT	final	66.2	32.8	1.0	15.10
	Surface	XRF	86.1	13.3	0.6	
M 1956/785 m4 Stater 7.695 g.	Ha		68.0	30.5	2.0	
	VT	final	67.5	30.5	2.0	15.14
	Surface	XRF	85.6	13.2	1.2	
M 1956/785 m5 Stater 8.019 g.	Ha		79.0	18.0	3.2	
	VT	final	78.7	18.0	3.3	16.22
	Surface	XRF	80.85	16.25	2.9	

From the collection of coins of the Swiss National Museum a total of 412 gold coins was analysed. About 150 to 200 coins from other collections were also measured. The majority of the analyses was made of Celtic coins.

Fig. 3 and Fig. 4 show 357 analyses of Celtic coins as well as 94 from other Celtic objects (Castelin 1985, Furger and Müller 1991). Fig. 4 includes some measurements of placer gold (Voûte 1991). Most placer gold samples contain less than 1% copper; only 3 samples, from the river Rhine, have contents of up to 2.8% Cu.

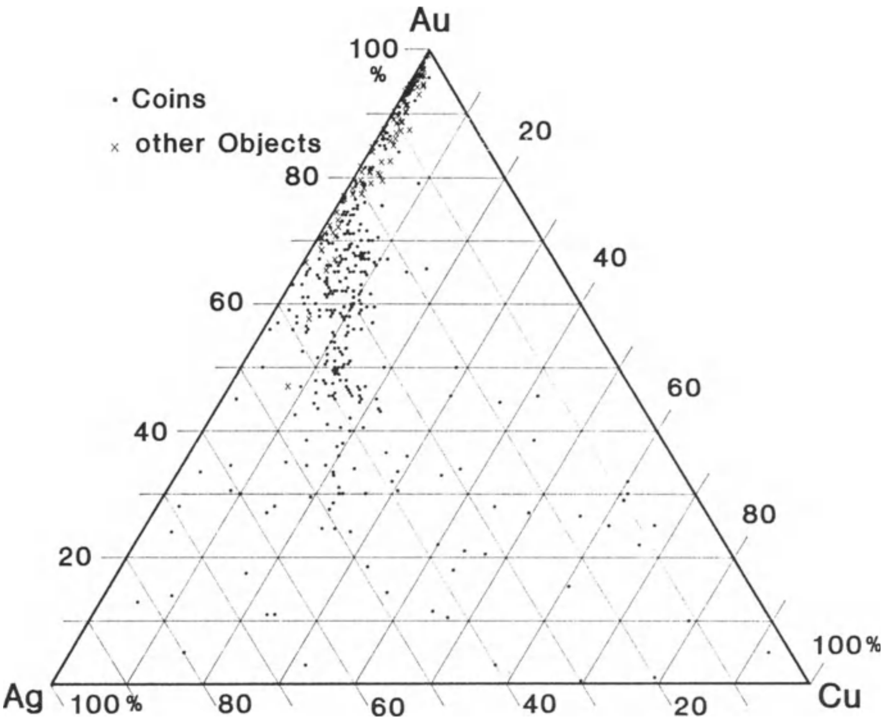

Fig. 3: Results of Celtic gold (weight %) (357 coins + 94 other objects)

Very noticeable in Fig. 3 is the trend of an increasing proportion of copper to silver with decreasing gold content. Below 80% the gold is certainly intentionally alloyed with silver and/or copper. This causes the colour of the alloy to be quite close to the colour of pure gold. In Fig. 4 the peak of the coin distribution at 95% depicts mainly the Philippus imitations. They seem to be made of natural gold which has a silver content of up to 10% or more. The peak at 60 - 68% depicts alloys which contain approximately 2 parts gold and 1 part silver and copper. The peaks at 48% and 30% may indicate a stepwise devaluation of the coinage.

The other objects, mainly jewellery, have their peak between 70 and 100%. They cover a range where there are relatively few coins. These objects are probably intentionally alloyed as required for mechanical or aesthetic reasons.

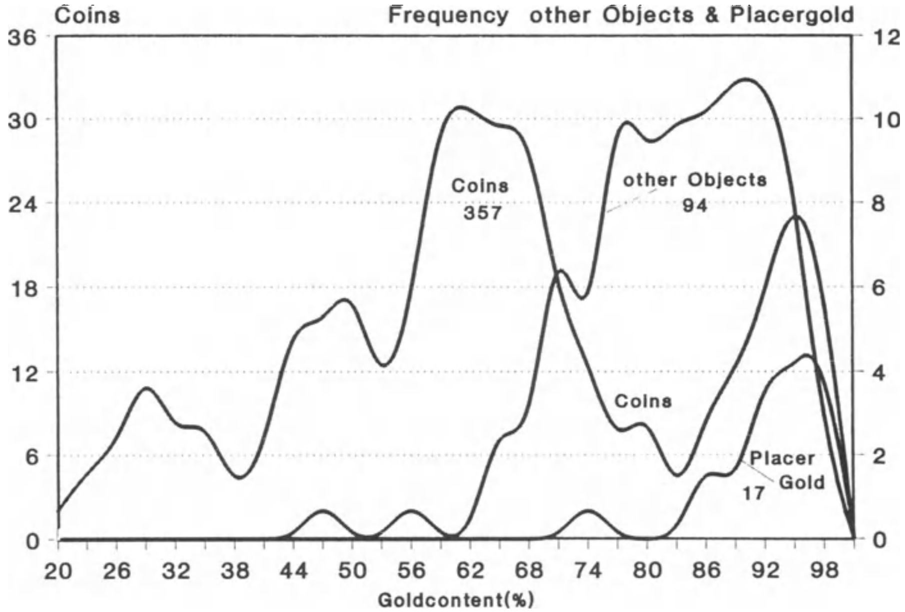

Fig. 4: Fineness of Celtic gold objects.

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Chapter 4

A LOOK INTO THE INTERIOR OF CELTIC GOLD COINS

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ABSTRACT. Within an archeometallurgical project sponsored by the Volkswagen Stiftung on "Prehistoric gold in the Czech Republica and Bavaria", some Central European Celtic gold coins were cut and investigated by various methods. Optical and scanning electron microscopy revealed surface structures and mineral inclusions in the coin alloy. EDS-analysis allowed to identify the chemical composition of the inclusions.
Surface wave-length-dispersive XRF-analysis was used to determine the major elements in the alloy. Density measurements were conducted to control the reliability of the analyses. Minor and trace element analysis was done by optical emission spectroscopy and instrumental neutron activation analysis.
Polished sections of the cut coins were prepared for metallographic interpretation of the internal structures which reflect the deformative and heat treatment history of the coin. Additional microhardness measurements helped to reconstruct the processes of minting.
EDS-line traces on the polished sections allowed to identify zonation and corrosion of the coin.

Introduction

Gold coins are mainly studied for their numismatic features such as weight, monetary value and die types and links. Chemical analyses are not always popular, since museum curators fear any damage to the objects. Hartmann (1970/1982) performed numerous optical emission spectrometric analyses and gave a first idea of the range of alloys and related this to contemporary metallurgy.

Since non-destructive surface analysis is becoming increasingly popular there has been much discussion about the possible corrosion and enrichment features of prehistoric gold coins and their influence on surface analyses of these objects. Comparisons between analyses of gold coin surfaces and the measured density of the coins indicated that the coins are enriched in gold at the surface. These observations had earlier been made for placer gold grains.

In the recent project on "Prehistoric gold in the Czech Republic and Bavaria", supported financially by the Volkswagenstiftung in its archeometallurgy programme five different types of gold coins where purchased for a detailed program of investigations, including cutting and preparation of polished sections, and microchemical analysis of the polished surface.

The gold coins studied are listed in Tab. 1 below; in the text they are referred to as Coins No. 1 to 5 following this list. The coins are illustrated in Fig. 1.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 341–355.

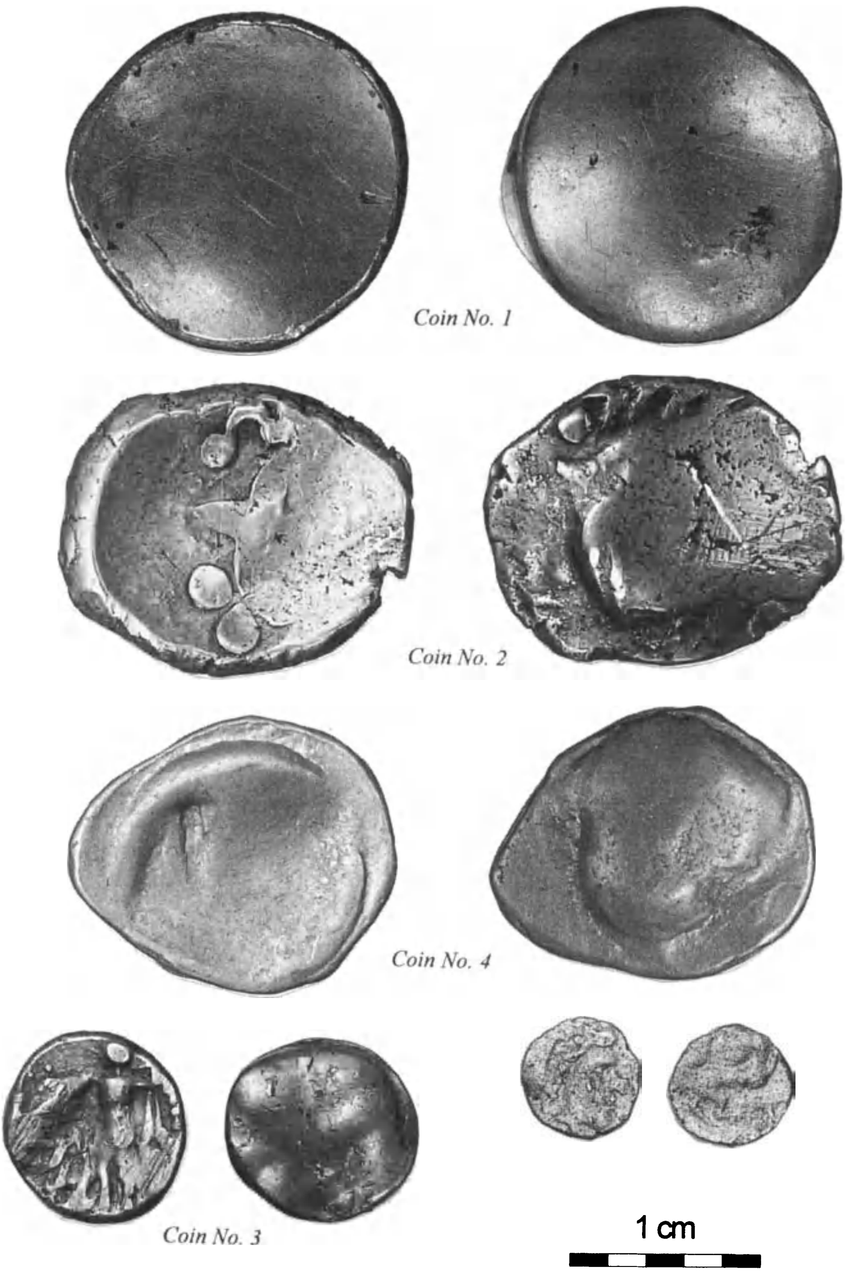

Fig. 1: Celtic gold coins used for the analytical and metallographic investigations

Table 1. List of investigated Celtic gold coins.

Coin 1: 1/1 Stater, Regenbogenschüsselchen, Type VA (southern German),
Weight: 8.037 g, Composition (XRF): 80 % Au, 16 % Ag, 4 % Cu.

Coin 2: 1/1 Stater, Regenbogenschüsselchen, Type IIE (southern German),
Weight: 7.504 g, Composition (XRF): 57 % Au, 29 % Ag, 14 % Cu.

Coin 3: 1/3 Stater, earlier gold minting (Boiian),
Weight: 2.747 g, Composition (XRF): 96.7 % Au, 2.8 % Ag, 0.5 % Cu.

Coin 4: 1/1 Stater, Mussel type; earlier minting (Boiian),
Weight: 7.230 g, 97.6 % Au, 1.8 % Ag, 0.6 % Cu.

Coin 5: 1/24 Stater, Type Manching A (southern German),
Weight: 0.305 g.

A sequence of techniques was applied to the coins, giving the first chance to view the previously hidden interiors of Celtic gold coins (Fig. 2). The results of the investigations form the main theme of this paper.

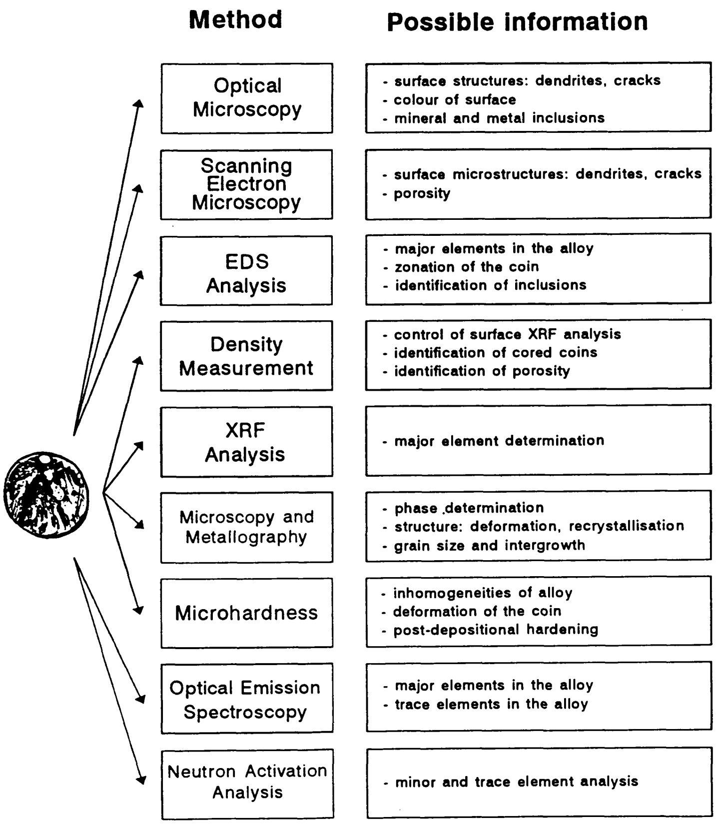

Fig. 2: Flowsheet of the investigation of the Celtic gold coins.

1. Optical microscopy of the surfaces

The first step is to describe the surface properties and colour of the coins. With a normal stereomicroscope one can identify surface structures such as dendrites and inclusions, from which information about the processes of production and composition can be derived.

The intensity of the yellow colour of gold coin surfaces gives a clear indication of the content of silver and copper. Silver gives the alloy a slightly greenish hue, becoming whiter as the silver content increases, while copper turns the colour more to red. Normally copper contents are not high (< 5 %) for the coins studied, so this colour effect is not very strong. Mechanical defects such as hot tears appear during cooling of the flan, while cracks can form due to the lack of ductility during the preparation of the flan or the striking of the coin. Inclusions can best be detected by an additional study with a reflected light polarising microscope, which shows even tiny details of the surface.

The sample coins exhibit the following significant features:

Surface structures:
The surface of Coin No. 2 shows strong cracks which result most probably from stress corrosion in the silver and copper rich alloy. On one side of Coin No. 2 dendrites could be observed (see also section 7). These visible dendrites indicate a) that the alloy had been completely molten and b) that the cooling was relatively moderate, probably from the furnace cooling of the metal. The dendrites were almost deformed during the striking of the coin and only in protected areas of the coin are they preserved.

Inclusions:
Coin No. 1 and 5 show a few shiny silvery spots of approx. 0.1 mm in diameter on the surface. These inclusions are harder than the gold alloy and thus come to stand proud of the surface. They can be clearly delineated as single grains, which show a less scratched surface than the surrounding coin matrix (Fig. 3). In the scanning electron microscope with energy dispersive spectrometry these spots proved to be platinoid metal (iridium, osmium, ruthenium) inclusions. This identification of platinoid inclusions corresponds to the observations made by Ogden (1977) and Meeks and Tite (1980), but is the first of such case in Bavaria. Hartmann (1970/1982) also reports chemically detectable contents of platinum group elements. Since in Central Europe occurrences of platinum group elements are only of mineralogical interest, these inclusions could be one of the much sought "fingerprints" to determine the provenance of the metal, even if Meeks and Tite (1980) deny this possibility. The best-known sources of platinoid-bearing alluvial gold sands are in northern Greece (pers. comm. E. Pernicka). Western Turkey also hosts considerable placer deposits with platinoid grains (Hatzl et al. 1990).

2. Scanning electron microscopy

The scanning electron microscope allows us to investigate the surfaces of objects at a very high resolution and, in combination with an X-ray spectrometer (EDS), the composition of the object can be directly measured at the spot seen on the screen. For quantitative analysis, however, polished surfaces are required for reliable results.

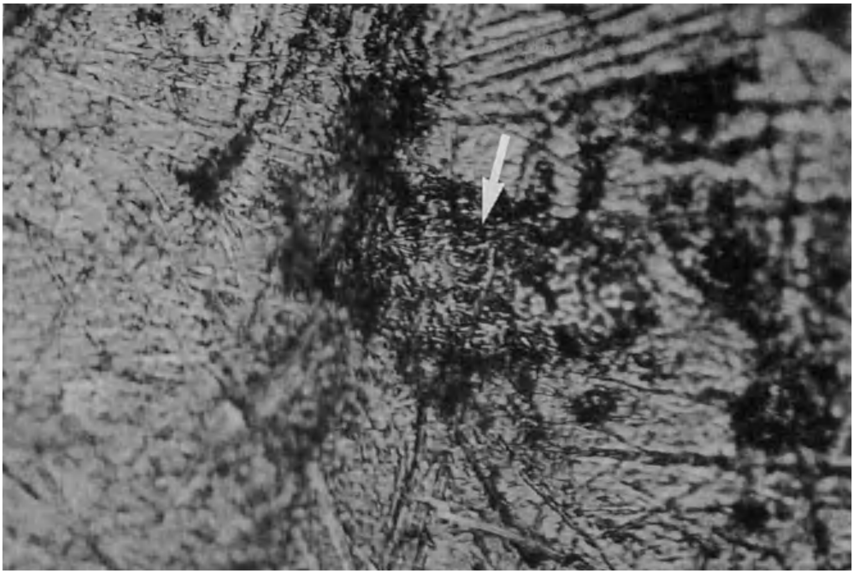

Fig. 3: Osmium-iridium inclusion in the surface of gold Coin No. 1. Microphotograph. Width of view: approx. 0.2 mm.

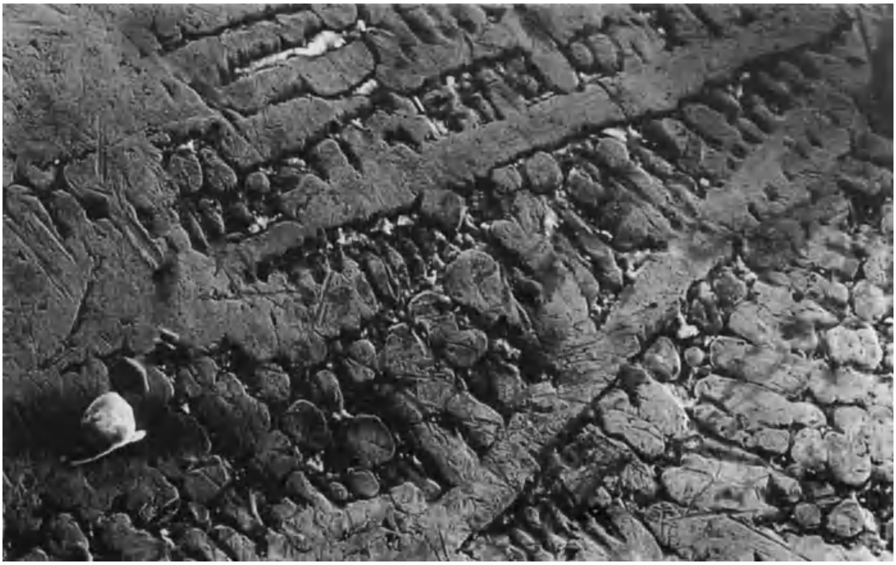

Fig. 4: Dendrites on the surface of Coin H44 from the coin hoard of Großbissendorf. Width of view: 1 mm.

The high resolution enables one to detect even tiny surface structures such as scratches, features of the die cutting, textures resulting from the melting and minting process and microinclusions.

An important result with the SEM can be the determination of the extent of deformation of the blank before it was minted by looking at the dendrites (Fig. 4). Dendrites are ideal structures for this much debated question, since they are formed directly during the cooling of the molten metal prior to any working process. Furtheron, the dendrites show clearly, that the material was not only sintered together.

EDS microanalysis in the scanning electron microscope allows a direct comparison of surface analyses with the composition of the material within recent scratches, so information about possible surface alterations can be acquired (see chapter 8).

3. Density

Density measurements of the coins, and a comparison with calculated density from surface analyses allows an estimate of the reliability of those analyses. The measurements were conducted with a laboratory balance in normal water with a few drops of a wetting agent. With leaching of Cu and Ag from the surface, the Au-enriched surface would lead to a higher calculated density than really exists. The correction of the analytical results using the density measurements was firstly applied by Voûte (1985). Practically, the slices of coins show that the values from the density measurements of the whole coins correspond fairly well with the density calculated from analyses of the cores of the coins (see section 8, Fig. 10). This means that density is a feature of the coin, which is little affected by alteration processes and therefore can be regarded as more characteristic of the coin than surface analyses can ever be.

4. X-ray fluorescence analyses (XRF)

XRF analysis is the easiest, most rapid and at present only non-destructive way to obtain information on the surface composition of gold coins. The main alloy constituents of the coins are relatively easy to analyse by this method, since the coins fit well into the standardized sample holders of the XRF analytical devices. The advantages and limits of this method are discussed in detail by Bachmann, Stern, and Voûte in this volume. Several authors (e.g. Voûte 1985, 1991 and this volume, Stern, this volume) found that there are strong differences between the measured composition and the true composition of the coins, obviously because of corrosion processes during deposition of the object in the ground. Any surface XRF analysis of gold objects should therefore be controlled by a calculation of the density of the coin from the surface XRF-analysis and a comparison of this value with the measured density. Differences in density of more than 0.5 g/cm^3 indicate, that strong compositional differences between surface and core exist.

Minor constituents and inclusions of the coins cannot easily be analysed by XRF. Practical experience shows that the chance having an inclusion within the window of the detector is rather low, and then the so called "nugget effect" would give contents of the metals in the inclusion, which were much too high.

5. Optical and electron microscopy of polished coin sections

Optical microscopy with reflected light of the polished sections of the coins shows internal structures such as cracks, porosity, inclusions, exsolution of alloy components and colour differences related to alloy inhomogeneities. For the investigation a normal ore microscope has been used.

A very interesting structure was noted in Coin No. 1. This shows a porous zone, 50 μm thick on the convex (overse) side of the coin, and approx. 10 μm on the concave (reverse) side, which can be seen very clearly in the scanning electron microscope (Fig. 5). The porosity does not seem to be of a type that is likely to have been generated while the melt was cooling in the mould. The two most likely causes of such porosity in a ternary Au-Ag-Cu alloy are the oxidation of copper during annealing of the blank, or the removal of copper and silver by post-depositional corrosion from beneath what appears to be a consolidated, enriched surface layer. The cracks in the surface do not argue against this conclusion, but would locally provide access for the corrosive environment.

The microscopic investigation of inclusions in the coins needs a very careful preparation of the polished sections, which is best done by hand on a textile slab with diamond paste. Fig. 6 shows a polished section of Coin No. 1, where a platinum group element inclusion was cut parallel to the coin's surface. It can be clearly seen that it was crushed during the striking of the coin and the fragments are dispersed in the weaker gold matrix. The discontinuity of the scratches on the polished surface show how the platinoid grain is much harder than the gold-silver-copper-alloy.

The optical microscopy should also be seen as a necessary part of the sample preparation for scanning electron microscopy and EDS microanalysis.

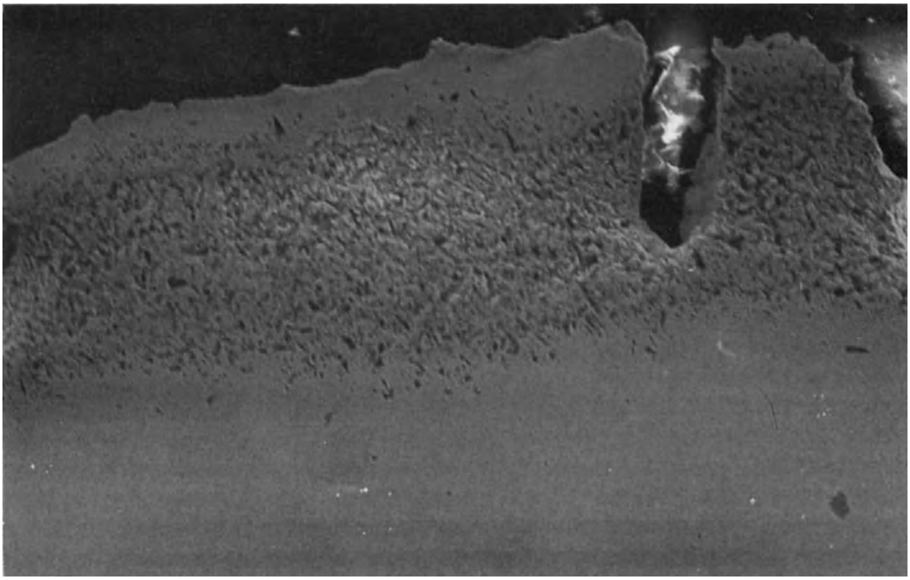

Fig. 5: Porous zone of gold Coin No. 1; SEM-photograph of a polished section. Width of view: 0.15 mm.

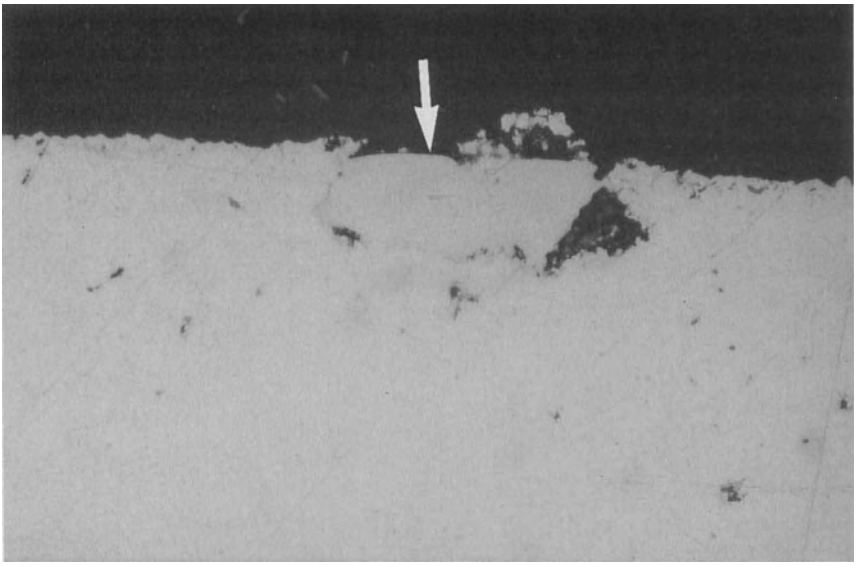

Fig. 6: Osmium-iridium inclusion in Coin No. 1, polished section, reflected light. Width of view: 0.18 mm.

6. Metallography

The polished slices of the coins were etched with a cyanide solution and the structures studied under a metallographic microscope. The fabric of the coins will reflect their metallurgical history through the minting process and show the effects of the different stages: melting, preparation of the blank through forging and annealing, and then striking.

Coin No. 1 shows a fully recrystallised equiaxed grain structure with prominent annealing twins, typical of solid solution gold alloys. There is no marked gradient in the grain size indicating that the blank had been uniformly worked before heat treatment. Hot striking can probably be ruled out as this would have led to severe fire staining of the metal and, historically, mint practice avoids interfering with the coin after striking. Even if the blank was hot struck, it must have been cold forged and annealed first: it is improbable that time at temperature, strain rate and energy input would have been sufficient to produce the observed structure from an 'as cast' blank. The porous zones observed just below both obverse and reverse surfaces will then be the result of the removal of copper oxide by acid blanching after annealing the cold hammered blank. It is possible that there were two or three cycles of cold work and annealing.

Coin No. 2 shows a coarse and irregular grain structure penetrated by major cracks. The structure is typical for blanks which were molten and cooled slowly. This is supported by the observation of some dendritic segregation, which is still preserved in parts of the structure, with extensive interdendritic porosity generated by exsolution of gases and/or shrinkage during solidification. The habit of using unfired coin moulds to melt the blanks probably added to the evolution of gas. There are no traces of recrystallisation. The cracks are very probably the result of stress corrosion, something to which low carat gold alloys are rather susceptable.

Coin No. 3 shows a rather coarse recrystallised grain structure with annealing twins. The recrystallised grain size is a function of time, temperature and prior cold work; grain size increases with annealing time and temperature but decreases with prior deformation. In this case the deformation before the last anneal was probably the determining factor as annealing times were probably short and the temperature appears to have been insufficient to completely homogenise the structure.

Coin No. 4, the Boiian stater also has a fully recrystallised grain structure with a large grain size and some residual segregation (termed 'coring'). In this case, though, the structure is severely deformed in the area illustrated with elongated grains, bent twin boundaries, and numerous deformation bands or slip traces. The cold reduction in this area since the last anneal is of the order of 30-40 %.

The interpretation of the metallographic data is greatly enhanced by microhardness testing; the etch used on these alloys does not always successfully reveal slip traces, so moderate amounts of cold work are not always detected, neither can it reveal the effects of precipitation and order hardening.

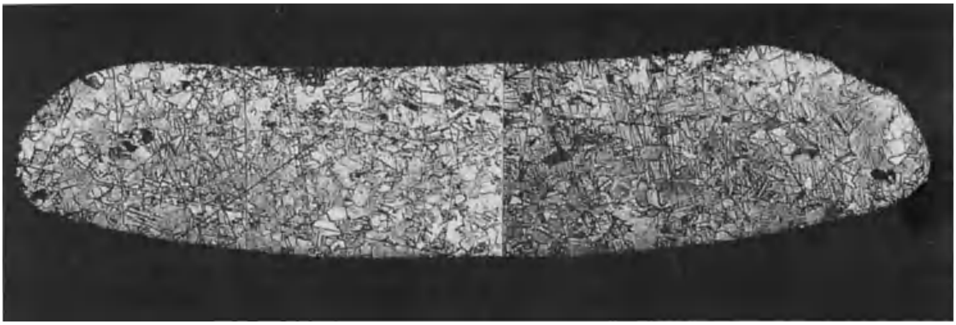

Fig. 7a: Etched polished section of Coin No. 1

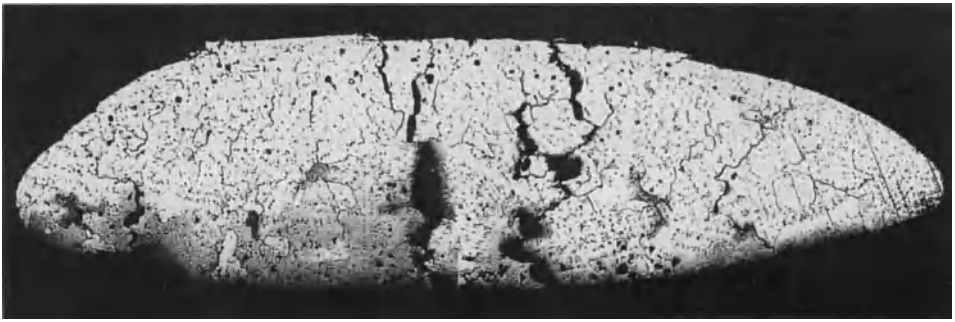

Fig. 7b: Etched polished section of Coin No. 2.

Fig. 8a: Detail of the fully recrystallised structure of Coin No. 3. Width of view: 1 mm.

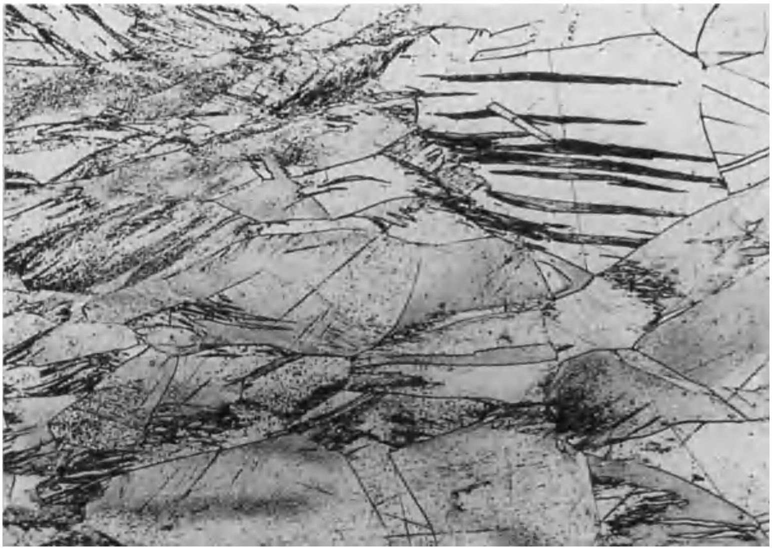

Fig. 8b : Detail of Coin No. 4 with elongated grains and slip traces. Width of view: 1 mm.

7. Microhardness

The microhardness of Au-Ag-Cu alloys is a function of composition, cold deformation and precipitation/order hardening reactions. While the alloys show a relatively low hardness after annealing, they harden strongly through deformation and appropriate compositions can also be hardened by heat treatment.

The Vickers microhardness has been measured with a DURIMET (Leitz) apparatus. The method is based on impressing a tretragonal diamond pyramid into the surface of the metal sample. The size of the indentation and the applied load are recorded and the hardness read from a table. Hardness measures the resistance of the material to indentation, a function of yield stress and work hardening rate. A disadvantage of the method is that a close spacing of the single measurement points is impossible due to the interactions between adjacent impressions.

The microhardness profiles from the polished sections of the gold coins (Fig. 9) show significant variations in hardness within individual coins, due to differences in cold work, heat treatment etc., and between coins, due mainly to compositional differences. The highest hardnesses are in Coin 2, as a result of its high alloy content, residual stresses from cooling and striking, and possible age-related precipitation hardening. The intermediate hardness of Coin 1 probably derives from limited cold deformation ($< 20\%$) not clearly etched, some solid solution hardening and, possibly, some ageing. The low values in Coins 3 and 4 are due to the much lower alloy content. Coin 3 is annealed throughout but localised deformation in Coin No. 4 results in the relatively high localised hardness values of 107 and 102 HV.

Within the coins the microhardness shows a clear trend only in higher hardnesses occurring in the more heavily deformed areas of Coin No. 1 (Fig. 9a) and Coin No. 4 (Fig. 9d).

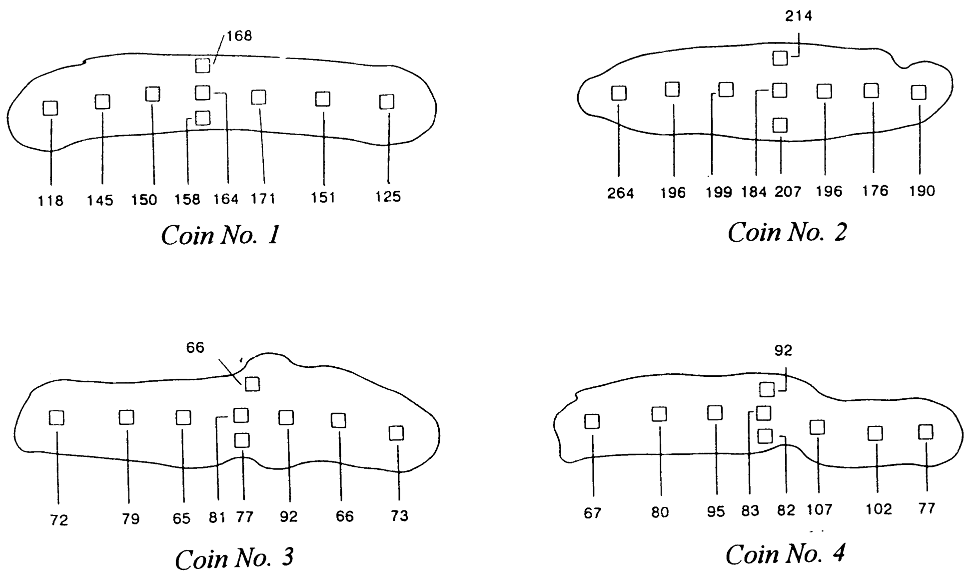

Fig. 9: Microhardness measurements on polished sections of gold coins.

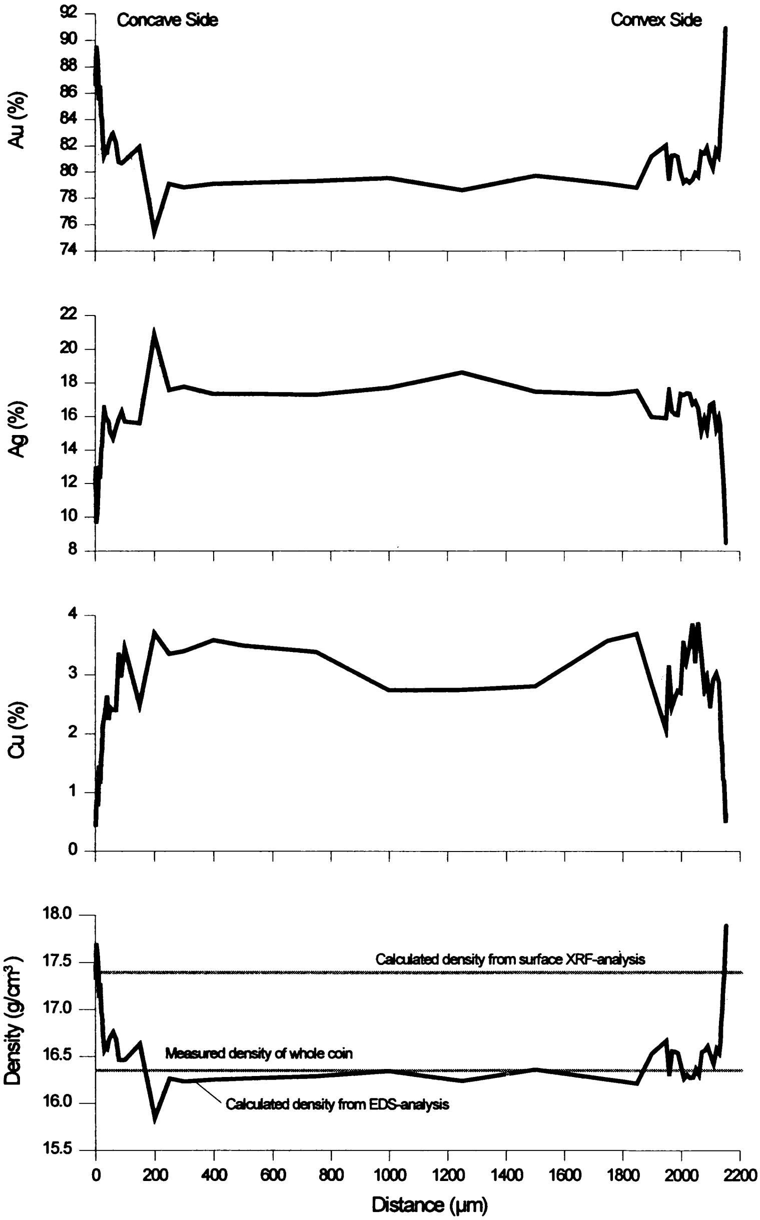

Fig. 10: EDS line traces of gold, silver and copper contents, and calculated density of Coin No. 1.

8. EDS line traces

Energy dispersive X-ray fluorescence (EDS) analyses have been made directly on the polished surface of the coin sections in the scanning electron microscope. Since the electron beam is approximately 1 micron in diameter, profiles can be analysed with steps of a few microns. The analyses were calibrated against a series of standards of commercially available gold-silver-copper alloys. The analyses were normalized to 100 %.

EDS probe profiles across a polished section of Coin No. 1 (Fig. 10) show strong variations in the composition and a clear zonation. The chemical analyses of marginal areas and the core can show differences of up to 10 % in a single element. The marginal zone with heavy depletion of silver and copper can be more than 0.1 mm thick, confirming that surface analyses cannot give the composition of the original alloy.

From the analyses the density can be calculated and plotted in profiles across the coin section (Fig. 11). The profile of Coin No. 1 (see also Fig. 10) shows, that the calculated density profile is almost identical with the calculated density from XRF analyses at the surface of the coin and also with the measured density of the whole coin in the core. Thus the measured density of the coin can be regarded to be identical with the core density, regardless the surface alteration, which has only a tiny effect on the overall density of the coin.

Natural corrosion processes are well known from placer gold deposits under nearly all climatic conditions all over the world. Nuggets typically show alteration rims some tens of micrometres wide and are doubtless caused by silver leaching processes mainly under oxidizing conditions in the soils or sediments (Möller, this vol.). The alteration rims show homogeneous composition and sudden changes are observed at the reaction front.

Due to the observation that surface alteration occurs relatively frequently, the often suggested method of sampling the surface of archeological gold objects by strikes with a touchstone must be viewed very critically, since the material picked up by this will represent only a few microns in depth. Even if a deeper level is reached by the touchstone, one will get a mixed sample of surface and core gold alloy.

A second very important field of application of the EDS analysis is the determination of the composition of inclusions of other metals in the coins. The results show, that almost all greyish metallic inclusions in the investigated Celtic coins consist of platinoid metals. For the identification of the inclusions surface analysis without polishing may be sufficient. Generally, EDS or microprobe analysis is the most powerful tool in analysing gold coins.

9. Optical emission spectrometry

The sections of the Coins No. 1 to 4 were used for semiquantitative spectrometric analyses. Optical emission spectrometry is an ideal method for identifying trace elements which are below the detection limit of the X-ray fluorescence method. The analyses (Tab. 2) show that Sn, Pb, Cu and Fe are the main trace elements in the coins. From the fact, that bronze alloys were added to the gold and silver as a copper source, Pb and Sn cannot be regarded to have a major significance for the determination of the provenance of the gold, since they are the bronze components. Iron can also be added with copper coming from a mineralization with mainly chalcopyrite as ore mineral. Thus one faces the problem of a multi-source alloy, which makes an interpretation rather difficult.

Table 2. Results of semiquantitative spectral analyses of Celtic gold coins.

Coin Type	1/1 Stater Type V A No. 1	1/1 Stater Type RIIE No. 2	1/3 Stater No. 3	1/1 Stater No. 4
Concentration	Elements	Elements	Elements	Elements
Optical emission spectrometric analysis with spark source				
Main elements	Au, Ag, Cu	Au, Ag, Cu	Au	Au
Minor elements	Fe, Sn	Pb	Ag, Cu, Fe	Ag, Sn
Trace elements	Bi, Mn, Pb, Si	Bi, Sn Si	Mn, Pb, Sn, Mg	Cu, Fe
Low traces	Zn, Mg	Co	Ni, Pt, Zn, Si	Si
Very low traces	As, Sb	Fe, Mn, Mg, Ni, Sb	Co	Mg, Sb
Optical emission spectrometric analysis with laser ablation				
Main elements	Au, Ag, Cu	Au, Ag, Cu	Au, Ag	Au, Ag
Trace elements	Ca, Sn	Ca, Si	Cu	Cu
Low traces	Fe, Mg, Ni	Fe, Mg	Fe, Ca	Fe, Sn

Main elements: > 1 %; Minor elements: ca. 0,1 - 0,5 %; Trace elements: ca. 0,1 %; Low traces: ca. 0,05 %; Very low traces: ca. 0,01 %

10. Instrumental neutron activation analyses (INAA)

The biggest advantage of INAA is the low detection limit for many trace elements. Samples of Coins No. 1 and 2 were analyzed by this method and a strongly elevated iridium content was found in Coin No. 1, which corresponds well to the observed Os-Ir inclusions in the coin.

For systematic and routine analyses INAA is not suitable, since the objects become strongly radioactive, especially if silver contents are high. Due to the strict regulations on radioactive material in most countries, such objects could not be shown in the museum for safety reasons for a long time.

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Chapter 4

ELECTROCHEMICAL CORROSION OF NATURAL GOLD ALLOYS

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Abstract. Corrosion of gold alloys is discussed as an electrochemical process which yields rims depleted in the less noble metal or spongy gold grains. High fineness of surface gold is the result of a refinement process. A similar process has to be considered acting on gold artefacts buried in soil. Corrosion is controlled by starvation of oxygen at the tips of crevices leading to oxidative dissolution of the less noble metals. This process is parallelled by an electronation processes at the surface such as reduction of oxygen, if present.
The kinetic interpretation offered by electrochemistry explains the observed features adequately.

1. Introduction

The fineness of native gold is defined by Fisher (1945) as 1000Au/(Au+Ag). A clear distinction should be made between fineness and Au/Ag ratio often used in literature. The latter refers to total gold and silver in the deposits.

The most important and abundant constituent of native gold is silver. Furthermore, it can be alloyed with Cu, Hg, Bi, Fe, Ni, Pd, and Pt. Intermetallic compounds with stoichiometric compositions are also known. Placer gold has a tendency to higher fineness than primary hydrothermal gold (Groen et al. 1990). At a higher resolution, detrital gold often exhibits higher fineness at the surface than in the bulk (Fisher 1945, Stumpfl and Clarke 1964, Groen et al 1990, Krupp and Weiser 1992). There is placer gold, however, that does not show surface refinement such as in the Witwatersrand conglomerates which have in common that they are sulphide- and graphite-rich, i.e. of low oxygen fugacity (Viljoen et al. 1970, Saager 1973, 1975). Furthermore, secondary gold in laterite terrains shows high fineness (Mann 1984, Glasson et al. 1988, Grimm et al. 1988, Santosh et al. 1992).

If primary gold is alloyed, for what reasons are gold-silver alloys unstable under natural conditions? Is the fineness of gold grains dependent on their environment?

In technical products gold is often alloyed with other noble metals because preferred properties are achieved or the more expensive gold can be replaced by cheaper gold alloys. Gold is commonly considered as a chemically very resistant metal, but it is well known that corrosion occurs when it is alloyed with other noble metals such as silver, copper, palladium etc. (Mason et al. 1974, Bogenschütz et al. 1980, Fritz and Pickering 1991, Forty and Rowlands 1981). The term corrosion comprises many features: pitting, stress-cracking, embrittlement, film-rupture etc. It is driven by the dissolution of the less noble component. Corrosion is common in Cenozoic placer deposits which formed under oxidizing, atmospheric conditions. It is less often observed in placer deposits in strongly reducing environments.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 357–367.

Corrosion being a natural process can be expected to affect also gold artefacts buried in soil. Thus, a study of the corrosion phenomena on natural gold grains should give some clue to those reported from archeological gold objects.

Archaeologists noticed that excavated gold artefacts are sometimes "covered" with a layer of gold of higher fineness than in the bulk. Man-induced chemical processing of the surface of artefacts could also have resulted in features similar to corrosion. In any case, long-term burial in soil would intensify the effect of any man-induced process. Thus, apparent corrosion phenomena on artefacts may be of both natural and man-made origin.

2. Electrochemical processes at gold surfaces

Gold is a strongly reductive element and Au^{3+} ions are among the strongest oxidants, only exceeded by O_2 and F_2. This leads to its positioning at top of the redox scale.

$$Au^{3+} + 3\,e \Leftrightarrow Au^{o} \qquad \varepsilon = 1.498 \qquad (1)$$

$$Au^{+} + 1\,e \Leftrightarrow Au^{o} \qquad \varepsilon = 1.692 \qquad (2)$$

Their oxidation potential of Au^{3+} and Au^{+} would remain unobserved in nature because the concentrations of the Au species are so low that there are no visible effects except the deposition of gold itself. Although the ore-forming processes are not well known in detail, it is obvious that reduction of ionic Au-species is the fundamental step. This is easily possible as long as chemical combination does not interfere seriously. Any oxidizable compound present in solution will reduce gold species which then are deposited as native gold. Together with gold, other noble elements are co-deposited forming alloys: Au-Ag, Au-Cu etc. Thus, gold grains contain variable amounts of Ag, Cu, As, Bi etc. (Boyle 1979): gold alloys are by far more frequent in nature than pure gold.

At first glance, one might think that the alloys might be as stable as pure gold metal, but observations contradict this. For example, Fig. 1 shows a photomicrograph of an alluvial gold-silver alloy with a silver-depleted rim of variable thickness. Fig. 2 represents samples of partially refined Au-Ag and Au-Cu alloys forming spongy gold or a porous Cu-depleted rim, respectively (Krupp and Weiser 1992).

In the project "Prehistoric gold in Bavaria and Bohemia" (financed by the Volkswagen Stiftung) G. Lehrberger (TU München) studied the distribution of minor metals in Celtic coins. One of his interesting observations (this volume) is that features of de-alloying similar to that of gold grains can also be found at the surface of Celtic coins (Fig. 3) and probably other gold artefacts if they had been studied. Particularly, the concave side of the Celtic coin exhibits typical corrosion phenomena, whereas the convex surface shows corrosion at some depth with a closed refined gold surface layer.

Irrespective of the different origins of gold grains and the Celtic coin the phenomena appear to be the same. In both examples, depletion of the less noble metal below the surface occurs leaving behind a porous structure associated with higher fineness in the remaining surface gold. The key question is: is this the result of a chemical process during formation of grains and artefacts or is it introduced by electrochemical processes acting on the final product in the course of time.

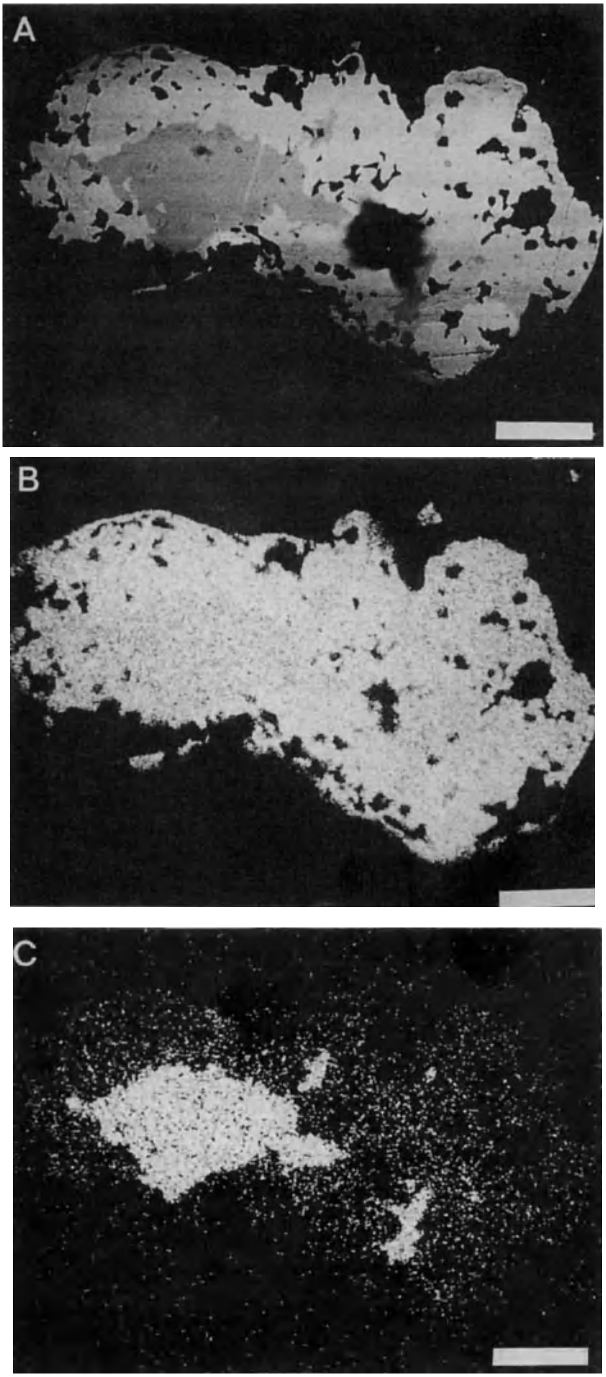

*Fig. 1: Photomicrograph of an alluvial gold grain. **A**: Backscattered electron image; **B**: X-ray distribution of Au; **C**: X-ray distribution of Ag; it is clearly to be seen that Ag is depleted in the rim; Burma (Krupp and Weiser 1992; by courtesy of Springer Verlag). Scale bar 50µm.*

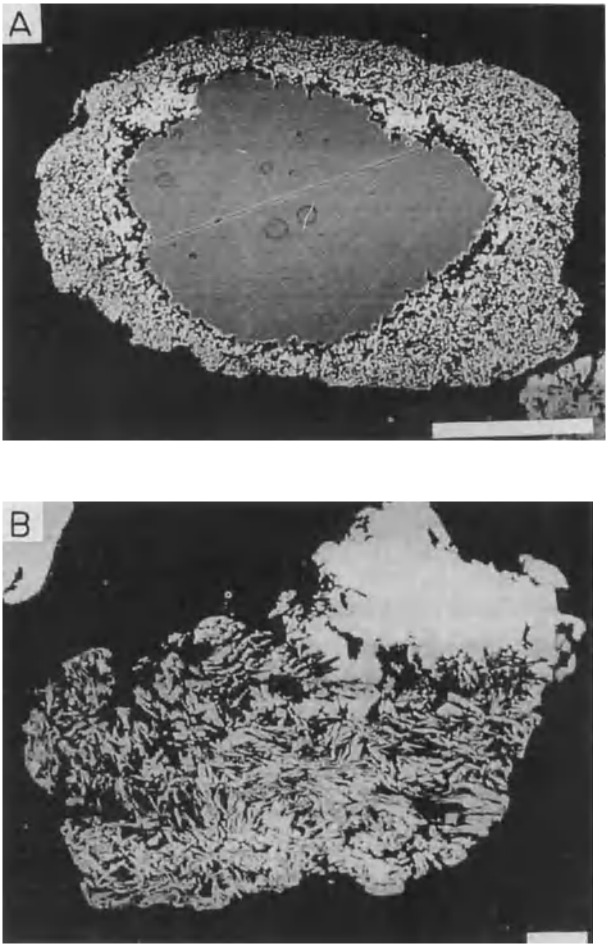

Fig. 2: Photomicrograph of alluvial gold grains. ***A:*** *Auricupride (AuCu) grain with a rather uniform porous Cu-depleted rim; Malaysia;* ***B:*** *Spongy gold showing mechanical deformation textures; Burundi (Krupp and Weiser 1992; by courtesy of Springer Verlag). Scale bar 50µm.*

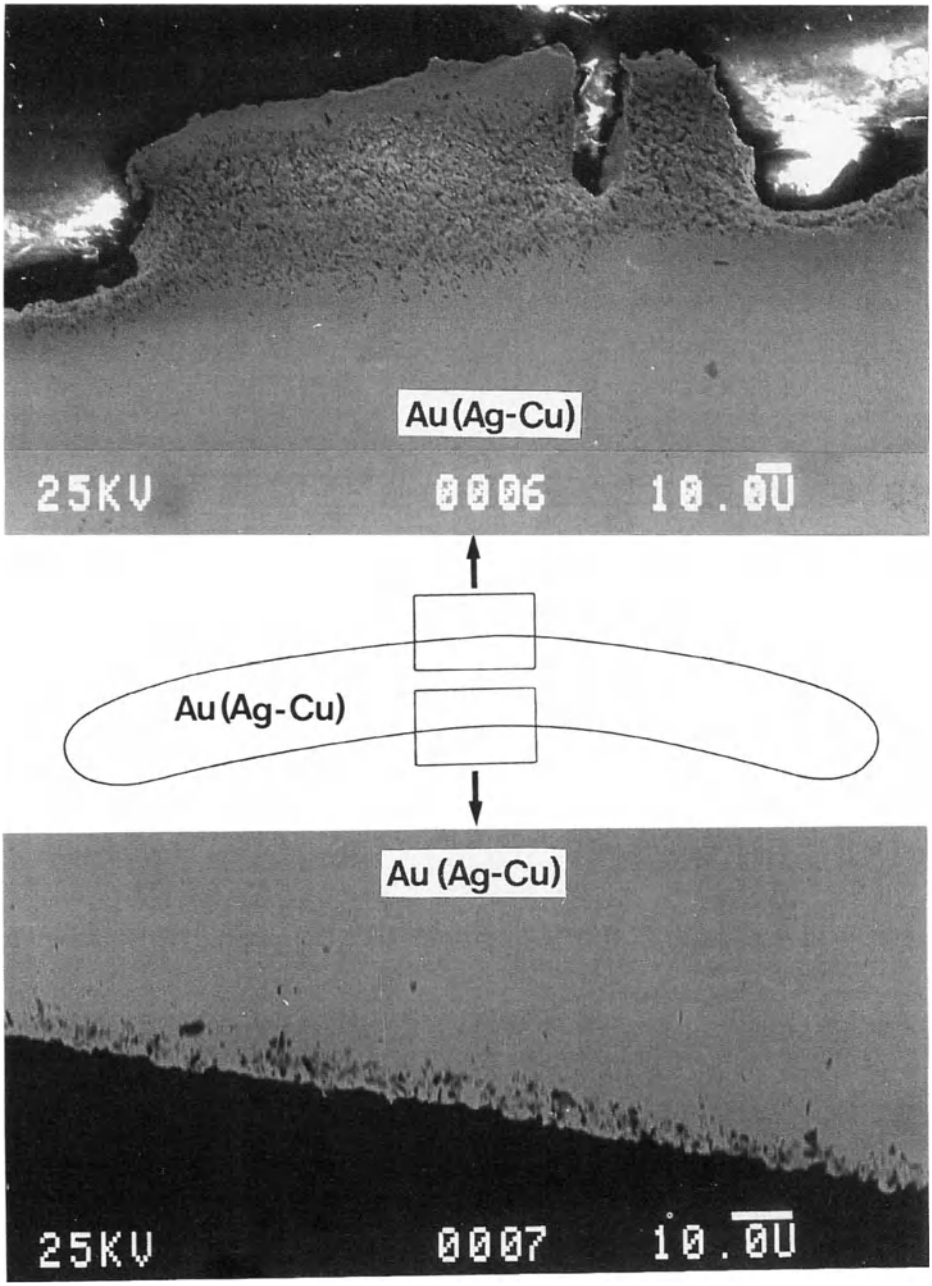

Fig. 3: Two photomicrographs of the concave and convex side of surface near section of a Celtic coin (Fotos are supplied by G. Lehrberger, TU München). The convex side is covered by gold of high fineness with a spongy zone beneath. At the concave side the spongy zone is at the surface.

3. Electrochemical corrosion

There are two different lines of reasoning in the literature to explain the observed features of corrosion: thermodynamical (classical) and kinetic (electrochemical).

Aiming at an explanation of the frequently observed corrosion of gold grains in placer deposits, Krupp and Weiser (1992) discussed the reasons for incongruent solubility behaviour in detrital gold alloys. The arguments are forward based on the assumption that dissolution and precipitation are exclusively controlled by the tendency of fluids to gain saturation with respect to the elements of the Au-Ag-Cl-O_2-S_2 system. Such phase diagrams conventionally represent the stable phases and allow a description of what happens to a given phase if one or more parameters are changed. According to them, the assemblage of a gold-silver alloy is stable in space A (Fig. 4) which is characterized by low fO_2 which shifts with both increasing aCl^- and pH to higher values. The association gold + chlorargyrite becomes stable at enhanced oxygen fugacities (space B in Fig. 4) thereby promoting exsolution of Ag from the alloy. Consequently, one would conclude that de-alloying detrital gold grains is controlled by high oxygen fugacities. Solubilty of $AgCl^o$ is higher than of Au^o; in any case, Ag^o has to be oxidized. Krupp and Weiser (1992) considered only chemical complexation with chloride as the controlling reaction: *"...The silver component will react to form silver chloride and will simultaneously be leached out due to the aqueous solubility of chlorargyrite. The remaining gold will assume a spongy structure or it may recrystallize as long as the river water is saturated with respect to pure gold"*.

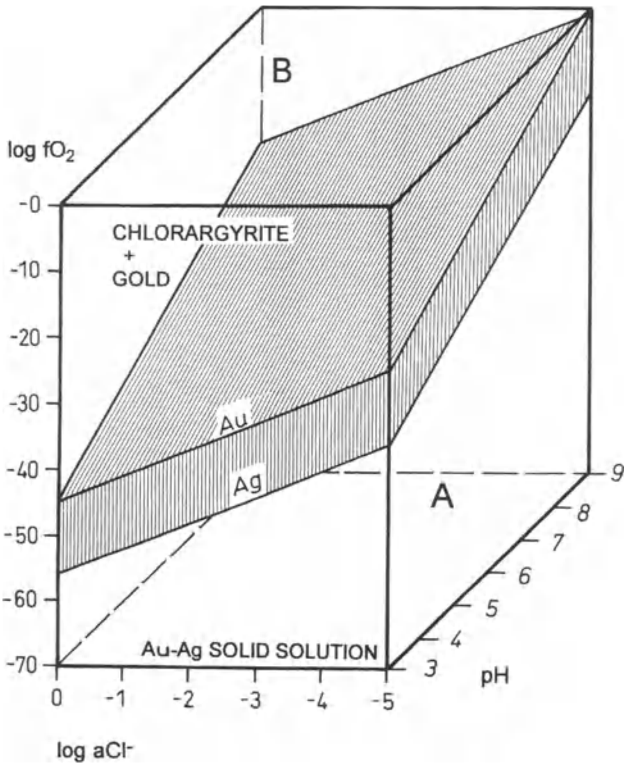

Fig. 4: Simplified Au-Ag-Cl-O phase diagram (redrawn after Krupp and Weiser 1992).

An electrochemical approach to corrosion of gold alloys is related to differences of chemical potentials such as gradients of oxygen fugacity as indicated in Fig. 5 (Bockris and Reddy 1973, Forty and Rowlands 1981). In crevices the supply of oxygen is exclusively controlled by diffusion which is slow compared to the faster electrochemical reactions taking place at the rim of the gold grains exposed to the infiltrating oxygen-enriched solutions. At the surface electronation of oxygen (= reduction of oxygen) occurs. The starvation of oxygen is most pronounced at the tip of the crevices which are progressively losing Ag^+ by de-electronation of Ag^o (= oxidation of silver), which is the less noble component of the Au-Ag alloy.

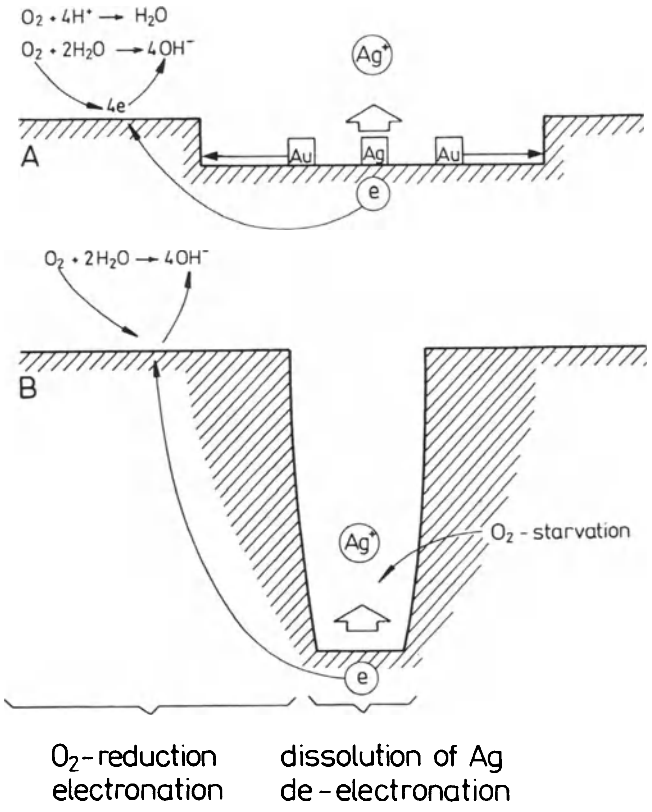

Fig. 5: Morphological changes occurring at the surface of an Au-Ag alloy undergoing corrosion. The upper and lower part illustrate the initial (A) and final (B) stage of electrochemical corrosion of an Au-Ag alloy. Oxygen is reduced at the outer surface, whereas Ag^+ is released at the tip of a crevice. The crevice deepens and narrows with the ongoing process, resulting in a porous rim.

Electrochemical reduction (electronation) of oxygen at the outer surface of the gold grains is then coupled with oxidation (de-electronation) of silver in oxygen-starving zones. The electrons thus obtained by de-electronation of silver immediately spread over the outer surface of the grain. At certain sites, such as grain boundaries and triple-points, growth terraces and fracture surfaces dissolved oxygen is reduced. According to the proposed process silver is dissolved where oxygen is lowest. The chemical reactions involved are

cathode:	$O_2 + 2\,H_2O + 4\,e \Leftrightarrow 4\,OH^-$	(3)
anode:	$Ag \Leftrightarrow Ag^+ + e$	(4)
sum:	$O_2 + 2\,H_2O + 4\,Ag \Leftrightarrow 4\,Ag^+ + 4\,OH^-$	(5)

The half-cell reactions (3) and (4) describe the processes that take place at different sites of the alloy. The overall reaction (5) just states that in the presence of oxygen silver is dissolved. The important difference between the two ways of describing the process is that the kinetic considerations (3) and (4) explain (i) the formation of a spongy structure of the rim and (ii) the evolution of a high fineness of detrital gold grains in more details than the overall reaction (5). The two different processes occur at two independent sites due to the high electric conductivity of the alloy.

The remaining gold atoms in the crevices are believed to be rather mobile as physi-sorbed atoms (Fig. 4). The observed porous gold rims of high fineness (Fig. 1-3) surrounding the residual alloy are the result of a sequence of morphological changes occurring on the surface of an alloy undergoing corrosion disordering and reordering (Forty and Durkin 1980). The surface of the Au-Ag alloy will continue to become disordered, as long as the less-noble atoms can be dissolved. The reordering of the remaining Au atoms depends on the ease with which surface vacancies or adsorbed Au-atoms can migrate. Since the mobility of adsorbed Au-atoms is expected to be high even at room temperature (Forty and Rowlands 1981, Fritz and Pickering 1991), they nucleate to form a "gold island and channel structure" (Forty and Durkin 1980). Surface migration of residual gold atoms exposes fresh alloy to the corrosive environment. This fresh surface becomes disordered by further selective dissolution and further reordering occurs by growth of the "gold islands". Thus a continuous process of disordering and reordering is established. As the "gold islands" of high fineness grow, the channels between them deepen. Finally, the channels coalesce and degenerate into the porous structure of the de-alloyed gold rim, enclosing the remaining alloyed core (Fig. 2a) or are welded to compact gold grains of high fineness. Extremes of the latter are gold "nuggets". Fig. 2b shows some tectonic deformation of a once spongy gold.

Electrochemically, gold alloys in a natural environment form an externally controlled self-driving cell which will go on until either oxygen is consumed or the bulk of the gold grain is refined. Thus, availability of oxygen becomes the controlling factor.

From the above, it is obvious that this refinement process is oxygen-controlled and cannot take place when the oxygen fugacity is very low as, for instance, in ancient anoxic environments like the Witwatersrand conglomerates. Here, the lack of a significant oxygen gradient prevented the progress of the de-alloying (refining) process. Oxygen is needed, which is present in weathering solutions but absent from deeply buried, sulfide-rich, sediments. This explanation agrees well with the high fineness (Fisher 1945) of placer and laterite gold in comparison to that of primary gold from the same gold field.

The foregoing discussion of corrosion elucidates the essential difference between the chemical and the electrochemical approach to this problem. The former assumes chemical combination of oxidized silver ions as the driving force to dissolve the less noble metals, whereas the latter is based on an oxygen gradient along the surface of each individual gold grain, where the less noble metals are dissolved at sites with lowest oxygen fugacity, and of course assisted by chemical complexation (Fig. 6).

The different role of oxygen in the two offered interpretations shows best the fundamental difference in interpreting the same observation from a thermodynamic or an electrochemical point of view.

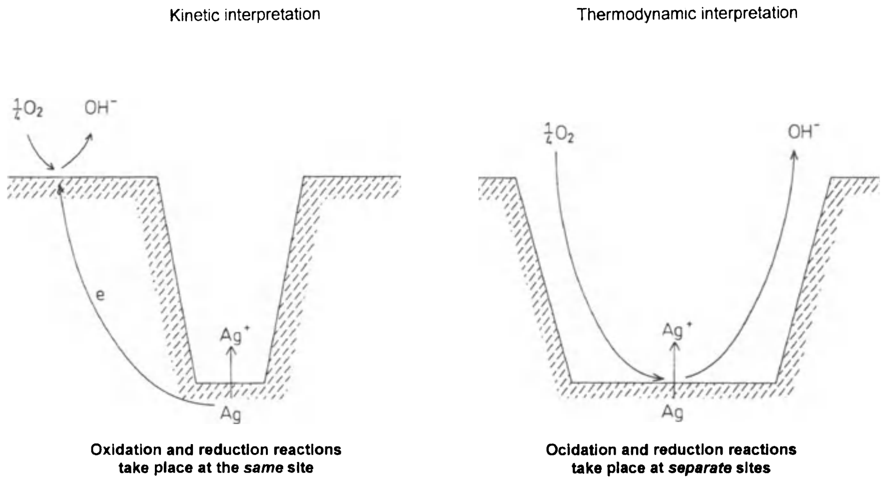

Fig. 6: Comparison of kinetic and thermodynamic view of corrosion. In thermodynamics oxidation and reduction processes occur at the same site, whereas in kinetics both reactions might occur at different sites but at material with sufficiently high enough electric conductivity.

4. Conclusion

High fineness of gold is electrochemically achieved where there is a gradient in oxygen fugacity. Less noble metals of alloys are dissolved at sites of gold grains with very low oxygen fugacity and spongy rims evolve surrounding the alloyed core of the gold grain. After de-alloying and compaction the welded gold grains show a high fineness. Similar processes are expected to act on gold artefacts because corrosion is a natural process. Surfaces of gold alloys become refined on the exposure of inner sections which become porous due to dissolution of the less noble metals. The reasons are that these alloys are not in equilibrium at all sites with the surrounding environment, and electrons are moving in the metallic conductor to places where they are consumed in reduction processes such as reaction (1). All reactions take place in separate micro-environments but these are electrically connected. Thus, in a thermodynamic sense, equilibrium cannot be achieved unless the reaction is finished by consumption of one of the reaction partners: oxygen or Au-Ag alloy. What we observe is a kinetic snap-shot of a process. From the foregoing it is self-explanatory that such a system cannot quantitatively be described by thermodynamic consideration.

Acknowledgement
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Chapter 4

THE COMPOSITION OF GOLD FROM THE ANCIENT MINING DISTRICT OF VERESPATAK/ROŞIA MONTANĂ, ROMANIA

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ABSTRACT. The gold deposits of Verespatak belong to the famous "Golden Quadrangle" (Romania). They have probably been exploited since ancient times. In order to obtain more detailed compositional information, native gold samples were analyzed by WDS and NAA. The results show that the gold from Verespatak has typically very high silver contents in the order of 20-25% and also contains tellurium and other trace elements in the matrix and bound to mineral inclusions. Melting experiments under oxidizing and reducing conditions showed that copper and tellurium contained in the gold were hardly affected. Thus copper contents of up to 0.4% and tellurium contents of up to 0.2% can occur in this gold type. Such high tellurium contents have so far not been found in prehistoric gold objects from this region.

1. Introduction and Geology

The mining district of Verespatak, or, as it is called today in Romania, Roşia Montană, is located in the northern area of the Transylvanian Ore Mountains, in the Carpathian Basin, and is also known as the "Golden Quadrangle". Without doubt it was exploited in antiquity and belongs among the richest gold occurrences in Europe.

The area is built up from a sequence of (sub-)volcanic rocks that originated during the final stage of the Alpine magmatism during the Neogene (= younger Tertiary period). Volcanic activity of predominantly andesitic character led to the formation of numerous porphyry copper deposits very rich in gold and silver and other non-ferrous metals (Ianovici and Borcoş 1982). These ore deposits are located within brecciated volcanic pipes and intrusions, altered by hydrothermal activity. The native gold and gold-silver ores are concentrated in the oxidation and the secondary enrichment zones near the surface. These parts of the ore deposits have been exploited almost quantitatively in earlier times.

Gold mining in the Transylvanian Ore Mountains continued until the middle of this century (Roman et al. 1982). In particular the area of Verespatak was rich in primary and secondary gold deposits, where gold mining was going on in the Csetate massif near the large fault pit at Verespatak. The Csetate is the most impressive example of how an ore deposit was ran-

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sacked by Roman mining activities, and the large fault pit (40 x 100 m) is said to be of Roman origin too. Between 1933 and 1939, 4000-5000 miners worked in the gold mines. For political reasons production figures remained obscure, but it is still apparent today that the area was intensively mined during the recent past. Gold was exploited both by panning and placer mining in the rivers, as well as by underground mining by very old-fashioned, almost medieval methods, that today are very helpful for understanding the techniques of prehistoric mining in the Old World. It is reported that lumps of gold of several kilograms were found. In the second half of the last century, 2124 kg gold were produced from the mines in the "Golden Quadrangle", in 1913 alone 2415 kg.

2. History

The abundance of gold in this area was certainly one of the major reasons for the two large military expeditions by the Romans at the beginning of the 2nd century A.D. After the province of Dacia was integrated into the Roman empire, enormous mining activities were organized in the area of "Aurariae Dacicae" (Wollmann 1976). At Alburnus Major, as the ancient Verespatak was called, gold was also exploited to a huge extent by opencast and underground mining. Most interesting details of Roman mining, and the organization under the supervision of the "procurator aurarium" were revealed by 40 wax-tablets with Latin inscriptions, found in the 18th and 19th centuries inside an ancient mine (Posepny 1868). Relics of firesetting as well as hammer and chisel work are still visible today in many ancient workings that were discovered during modern mining activities, and Roman mining tools were found inside the mines (Téglás 1888). Obviously, the Romans did not spare any effort to set up a sophisticated drainage system within the mines. This is shown by several bucket wheels found at depths of up to 60 m. The Roman mining activity within the primary ore bodies of Dacia is manifold and well dated by archaeological and textual evidence. Unknown, however, is the real age of the alleged Roman placer workings, visible along the rivers and streams of the "Golden Quadrangle". There is no indication for hydraulic mining of the type well known e.g. from Roman gold mining at the Iberian Peninsula.

The exploitation of gold in the Carpathian Basin is most likely much older, and it may turn out that Roman mining was nothing more than a reorganization and enlargement by improved technology of earlier mining activity in this area. Evidence for such a development is common from other sites (Rio Tinto, Cyprus, Feinan, Timna). The first textual evidence comes from Herodotus who described the gold fields in the 5th century B.C. The prehistoric exploitation of gold in the Transylvanian Ore Mountains was postulated at the end of the 19th century, when Téglás (1888) found some grooved hammerstones. He also claimed that gold high in silver would originate from the "Golden Quadrangle". Similar observations were made by Hartmann (1970). In his investigation on prehistoric gold in Europe, he defined several groups of Bronze Age gold artefacts with high silver contents, that, according to some analyses from the beginning of this century (Schumacher 1912), were considered to be typical for the ores from this area. Some authors seem to take the prehistoric exploitation of these gold deposits for granted (Bacskay 1985). Although it is not unlikely that some prehistoric gold derives from this area, this question remains open at present, because Hartmann (1970) did not publish any analyses of native gold from there.

3. Mineralogical and chemical composition of the gold

For this study, 15 samples of "native gold from Verespatak" (exact locality of the mine unknown) from the collection of the Deutsches Bergbau-Museum were analyzed for their chemical composition by EDS-system attached to a scanning electron microscope. Of these, eleven were mounted for metallographic and WDS analyses, and four of them were selected for detailed analyses by neutron activation (NAA). Two samples were used for melting experiments, using oxidizing and reducing conditions respectively. The results are compiled in Tables 1 to 3.

The samples consist of thin flakes, featherlike dendrites, and elongated crystals (Fig. 1) of native gold, yellow to pale lemon coloured, weighing up to several grams. The surfaces show occasionally distinct growth fabrics such as flat triangular (octahedral) pyramids (Fig. 2). The gangue is mainly quartz, with minor baryte. Native gold is sometimes embedded in iron sulfides. The aim was to obtain native gold samples in a form also accessible to ancient metallurgists, not modern low grade ore; thus any gold inclusions in matrix minerals have been neglected.

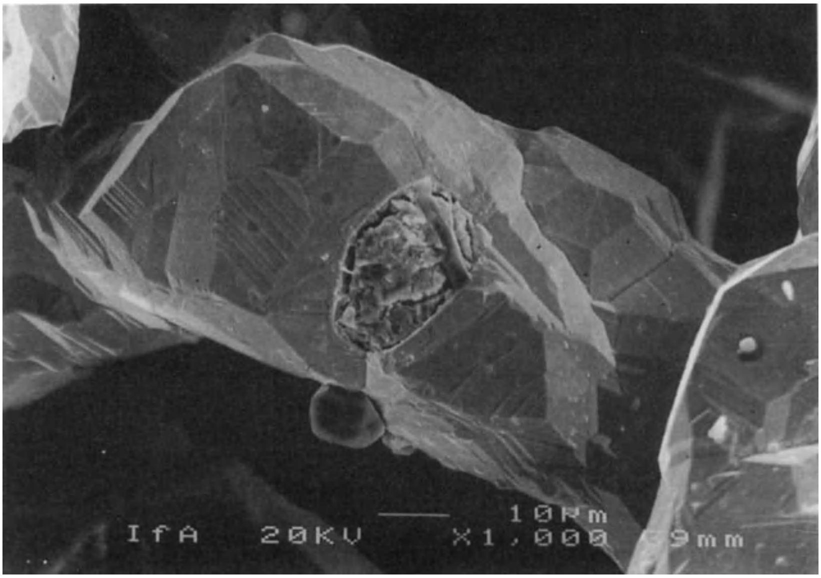

Fig. 1: Verespatak, sample Ro III. Elongated gold/electrum crystal with well developed surfaces and telluride minerals (center); SEM picture, secondary electron mode.

The gold has consistently very high contents of silver. The majority of the samples range between 20 and 25 wt%, sometimes reaching more than 30 wt%. (Fig. 3, Table 1). Thus it should rather be termed as electrum, which is typical for this ore deposit. Gold and silver add up to more than 99 wt%. Other elements detected with the WDS-system of the electron microscope included tellurium and copper. Out of eleven samples, six have tellurium concentrations between 1000 and 1700 ppm, two contain copper around 500 ppm, and two others show 2000 and some 4000 ppm Cu, respectively. For WDS analyses, five points on each sample were analyzed with a beam current of about 3 nA. Counting times were 250 sec for tellurium, arsenic, antimony, copper, nickel, and iron, and 100 sec for gold and silver, using LiF and PET crystals and a Phi-Rho-Zet correction procedure. Only analyses with a total between 98 and 102 wt% were accepted. Due to the gold matrix, the detection limits for tellurium, arsenic, and antimony are near 1000 ppm, and for copper, nickel, and iron near 500 ppm. Results with an error from counting statistics > 20% are indicated with a " ≈ ". If the statistical error exceeded 25% then the element was considered not detected and indicated with a "-" (Tables 1 and 3).

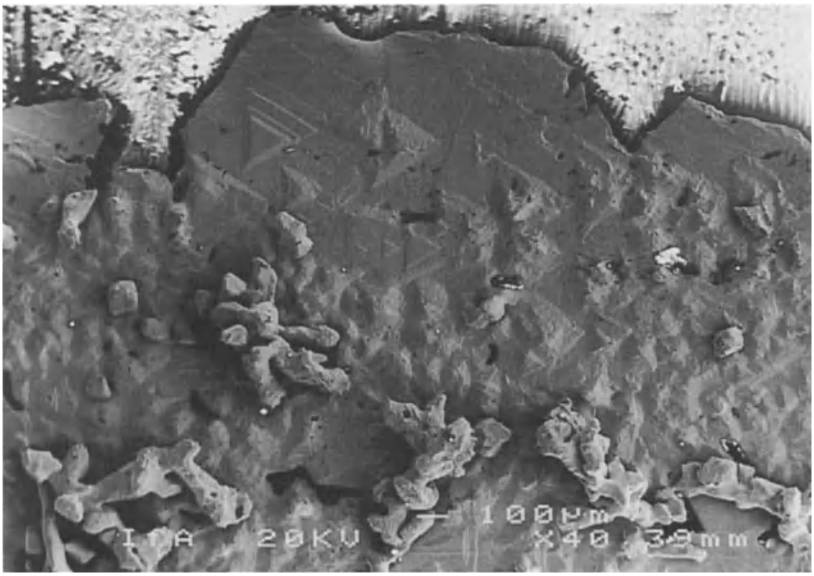

Fig. 2: Verespatak, sample Ro III. Natural surface of a gold/electrum specimen showing growth fabrics such as triangular (octahedral) pyramides and dendrites; SEM picture, secondary electron mode.

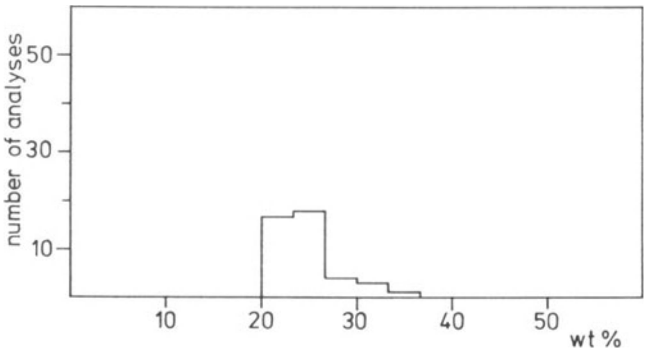

Fig. 3: Silver content in gold from Verespatak ranges between 20 and 25 wt% in most samples . Therefore, it should rather be called electrum. In a few cases, silver increases up to more than 30 wt%. Such high concentrations were only measured next to inclusions of gersdorffite (NiAsS) in the gold. The histogram shows the composition of 11 different samples.

Table 1. Chemical composition of native gold and electrum from Verespatak. The data of samples Ro III and Ro VII are given in Table 3 in order to provide a better comparison of the natural alloy with the compositions produced by melting experiments. The microanalyses were performed by a WDS system attached to a scanning electron microscope. Fe, Ni, As, and Sb occur mainly in inclusions. Therefore, these elements were not detected by this method in the Au/Ag matrix. For analytical procedures and limits of detection see text.

Sample no.		Au [wt%]	Ag [wt%]	Te [wt%]	Cu [wt%]
Ro I	1	78.5	21.4	-	-
	2	80.7	21.6	-	-
	3	77.6	21.7	-	-
	4	79.7	22.1	-	-
	5	79.3	21.0	-	-
Ro II	6	77.5	22.0	0.13	-
	7	75.9	24.1	0.1	-
	8	76.3	22.4	≈ 0.1	-
	9	75.5	24.6	0.1	-
	10	75.6	24.5	≈ 0.1	-
Ro IV	17	72.0	28.2	0.11	0.20
	18	69.6	29.5	0.12	0.22
	19	73.7	25.2	0.13	0.16
	20	69.6	29.5	0.13	0.21
Ro V	21	77.0	23.2	≈ 0.1	≈ 0.1
	22	79.5	23.3	≈ 0.1	≈ 0.05
	23	78.6	23.5	≈ 0.1	≈ 0.05
Ro VI	27	79.4	22.8	0.11	-
	28	77.7	22.5	≈ 0.1	0.08
	30	76.3	24.6	≈ 0.1	-
Ro IX	32	75.1	23.1	0.11	-
	33	76.9	22.2	-	-
Ro 36	1	78.0	24.7	≈ 0.1	-
	2	75.7	24.3	≈ 0.1	-
	3	75.1	24.1	≈ 0.1	≈ 0.1
	5	77.6	24.3	≈ 0.1	-
Ro 37	7	75.5	24.9	-	-
	8	74.0	24.0	-	-
	9	73.9	23.9	-	-
	10	73.8	24.5	-	-
Ro 40	11	76.9	24.2	≈ 0.1	0.44
	12	76.1	23.9	0.10	0.41
	13	76.0	22.8	≈ 0.1	0.43
	14	67.7	23.8	0.16	0.49

Platinum group elements are expected to be low in this type of gold deposit. Nevertheless, four samples (Ro 38, 39, 41, and I) were subjected to neutron activation analysis in an effort to confirm this conjecture and possibly to detect any other trace elements (Table 2). Subsamples of 1 to 3 mg without any adhering crust or accompanying minerals were irradiated for 2 hours at a neutron flux of $6x10^{12}$ cm^{-2} sec^{-1}. Because of the high activity of ^{198}Au, Cu, As, and other elements with relatively short-lived radionuclides could not be determined. An additional complication was the high silver content of the samples, which leads to a high and long-lived activity of ^{110m}Ag, so that a radiochemical separation of silver was necessary. For this purpose the samples were dissolved in aqua regia in a closed teflon container and the silver chloride separated by filtration. Any remaining ^{198}Au activity was removed by extraction with diethyl ether and the remaining solution measured with a hyperpure germanium detector. Previous experiments had shown that the elements sought were not adsorbed on the silver chloride precipitate to any appreciable extent. Only osmium is lost by volatilization. This method is not very sensitive for tellurium. Therefore only upper limits of 600 to 1900 ppm could be determined for this element, which at least do not contradict the results obtained with the scanning electron microscope. Of the platinum elements iridium can be determined most sensitively. However, it was always below the detection limit ranging from 0.09 to 0.20 ppm. The same is true for various elements sought, like Cr, Co, Sb, Se, and some lithophile elements, which were all below the detection limit in the order of 1 to 10 ppm. Only mercury was present in measurable amounts, and ranged from 80 to 150 ppm.

Table 2. Te, Ir, and Hg contents of four gold/electrum samples from Verespatak measured by neutron activation analysis (Heidelberg). For analytical procedures and limits of detection see text.

Sample no.	Te	Ir [ppm]	Hg
Ro 38	≈ 1900	≈ 0.20	100
Ro 39	≈ 600	≈ 0.09	82
Ro 41	≈ 1000	≈ 0.09	130
Ro I	≈ 1700	≈ 0.11	150

Besides the accompanying gangue minerals mentioned before, other ore minerals occur together with the gold. Several gold-silver tellurides, sometimes close to sylvanite, $(Au,Ag)_2Te_4$, or petzite, Ag_3AuTe_2, form particles of 10-20 μm diameter and only a few microns thick. They are bound to the surface, closely packed in certain areas (Fig. 4) but never incorporated in gold grains (Fig. 5).

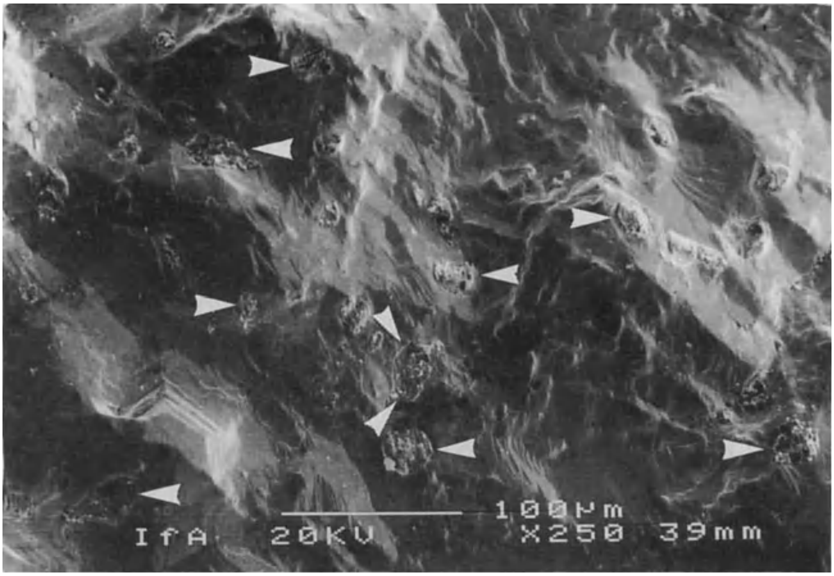

Fig. 4: Verespatak, sample Ro VI. Natural surface of a specimen showing pocks of various tellurium minerals (arrows); SEM picture, back-scattered electron mode.

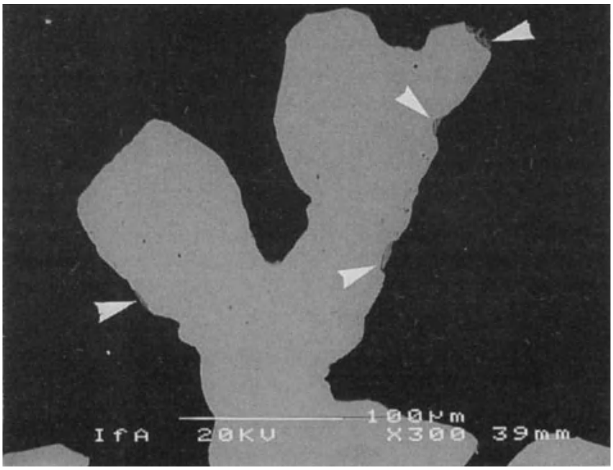

Fig. 5: Verespatak, sample Ro II. Dendrite of gold/electrum with Au-Ag-tellurides (arrows). These are grown upon the dendrite while the alloy itself is free of inclusions; polished sample, SEM picture, back-scattered mode.

Gersdorffite, NiAsS, is the second most frequent ore mineral in the samples investigated; it occurs as inclusions of several 10 μm diameter within dense gold grains (Fig. 6). Gersdorffite is always associated with high silver concentrations in gold, i.e. typically over 30% Ag. About one tenth of the nickel is substituted by iron, while no cobalt was found in the gersdorffite. Other minerals were only rarely found in the samples; they include sphalerite, polybasite, and baryte.

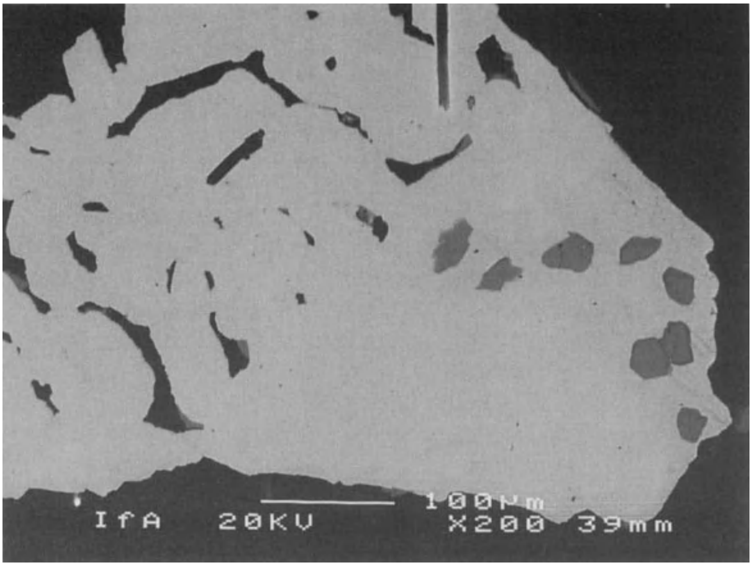

Fig. 6: Verespatak, sample Ro VII. Gold/electrum grain with inclusions of gersdorffite (grey); polished sample, SEM picture, back-scattered mode.

Te, Cu, Ni, Fe, and As are typical elements that occur often correlated with high Ag-contents. But they are mainly bound to inclusions and not to the matrix itself. Thus, the type of processes used in smelting and melting will have a decisive effect on the final concentrations of these elements in the gold.

4. Melting experiments

Two samples were selected for melting experiments under both oxidizing and reducing conditions; one sample rich in tellurium minerals (Ro III), and one with gersdorffite inclusions (Ro VII). One third of each sample was mounted unaltered in resin. The rest of the samples were used for the experiments in an electric furnace. In a first run, another third of each sample was heated for 15 minutes at 1200°C in a porcelain crucible under air (oxidizing conditions). The second run was performed under the same conditions, but in a graphite crucible, covered with charcoal (reducing conditions). The resulting reguli were mounted in resin for metallographic and comparative WDS analyses (Table 3).

Table 3. Chemical composition of two gold respectively electrum samples unchanged "(ore)" and melted under oxidizing "(ox)" and reducing "(red)" conditions (WDS data). For analytical procedures and limits of detection see text.

Sample no.		Au	Ag	Te	As [wt%]	Cu	Ni	Fe
Ro III	11	79.8	23.0	-	-	-	-	-
(ore)	12	79.3	23.2	-	-	-	-	-
	14	78.1	22.1	-	-	-	-	-
	15	75.4	23.7	-	-	-	-	-
Ro III	6	77.6	22.1	-	-	0.11	-	-
(ox)	7	79.4	23.0	-	-	0.14	-	-
	8	77.7	22.1	-	-	0.12	-	-
	9	79.0	22.1	-	-	0.08	-	-
	10	74.6	21.9	-	-	0.13	-	-
Ro III	11	76.0	21.5	-	-	0.12	-	4.4
(red)	12	75.2	21.9	-	-	0.09	-	4.4
	13	75.8	20.8	-	-	0.15	-	3.5
	14	75.7	21.5	-	-	0.34	-	3.3
	15	76.0	22.2	-	-	0.13	-	3.7
Ro VII		68.3	32.3	0.17	-	0.05	-	-
(ore)		68.6	30.2	-	-	0.06	-	-
		70.9	30.4	-	-	0.05	-	-
		66.6	33.6	0.15	-	≈ 0.05	-	-
		69.6	29.7	0.11	-	0.07	-	-
Ro VII		69.6	30.5	0.11	-	0.05	-	-
(ox)		69.5	31.2	-	-	0.10	-	-
		71.1	30.7	0.10	-	-	-	-
		70.9	31.1	0.16	-	-	-	-
		66.8	32.2	0.15	-	0.11	-	-
Ro VII		69.9	31.6	0.18	-	0.11	0.03	0.04
(red)		68.5	32.1	0.10	0.70	0.08	0.02	≈ 0.02
		70.7	31.8	0.12	0.32	0.10	≈ 0.02	0.04
		68.0	32.0	0.10	0.91	0.09	0.10	0.09

The sample Ro III is characterized by many tellurium minerals on its surface (see Fig. 4) and is partly covered with iron sulfides. The gold matrix has about 22% Ag and only very small concentrations of trace elements (Table 3). The metallographic structure is that of a dendritic filigree, with well developed crystal surfaces and tellurium minerals residing in small pockets (Fig. 1). Other minerals observed include polybasite, sphalerite, baryte, and quartz.

The sample melted under oxidizing conditions solidified in a dense droplet without any visible microstructure. Compared with natural gold it shows a significantly higher copper content, averaging around 0.12%. Tellurium remains unaltered within the analytival precision. As expected, no change of the silver concentration was observed.

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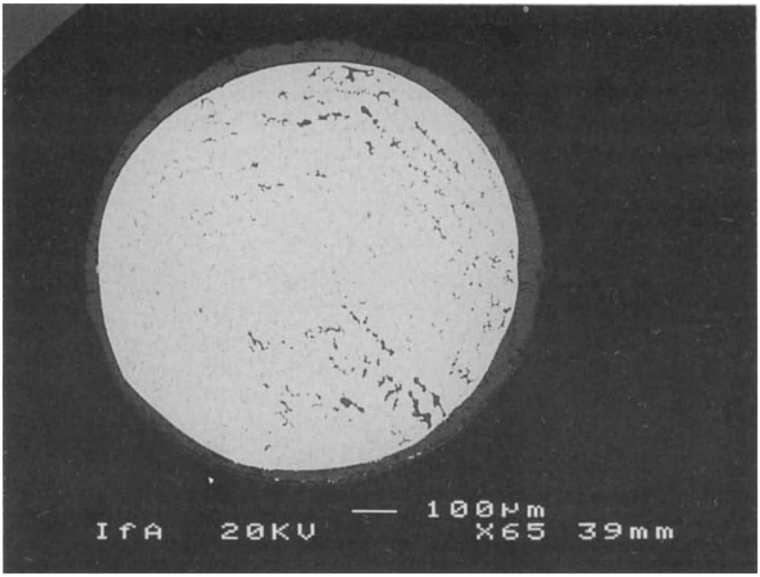

Fig. 7a: Verespatak, sample Ro III. Gold respectively electrum melted under reducing conditions. The prill has a rim of iron sulfides (mainly pyrrhotite, $Fe_{1-x}S$). The inclusions consist of iron sulfides and iron; polished sample, SEM picture, back-scattered electron mode.

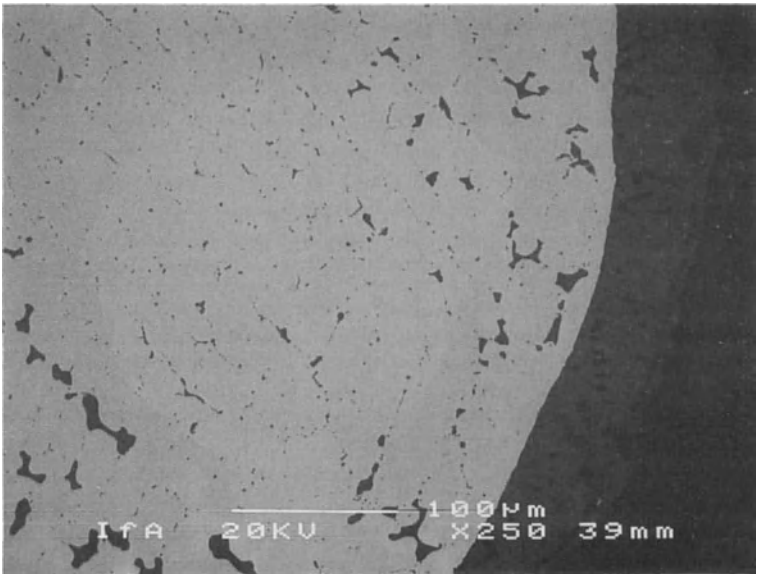

Fig. 7b: Verespatak, sample Ro III. Detail of Fig. 7a showing the dendritic structure and interstitial iron sulfides and iron in more detail. At this magnification, however, it is not possible to distinguish between these two phases; polished sample, SEM picture, back-scattered electron mode.

Different results are obtained after melting under reducing conditions. The prill has a rim of iron sulfides and a well developed dendritic structure with interstitial iron sulfides and metallic iron (Fig. 7a,b). The sulfide consists mainly of $Fe_{1-x}S$. Furthermore, tiny exsolution lamellae of iron in the sub-micron range are omnipresent in the gold matrix. On analysis, this is reflected in an iron content of the gold of nearly four percent. The copper content is about 1700 ppm with a maximum value of 3400 ppm. The gold and silver contents are slightly lower, but only due to the presence of iron. The gold/silver ratio remains unchanged compared with the original sample.

Sample Ro VII is a sample of mainly dendritic, sometimes densely crystallized gold. Gersdorffite is present not only as inclusions in the dense parts, but also along the edges of the dendrites (Fig. 6). About one tenth of its nickel is substituted by iron. Other minerals observed include quartz, magnetite, and sphalerite. The gold matrix itself is homogenous with little over 31% silver, about 1500 ppm tellurium and 500 ppm copper detected by the WDS system (Table 3).

To sum up, melting under oxidizing conditions did not change the composition of the prill. Tellurium and copper remained unaltered within the statistical errors of the analyses. No inclusions were visible in the gold button, but a significant quantity of dross remained in the mould. Melting under reducing conditions with a charcoal cover produced an alloy with a similar appearence as Ro III melted under reducing conditions. The structure is two-phased with a dendritic pattern. The inclusions consist of nickel-iron arsenides (Ni, Fe)As. The iron/nickel ratio is the same as in the gersdorffite with no sulfur left. The gold matrix is significantly enriched in nearly all trace elements measured. Arsenic averages around half a percent with a maximum near one percent, copper is clearly present at a concentration of about 1000 ppm, iron and nickel are both in the order of 500 ppm, and tellurium is still between 1000 and 1800 ppm.

In both cases, the copper contents of the gold matrix increased during the melting experiments. The most probable source for the copper are the accompanying ore minerals. This observation is in accord with data from an early gold workshop in Ecuador, where spilled prills are slightly enriched in copper compared with the original gold, panned from the same archaeological workshop sediments (Rehren and Temme 1994).

5. Discussion

The most characteristic features of native gold from Verespatak are relatively high silver, mercury, and tellurium contents. Qualitatively, this has also been observed by Neuninger et al. (1971). In addition, some other elements such as S, Te, Cu, Ni, Fe, and As occur with associated mineral phases. In prehistoric times, it would not have been possible to separate silver and gold. Thus, gold objects believed to derive from this area should contain in the order of 20 to 25% silver. The behaviour of the other elements depends mainly on the nature of the metallurgical processes used. Both cold working and sintering of gold concentrates will certainly conserve many of the mechanical impurities, i.e. isolated minerals as well as any inclusions present, and the mercury content as well (Éluère and Raub 1991).

On melting under oxidizing conditions, the major part of the accompanying elements will be removed either as floating dross or by evaporation. It would be impossible, however, to separate all impurities completely from the gold. Under reducing conditions a large fraction of the elements in mineral inclusions will be reduced and taken up by the liquid gold. This is particularly true for iron, arsenic, and copper. The iron uptake can even go beyond its maximum solubility in gold, resulting in a pronounced oriented exsolution of interstitial iron between gold dendrites. According to the presented experiments copper seems to be enriched depending on the copper content of the associated minerals. Tellurium remains unaltered on melting argentiferous gold regardless of the redox conditions. This may be due to the formation of compounds with silver and gold. In modern gold metallurgy on an industrial scale the complete removal of tellurium and, incidentally, also mercury is generally considered to be difficult (Yannopoulos 1991).

Thus, the chemical characteristics of melted gold from Verespatak seem to be silver contents of 20-25%, copper contents of up to 0.4%, and tellurium contents of up to 0.1% (see also Table 1). Considering that Hartmann's (1970) detection limit for Te seems to have been in the order of 0.01%, it is therefore somewhat surprising that he found only one gold object from the Danubian region in his investigations of prehistoric gold artefacts that contained any measurable tellurium. This raises the question if Verespatak was indeed an important source for prehistoric gold in southeast Europe as is frequently held. Hartmann (1970) suggested, for instance, that the gold of his group A3 that is, on average, characterized by 25% Ag, 0.3% Cu and occasionally small contents of tin, may have its origin in Transylvania. It is mainly to be found in artefacts of the Early and Middle Bronze Age and Hartmann also suggested that this type of gold may be the earliest that derived from hard rock mining. It is tempting to relate this group to the native gold of Verespatak but Hartmann did not detect tellurium and the authors did not detect any tin. At this stage one must concede that too few samples have been analyzed in order to characterize the elemental range of minor elements within an ore deposit. Thus it is still possible that gold with lower tellurium contents and with some tin may also occur at Verespatak or any other deposit within the Golden Quadrangle. In addition, there are several other gold occurrences in the western Balkan, the northern Carpathians and in the Slovakian Ore Mountains - all within some 200 km distance - that have not even been analyzed, except for one sample of native gold from Kremnica (Kremnitz) that was rather similar in composition as the native gold from Verespatak (Neuninger et al. 1971). At present the question of the prehistoric gold sources must remain unanswered but the recent progress in mining archaeology has shown that underground mining for copper was already well known in the European Bronze Age (see Weisgerber and Pernicka, this volume) so that it is more than likely that also gold was mined in this way. The Golden Quadrangle remains as a very good candidate in this respect.

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CHAPTER 5

Manufacture of Gold in Prehistory

Chapter 5

TECHNICAL ASPECTS OF PREHISTORIC GOLD OBJECTS ON THE BASIS OF MATERIAL ANALYSES

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ABSTRACT. Starting with the analyses produced in the SAM (Studien zu den Anfängen der Metallurgie) project of prehistoric gold objects from Spain and Portugal several aspects of the composition of the gold are discussed. According to the content of silver, and especially of copper and tin, there exist specific groupings of the analyses that correlate with the period and cultural context. The reasons for such distribution patterns are various: different natural sources of the raw material, impurities, intentional alloying, remelting etc. The composition of "natural gold" is also discussed, as is the relation between composition in the Au/Ag/Cu - system and the properties of gold. Colour, melting point, hardness, ductility etc. depend on the content of silver and, especially, copper; these qualities are very important for the different technological processes of goldworking in prehistoric times.

1. Introduction

This contribution is simply intended to be a catalogue of observations and questions about the technological aspects of gold posed by an archaeologist. Some of them have been mentioned in publications, but this is an opportunity to introduce them into an interdisciplinary discussion involving different cultural and natural sciences. To the author this is the only way to answer these very important questions about the role of gold in the development of human society in prehistory.

2. The SAM analytical project

This paper might be thought to be starting from a not very up-to-date point of view, because it will consider only some observations made studying the many analyses of archaeological gold objects from the Iberian Peninsula. They are part of the well-known, but now sadly ended project of SAM (Studien zu den Anfängen der Metallurgie) in Stuttgart (Schroeder 1991, Hartmann 1972, 1982). The part of this project that concerns the metallurgy of gold is not without critics, especially today, because it is based on analytical and statistical methods of the 1960s. (Härke 1978, Pernicka 1989). At this point it is useful to underline some aspects of this project, which are still of considerable value for archaeo-metallurgical investigation today:

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 385–398.

1. It is the largest database of analyses of prehistoric gold objects even today; the SAM project produced in its 10 to 15 years' existence nearly 5.500 analyses from about 5.000 gold objects.
2. The analyses were all made with the same methods and therefore are directly comparable with one another.
3. They cover an enormous range of time and space; in Stuttgart objects from the Copper Age until the coming of the Romans, from Ireland to the Aegean, and from Portugal to Denmark have been analysed (Fig. 1). This means that the map of Europe is covered with a dense pattern of gold-analyses, which only has white areas in the north of Scandinavia, in the south of Italy and in a few parts of eastern Europe.
4. This project offers unique opportunities to study aspects of gold-metalworking over the whole Old World on the largest scales of time, space and culture.
5. The great number of analyses offers a good background for statistical methods.

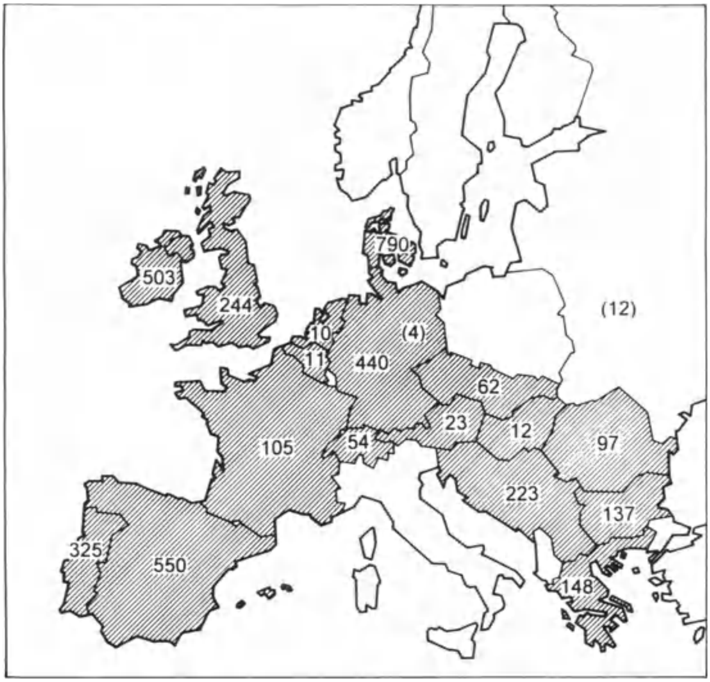

Fig. 1: Map of the distribution of SAM-analyses in Europe.

The Iberian Peninsula, which has already been mentioned, is in the writer's view one of the most interesting regions of all; not only because of the old traditions (for instance recorded by Strabo or Pliny the Elder; Pingel 1992), which see it as one of the richest provinces in natural gold of the ancient world, but also because of the fact that the cultures in antiquity are related to the classical Mediterranean world as well as to the Atlantic and Central European area.

Another important fact are the nearly 900 analyses from Spain and Portugal, which represent more than a half of all known gold objects of pre-Roman time (Hartmann 1982). Studying these analyses and objects it was possible to make many observations concerning aspects of gold technology (Pingel 1992). They are valid for the other European regions as well. In the publications of all the analyses by Hartmann from 1970 and 1982 such problems were not touched on. Hence, some of them will be presented here in a wider context, to emphasize not only their value and possibilities, but also the limitations of these data in further technological studies in prehistoric gold.

3. Analyses of Iberian gold artifacts

Because of the limited space the methods and the results of the grouping of the analyses into 15 or 20 types of gold by Hartmann are not discussed in detail. In a simplified view this grouping is primarily based on the elements silver (Ag) and copper (Cu), which are present in all the SAM analyses in varying quantities, and the elements tin (Sn) and platinum (Pt), which do not occur in all the analyses, and then only in low percentages (Sn always below 1 %; Pt below 0.1 %). For the grouping of the analyses both elements are more important by their presence rather than their quantity.

The analyses are mainly characterised by their content of silver vs. copper. The two-dimensional diagram for Ag vs. Cu (Fig. 2), contains all of the Iberian analyses. It can be seen, that silver is spread over a range from very low values of 1 or 2% to more than 30 or 40%, whilst copper ranges from only of 0.01% to 10% or, in some cases, 20 or 25%.

The diagram shows that the distribution of the analyses of Spain and Portugal in terms of their contents of silver and copper is not totally disordered, but shows some considerable concentrations, and some less occupied areas. For instance there are concentrations in the areas around 0.1% of copper and 10% of silver, or 5% of copper and 5-10% of silver, or 3-5% of copper and 20-30% of silver etc.

There is a similar pattern in the Cu vs. Sn diagram (Fig. 3), with high and low concentrations of tin; it is very notable that the analyses with low tin correspond with high Cu-values. More than one hundred analyses without tin are also indicated and the greater part of them are also in the range of high copper contents.

The problem is how to interpret these pictures: what are the reasons for such distributions of the gold compositions, not just in the Iberian Peninsula? In general the explanation could be:

1. There are different species of natural gold.
2. There are impurities of copper and silver and/or tin.
3. There are intentional admixtures of silver, copper and/or tin; i.e. an intentional alloy.
4. They are the result of remelting of old gold objects.

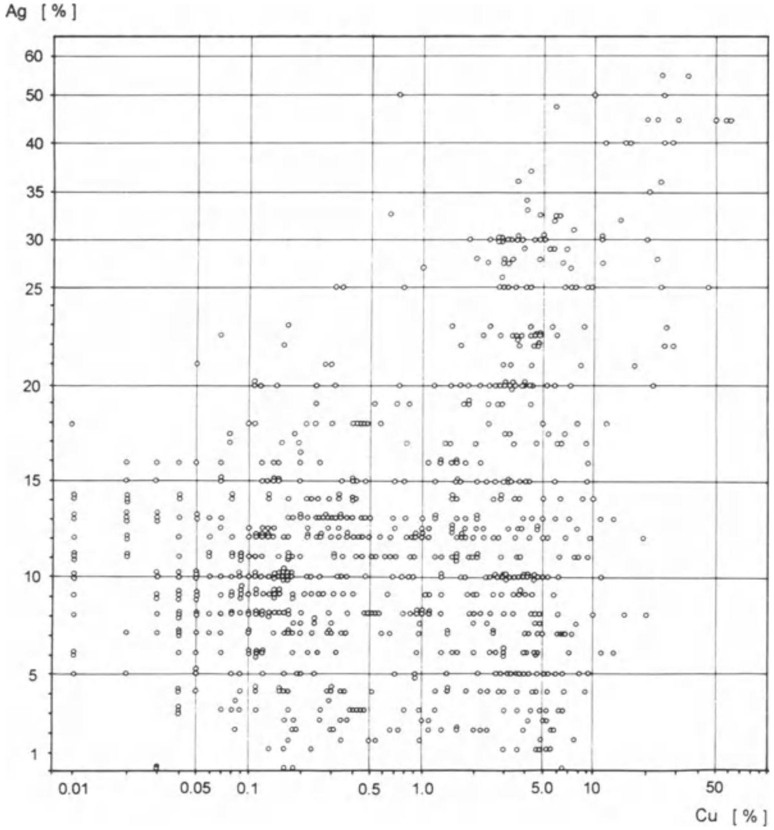

Fig. 2: Two-dimensional diagram of Ag vs. Cu percentages of the analyses from the Iberian Peninsula; Cu in logarithmic scale, Ag percentages in relation to Au = 100.

The first or main problem to be solved is the composition of natural gold, to see what may be natural and what must be artificial (impurities, alloys etc.). Published and accessible analyses of natural gold tend not to include other elements besides silver, which means copper, tin or platinum. For European sources of natural gold less than one hundred analyses with percentages of silver and copper were found in the literature. They indicate some variation in the composition of natural gold. In Fig. 4 70 analyses of natural gold from all regions of Europe are plotted in an Ag vs. Cu diagram for the Iberian objects. The discussion of the composition of natural gold is rather controversial, especially the amount of copper. The silver contents of natural gold are very widespread and correspond to the whole range of silver contents in the analysed objects from 1% to 40%. That means, that nearly all the silver results from the SAM analyses could correspond with natural gold; this is also the case with other European regions.

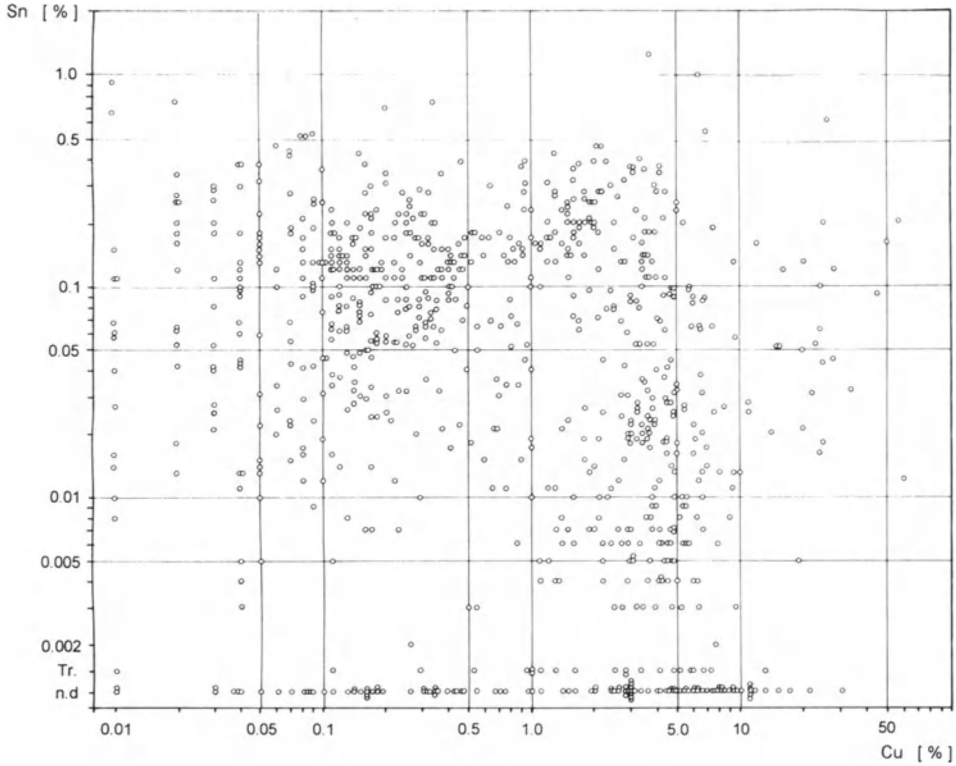

Fig. 3: Two-dimensional diagram of Cu vs. Sn percentages of the analyses from the Iberian Peninsula in logarithmic scale.

The maximum amount of copper in natural gold is much more difficult to define. Hartmann (1970) fixed it at around 1.5 or 2 %; hence Mohen (1990) or Tylecote (1987) mention 1 %, but he also stated, that all copper-amounts above 3 % cannot be from natural sources. This problem cannot be studied here more in detail: it should be a very important task for future investigation. For the purpose of this discussion, until more data are generally available, the limit will be set at around 2 %. For the moment it must be assumed that all analyses of gold with more than 2 % of copper are not made only of natural gold. The role of tin and platinum can only be touched on; their role in natural gold is much more complicated and not well studied. Both elements occur only in very small quantities, which may indicate some specific natural sources.

The contents of tin in the analyses from the Iberian Peninsula seem important in relation to the problem of remelting old gold objects. Often the higher, "unnatural" contents of copper are interpreted as the result of remelting. But in the Cu vs. Sn diagram (Fig. 3) together with the high copper contents tin percentages of the same or a lower degree and a considerable concentration of analyses without tin are found. Without entering into more details, this may indicate, that the high, "unnatural" copper-content of 2 % or more cannot be only the result of remelting. There must be other explanations for the high contents of copper and the absence or low contents of tin in the analyses.

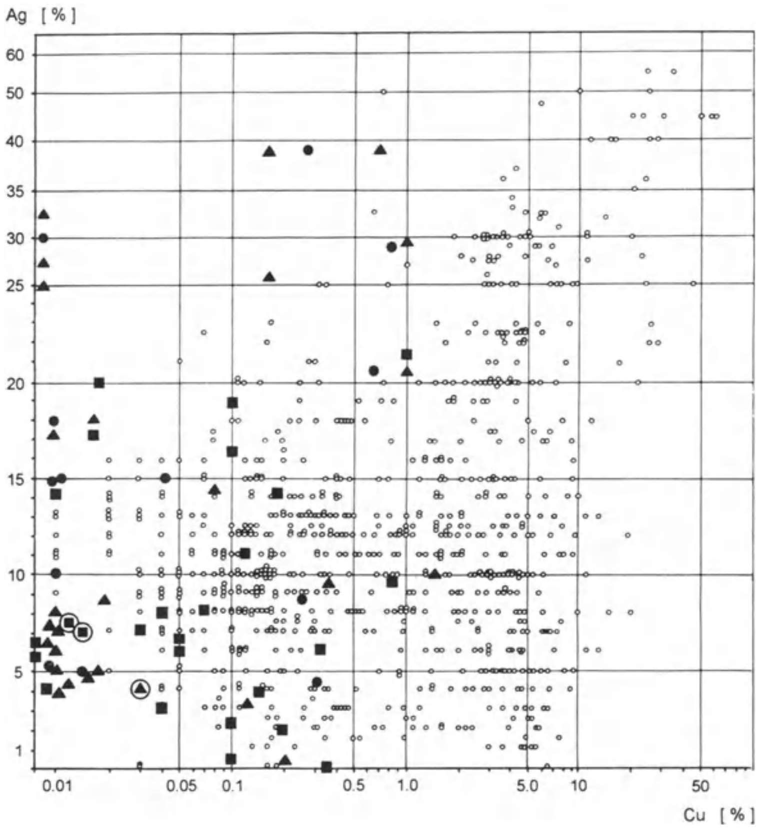

Fig. 4: Distribution of published "natural gold"-analyses from European sources in the Cu vs. Ag - diagram; solid circles: vein-gold, solid squares: placer gold, solid triangles: uncertain, open circles: with tin content.

Returning to the previous plot of the contents of silver and copper in Fig. 5, at the left side many of analyses which may belong to natural gold are found; here are concentrated the objects of the Copper and Bronze Age of the Iberian Peninsula. If chronological groups of analyses (Pingel 1992) are separated the development from lower to higher copper percentages can be seen. Here are only marked the Bronze Age analyses; the analyses of the Copper Age would be concentrated near the left border of the diagram.

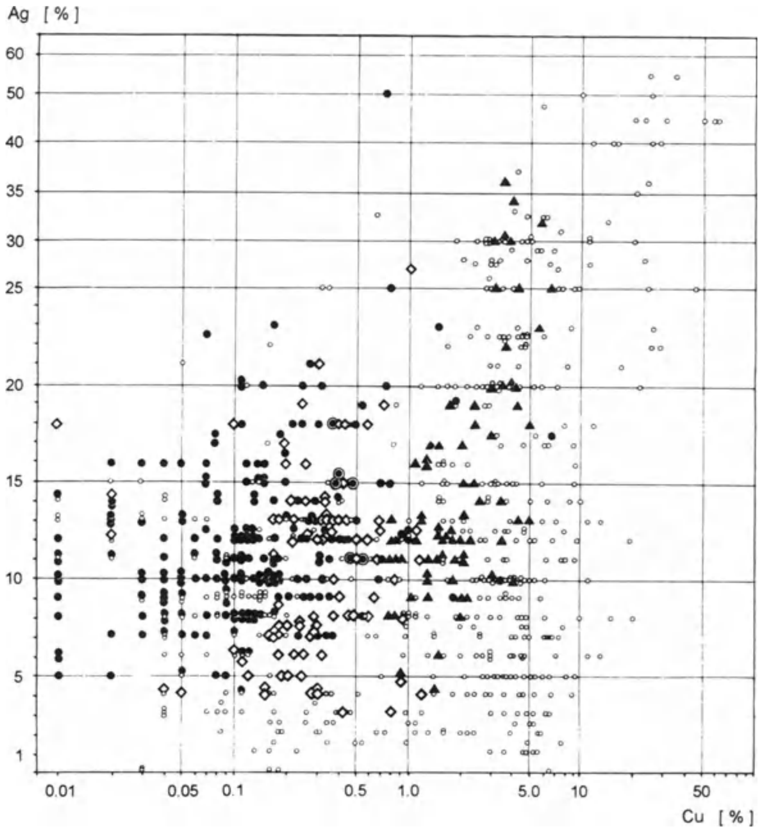

Fig. 5: Cu vs. Ag - diagram of the gold-analyses from Spain and Portugal of the Bronze Age; solid circles: Early and Middle Bronze Age; open rhombs: older Late Bronze Age; solid triangles: younger Late Bronze Age; half filled circles: hoard from Lebrija.

The Early and Middle Bronze Age analyses are concentrated around 0.1% of copper. The most famous complex of this group is the hoard from Caldas de Reyes in north-west Spain (Pingel 1985); it contains more than 15 kg gold in the form of vessels, rings, and a comb etc.

The Late Bronze Age analyses are subdivided into two chronological, and also cultural groups: the older objects of this period, that is of the 12th - 10th century B.C. have a copper content of around 0.3-0.5%. This group can be represented by the hoard from Villena in south-east Spain (Pingel 1992), also with a lot of gold-vessels and rings, but in a more elaborate or developed technique.

Six analyses of a hoard of very similar objects, which look like candlesticks are marked seperately; they were found together in Lebrija in southern Spain (Pingel 1992). It is not possible to discuss here the function and cultural background of this very interesting hoard, but the close grouping of these analysis must be emphasized. It is the writer's belief that they must have been manufactured in one workshop and from the same gold. This is rather astonishing because each of the candlestick is more than 70 cm high and in total the hoard weighs 7.7 kg. It is quite improbable, if not impossible, that the gold for these objects was prepared all together in one step or process, and it must be assumed that different melting charges had exactly the same composition. Whether these could be obtained by using natural gold in such quantities or an exactly mixed alloy cannot be answered today. Similar observations can also be made in other European regions and also in other periods indicating the same range of the raw materials and alloys in these diagrams.

As interesting is the later group, which belongs to the latest phase of the native Bronze Age of the Peninsula, meaning the 9th or 8th century B.C. These objects are made of gold with more than 1% copper up to 5%. Many must be made of gold which cannot be simply natural but must contain some percentage of added copper. These must represent the first real alloying of gold in the Peninsula. A similar situation obtains in other parts of "barbarian" Late Bronze Age Europe.

In Spain perhaps an archaeological background for this is found. At more or less the same time as these Late Bronze Age objects near the Mediterranean coast of southern Spain the first Phoenician "colonies" with their strong influence on jewellery forms and new techniques like filigree and granulation, soldering and the experience of alloying occur. In another diagram (Fig. 6) the analyses of these early Phoenician or Phoenician-influenced objects of the 9th, 8th or 7th centuries B.C are plotted. They have copper contents from more than 2 % to 10 %.

An example of one of the finds of the first Iron Age gold of southern Spain is the inventory of a tomb of Trayamar, near Malaga; with typical Phoenician forms of sheet and massive gold, with granulation, filigree etc. (Pingel 1992, plate 89). It is very interesting, that all the analyses of sheet gold (beads, some of the rings etc.) are close together, and the three remote analyses from Trayamar are from the massive gold rings. Here this problem cannot be dicussed in any more detail, but it must be remembered that in the eastern Mediterranean area the alloying and soldering of gold was known by the middle of the second millenium B.C., if not earlier.

The high standard and the characteristic grouping of Early Iron Age complexes can also be shown by the famous and homogeneous gold work, possibly grave goods, from Aliseda (Extremadura) (Perea 1991); the analyses have a rather low silver content, normally 2-7%.

Another example is the assemblage of jewellery from Baiao (Portugal), with earrings, chains, necklaces etc. of high quality and a total weight of 500g. (Pingel 1992, plate 104). The analyses are close enough together to imply a single manufacture and an intentionally produced alloy.

The diagram also shows other, later Iron Age analyses from Spain and Portugal, with a percentage of copper mostly in the range 2-10%. One of these is the famous hoard from Javea in eastern Spain with a very fine and extremely high standard of the technique, the finest filigree or granulation, chains of very thin wires, etc. (Nicolini 1990). The analyses also form a tight cluster, but have a very low silver content and around 5% of copper. It is very probable that at least five, or even all, of the objects were made from the same gold, which was prepared by adding copper to gold which had been refined to remove the silver content; this technique was also known by this time.

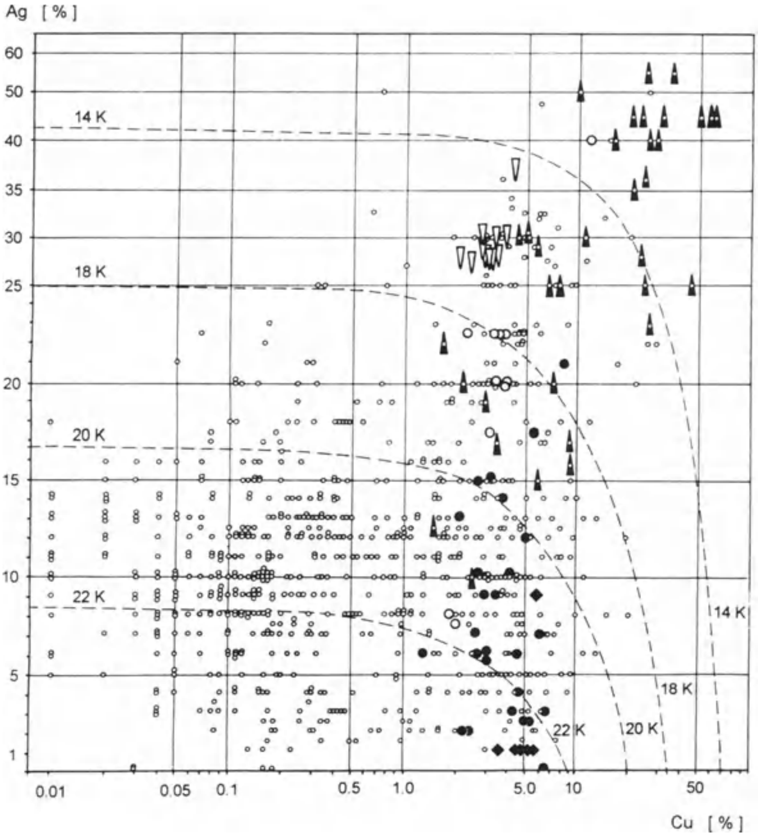

Fig. 6: Cu vs. Ag - diagram of the gold-analyses from Spain and Portugal of the Iron Age; open circles: Trayamar, solid circles: Aliseda, open triangles: Baiao, solid rhombs: Javea, solid triangles: "Torques".

Another group of objects can be found close the right and the top borders of the diagram. This means that these objects are made from a bad gold with a high level of both silver (20-50%) and copper (5% up to 40% or 50%). (It must be remembered that these high copper values are stated in the SAM format of Cu per 100 parts Au). These objects are all neckrings or "torques" of the later Iron Age in the north-west of the Iberian Peninsula (Pingel 1992, 141ff). They have good golden colour but they are certainly made from an alloy with a lot of silver and copper and many other impurities. It is very interesting that they are made and used in a region, which is extremly rich in natural gold sources which have been intensively exploited at this time, as described by the Romans (Pingel 1992, 159ff).

Another observation is important: other objects of this time and culture which are often closely related to the "torques" in the same hoard, are made of gold of a much higher fineness. This means that people were not forced to work with such bad gold. Plainly they had enough gold and could use it with a high technical standard and quality, but with the torques they chose to use an alloy with a much lower caratage. They did this with great skill, giving it a surface finish like that of a good gold alloy.

This catalogue of observations with all the analyses of the SAM project throughout Europe could be enlarged. In particular, the combination of gold with copper and silver seems in most of these analyses of greatest importance for the aspects of technology.

4. Properties of gold alloys

There is not the space here to discuss in detail those properties of gold which have always held a special interest for people. Some of these are important not just for its aesthetic or economic value, but also for some of the technology of goldworking. These qualities are well known, such as colour, specific gravity, chemical resistance, ductility, but also include more technical aspects like the melting temperature, hardness etc. must be included. These properties depend on the composition of the gold, particularly on the relative proportions of silver and copper. This last section of the paper will attempt a brief discussion of how the analyses of the prehistoric gold objects from the Iberian Peninsula might be used for studying these questions.

The ternary system Ag-Au-Cu is quite well-known in metallurgical science and in practical goldworking (Brepohl 1968). Some relevant ternary diagrams can be used to help describe some aspects of these alloys.

The most evident quality of gold is its colour. Fig. 7 shows the relationship between the colour and increasing silver content, tending to whiten the gold, and copper, tending to redden it. The addition of copper to a white, silver-containing gold can shift the colour back towards a yellow or reddish-yellow. It is important to be able to quantify these colour changes. For example, a relatively small addition of silver, say 10% or 20% changes the colour to green-yellow, but 5% or 10 % copper changes this paler gold back to a yellow, or red-yellow, really golden colour. A balance like this may have been used with the "torques" to get the best colour for the objects of low gold.

The next property is the "melting point"; pure gold melts at 1063 °C but this will be lowered by the addition of other elements. This fact is of great importance for technical processes which involve fusion, soldering, etc. Fig. 8 shows in a simplified manner the important role of copper as silver on its own does not have a large effect. The diagram shows that an addition of 20% copper to pure gold lowers the liquidus temperature by nearly 200 °C, while only 5% copper already brings it down to 1000 °C.

Copper also has an important role in influencing the hardness of gold alloys (Fig. 9). The addition of 5 % of copper raises the hardness efficiently for many technical or functional purposes, while 30 % copper can produce the highest hardness in the binary Au-Cu system. Silver alone has a limited effect on the hardness of gold.

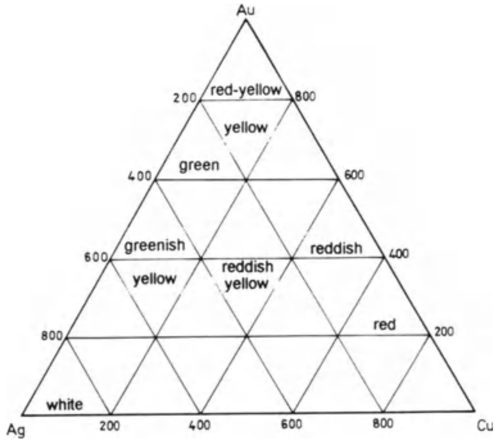

Fig. 7: Au/Ag/Cu - system and the colour-areas of gold (after Ullmann 1957).

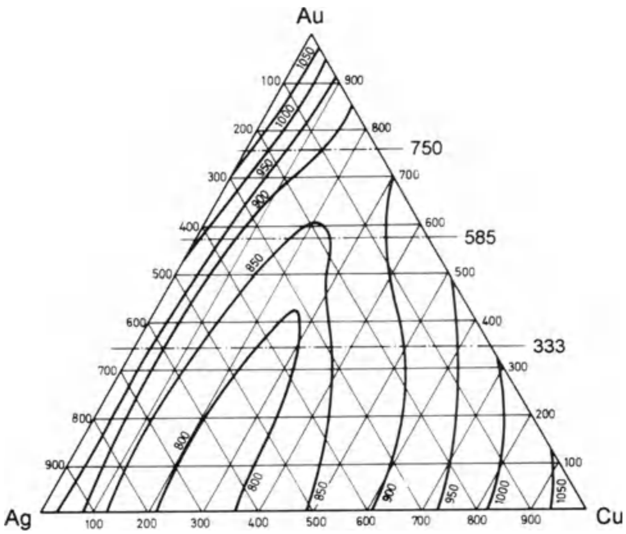

Fig. 8: Au/Ag/Cu - system and the melting point temperatures of gold (after Brepohl 1968).

Figs. 10 and 11 show how other mechanical properties change with composition across the Ag-Au-Cu ternary system. Fig. 10 shows the ductility. The best or highest ductility shows with gold with only some percent of silver (max. 5 %) and at considerable high contents of copper with 20 or 30 %. This quality is very important for the goldsmith to hammer or to beat thin sheets etc. But the diagram shows also, that pure gold with only few silver (till 5 %) and some percents of copper has also a rather high ductility (more than 40 %). This might for instance have been important for the objects from Javea with very low silver and higher copper - contents.

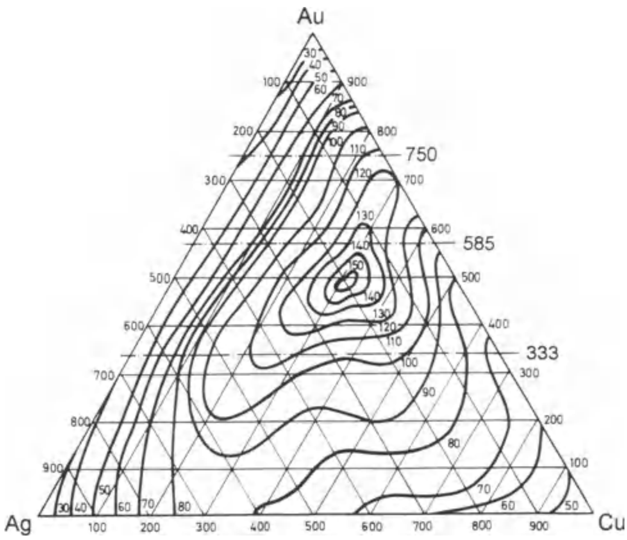

Fig. 9: Au/Ag/Cu - system and the Brinell-hardness of gold in kp/mm² *(after Brepohl 1968).*

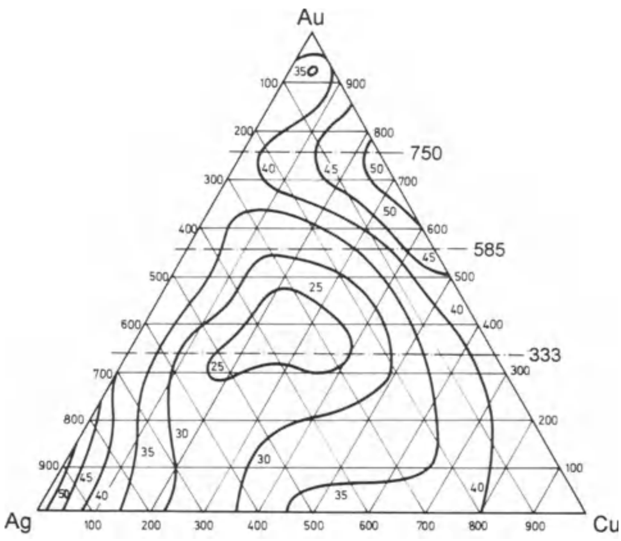

Fig. 10: Au/Ag/Cu - system and the ductility of gold in % *(after Brepohl 1968).*

Fig. 11 shows the tensile strength of gold-silver-copper alloys. This quality, which is very important for some technological aspects like wire-tearing etc. is mainly altered or raised by the factor copper. The highest strength is observed again with 20 % copper (and 25 or 30 % silver, but nearly the same strength is obtained with only some 5 % of silver).

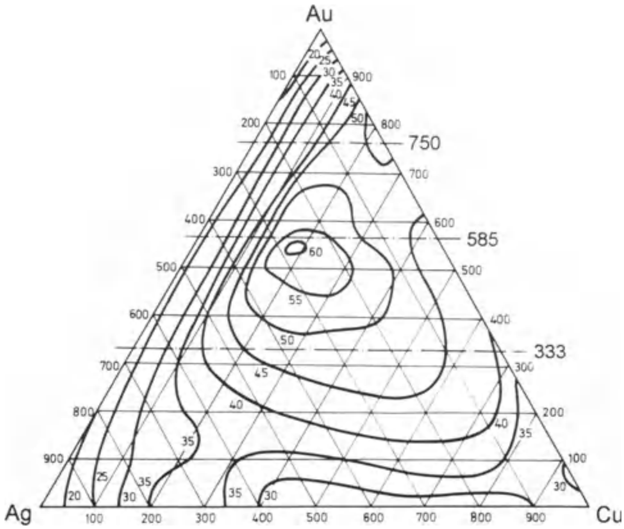

Fig. 11: Au/Ag/Cu - system and the tearing-strength of gold in kp/mm² (after Brepohl 1968).

5. Conclusions

This discussion has been presented from the point of view of an archaeologist, and is necessarily selective; the questions raised have to be discussed more intensively by specialists from different sciences. Firstly the discussion has demonstrated the role of copper and, in some cases, of silver, in man-made gold alloys. Secondly it has shown that the analyses of prehistoric gold objects show remarkable and informative groupings based on just these two components. Partly they express the range of natural gold, partly they define the range of artificial and, possibly, intentional mixtures or alloys. The reasons for such concentrations of similar analyses are surely various. Beside the possibility of different natural sources, the technological reasons must be considered. It is to be hoped that this paper has succeeded in presenting some ideas of the directions in which can be searched for answers, and to what extent the SAM analyses may be helpful.

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Chapter 5

ROTARY MOTION - LATHE AND DRILL
Some new technological aspects concerning Late Bronze Age goldwork from southwestern Europe

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ABSTRACT. This paper deals with the study of ancient gold jewellery manufacture, in particular the presentation of details of the lost-wax casting method. The aim is to illustrate the use of rotary tools, such as lathe and drill, in connection with the manufacture of rings. The types of materials and tools used in these processes are discussed. This new technological information was obtained by optical examination of bracelets and finger-rings of the Late Bronze Age Villena/Estremoz types. A combination of the identification of tool marks, experimental archaeology, analogies from ethnoarchaeology, ancient illustrations and literary descriptions leads to the conclusion that rotary tools were used. An interdisciplinary approach to assess the value of experiments and technological studies for the classification of metal artifacts is proposed.

1. Introduction

The Late Bronze Age goldwork from southwestern Europe is characterised by heavy, massive ornaments and embossed vessels (Ruiz-Gâlvez 1989, Perea 1991). In antiquity, the Iberian Peninsula was famous for the supply of gold from its rich alluvial deposits, and for other mineral resources, which have been exploited since Chalcolithic times. This led to the early development of cultural contacts and trading routes during the Bronze Age (Ruiz-Gâlvez 1986). At the end of the second and the beginning of the first millenium B.C. the supply of gold seems to have been especially abundant, as the great quantity of heavy gold objects of this period in Atlantic Europe reflects. Many different types of ornament coexisted in the Iberian Late Bronze Age: massive neck rings, bracelets with circular or polygonal section, vessels, sheet applications and Villena/Estremoz-type rings.

2. Villena/Estremoz gold ornaments

This name for a class of gold jewellery is derived from the most elaborate bracelet from Estremoz (Evora) (Fig. 1) and the treasure from Villena (Alicante). The cylindrical bracelets and finger-rings of this type are classified by their specific cross sections (Perea 1991, Fig. 6), shape - finger-rings or bracelets, open or closed - and ornamentation. The inner surface is smooth, while the outside profiles are formed from three basic elements in different combinations: ribs and grooves, points, and perforations. The Estremoz bracelet, found before

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1872 and made of nearly 1 kg of metal, is closed and perfectly worked (Reinach 1912). The treasure from Villena (Alicante), found in 1963, contains about 9kg gold and 0.5kg silver, made up from 28 open bracelets in this technique, several gold vessels, decorated gold sheets, amber and two iron objects of ornamental character (Soler 1965). The bracelets have a great variety of cross-sections (Fig. 2). In the Villena treasure, defective and repaired cast objects, crude, as well as elaborate pieces were found.

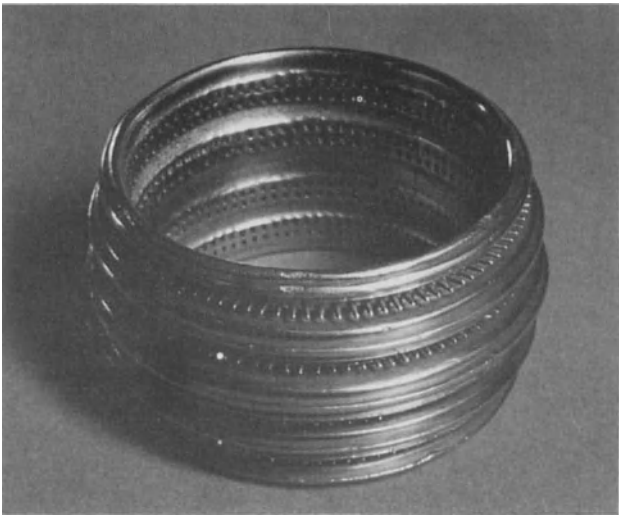

Fig. 1: Bracelet Estremoz (Evora), max. diameter 91 mm, L 50mm, wt. 978.5g.

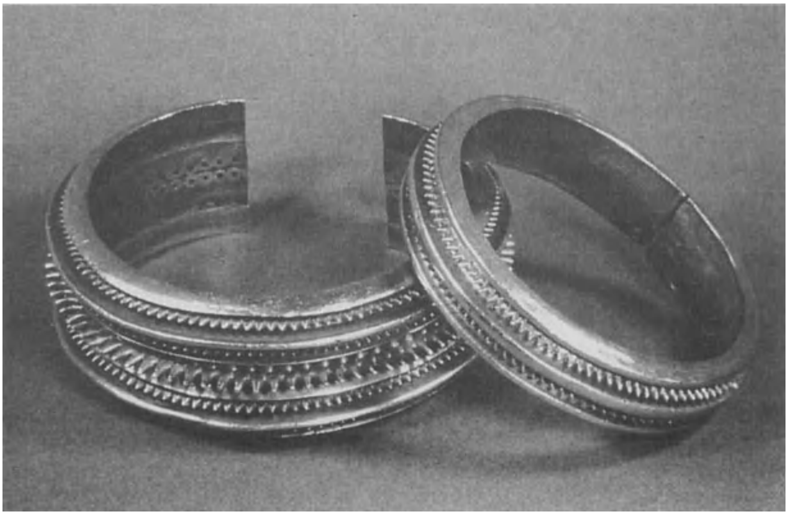

Fig. 2: Two bracelets from the Villena treasure.

To date, some fifty-eight Villena/Estremoz type ornaments are known (see catalogue below); for the technological study forty-eight bracelets and finger-rings were examined. Because of the large number of ornaments a selection had to be made. This was based on an attempt to present a fair picture of the variety of Villena/Estremoz jewellery other than that in the Villena hoard, which will be presented elsewhere. So, besides the above-mentioned items from Estremoz and Villena, the following ornaments will be presented toward the end of the paper: two pieces from Spain, an almost unknown bracelet from La Torrecilla (Madrid) and a bracelet from an unidentified location, dated to the "Early Bronze Age", and four exeptional, but so far under-appreciated pieces from Portugal, a ring from Trindade (Beja), bracelets from Aljustrel (Beja), Colos (Beja) and a composite ornament from Cantonha (Guimarães, Braga).

3. Chronology

The Iberian Late Bronze Age gold objects are difficult to date precisely since they are almost all isolated finds. There are no gold finds from tombs or settlements. In hoards they are associated with other gold items and only rarely found with other artifacts such as ceramics. A similar lack of associations is true for most gold ornaments found in western Europe from this period. In the past, the Estremoz bracelet, as well as the one from Portalegre have been dated to the Iron Age because of their complex shapes, elaborate execution and the lack of associated finds (Reinach 1912, Blanco 1957, Cardozo 1959, Alvarez-Ossorio 1941, Cardozo 1944).

Since the Villena and Cabezo Redondo hoards were found in the southeastern province of Alicante in 1963, the Villena/Estremoz type goldwork has been dated to the Late Bronze Age (Soler 1965, 47-51, Schüle 1965, 177-180, 1976, 166-167). Also, the hoard of Abía de Obispalía, Cuenca, recorded at the British Museum in 1921 but not published before 1974, has made the Bronze Age classification more plausible (Almagro Gorbea 1974). This chronological interpretation is supported by several authors (Eogan 1981, 353, Ruiz-Gálvez 1989, 54-56, Perea 1991, 131, Pingel 1992, 61-73). The Villena treasure contains not only precious metal products, but also amber and the first known iron objects in that area, a probable bracelet and a gold-plated hemispherical object of ornamental character. They are indicative of contact with iron working cultures, but their ornamental style does not allow an Iron Age dating. As suggested earlier, there are few associated finds to record; the existing ones are all older than the Iron Age. The diadem and wire spiral from Cabezo Redondo, the sheet work from Villena and the sheet applications for dagger or sword hilts from Abía de Obispalía are clearly of Bronze Age character. The provenance of that style is not known, as no prototypes have yet been identified. The eleven gold-vessels from Villena are very similar to the vessel from Zürich-Altstetten (Kimmig 1983). A recent technological study of the Zürich vessel allows this Late Bronze Age dating (Nagy 1992). Other writers have retained the idea of an Iron Age context for this type of vessel and have compared the Villena goldwork with Hallstatt gold (Eluère 1982, 166, Kimmig 1983, Lenerz de Wilde 1992, 176-178).

The geographical distribution of Villena/Estremoz goldwork shows a concentration in the western area (Fig. 3). This may not accurately reflect the prehistoric spread. The apparent western emphasis of the distribution might be completely altered by considering the number of artifacts - more than half - collected in three hoards in the eastern part of the peninsula: the twenty-eight bracelets from Villena (Soler 1965, Pl. 12-22), ten finger-rings and one fragment of a bracelet from Cabezo Redondo (Soler 1965, Pl. 53+54,1) and four bracelets from Abía de Obispalía (Almagro 1974, 42 Fig. 1). It has been suggested recently that the thirty-four bracelets known so far point to the existence of the first definable goldsmith's workshop from the Iberian Peninsula (Perea 1993, 24).

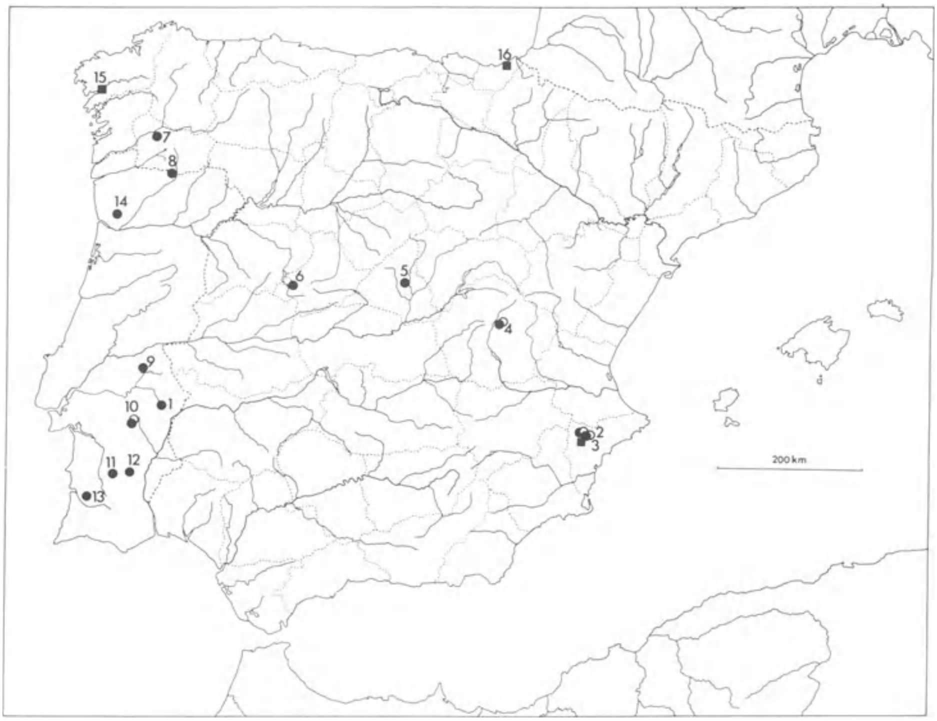

Fig. 3: Map of Villena/Estremoz type rings: 1. Estremoz, Evora; 2. Villena, Alicante (28 examples); 3. Cabezo Redondo (10 examples), Villena, Alicante; 4. Abía de Obispalía, Cuenca (4 examples); 5. La Torrecilla, Madrid; 6. El Torrión, Navamorales, Salamanca; 7. Toén, Orense; 8. Chaves, Vila Real; 9. Portalegre, Evora; 10. Evora (2 examples); 11. Aljustrel, Beja; 12. Trindade, Beja; 13. Colos, Beja; 14. Cantonha, Guimarães. Two pieces of "no location" are not marked, MAN Madrid: Inv. No. 16853 and fragment Inv. No. 1962/7; and gold vessels: 15. Leiro, Rianxo, La Coruña; 16. Axtroki, Guipuzcoa; 1. Villena (11 examples).

The technological and morphological sequence of the twenty-eight bracelets associated in the Villena treasure could have been used to build up a chronological system if the rings had been found individually (Schüle 1976, 168). This shows how weak the typological method can be in the absence of contextual evidence. Equally the interpretation of ownership, use, cultural role and symbolic meaning of the precious metal is much harder if the archaeological context is missing. The chronological correlation and cultural interpretation of gold is based on stylistic criteria arranged in a developmental sequence. For dating and seriating prehistoric goldwork information from the material and the manufacturing techniques should be included with the stylistic method. The typology based on exterior form and detail should be extended by chemical and optical analyses to create an interior typology based on technological data. To advance the discussion of many prehistoric metal products it is obvious that, besides the abstract scientific study of artifacts including compositional and metallographic analysis, attention must be paid to research in the history of the craft, something which has all too rarely been considered (Hundt 1964, 261).

4. The techniques of the goldsmith: workshop, tools, and materials

No identifiable goldsmith's tools survive from the Peninsular Bronze Age, though new investigations and surveys are needed. However, it is impossible to believe that the great quantity of gold objects was manufactured elsewhere. Until new finds are available the direct evidence of the gold ornaments themselves must be relied upon to provide the technical background. Detailed discussion of Bronze Age tools known from other areas is not within the scope of the present paper. Thus it is on the basis of tool marks that the goldsmiths' methods are presumed to be:

- casting: ingots cast in open moulds, multiple moulds of stone, bronze or clay; the lost-wax process
- shaping: forging (sheet), raising, repoussé, bossing
- forging and twisting wire
- decoration: tracing, scribing
- cutting, only known as dividing or splitting with a chisel
- joining: casting on, riveting and folded edges
- finishing: grinding, milling, polishing with abrasives
- heat treatments: annealing, hardening

Normally no precious material is lost, except small amounts from scribing and cutting, and from the finishing process with abrasives such as clay or ash. The joining techniques produced only mechanical connections. Alloying, soldering and welding seem to have been unknown at that time and flourished only during the period of Phoenician contact. Even metal-cutting removing larger quantities of metal, like engraving with burin, scraper and chisel were only used later, with iron or steel implements (Lowery et al. 1971, 170). Goldwork is generally wholly dependent on the ability and knowledge of the adept craftsmen, the raw materials and tools available and techniques adapted. Certainly, symbolic values and the framework of traditional design have a large influence on style, but it is the means of craftsmanship that place limitations on the potential of creativity.

The essential equipment of a goldsmith's workshop was based on technical ceramics: hearths with fuel, tuyères with bellows, crucibles and moulds. Bees-wax, possibly hardened with resin, was employed for the production of wax models, formed with spatula, awl and knife. Wood, bone and other organic materials were used for tools like tongs, punches, hammers and anvils; rotary tools were also made out of wood. Fibres and abrasive powders were used for grinding and polishing as well as for cutting in the manner of a modern wire/abrasive saw. Stone was used for percussion tools like hammer and anvil, and for milling and grinding. Bronze implements such as punches, chisel, hammer and anvil could be used for forging, raising, chasing/repoussé, cutting/dividing. There are no percussion tools of bronze identified from Late Bronze Age Iberia. The only hammer published (Coffyn 1985, Pl. 53, 5) is in reality a fragment of a broken socketed axe.

5. Technological study of Villena/Estremoz goldwork

For eighty years archaeologists have focussed their attention on the creation of the extraordinary forms of Villena/Estremoz type bracelets. Studies were carried out with binocular microscopes or magnifiers (Blanco 1957, 7, 8, Perea 1991, 98) and took the advice of modern goldsmiths and technicians (Reinach 1912, Cardozo 1959, 24, Schüle 1976, 155-157). Unfortunately, the modern craftsmen could not comprehend the abilities and the fundamentally simple equipment of their prehistoric colleagues. The supposed techniques were not supported by macrophotographs making interpretation a problem for the modern reader. Opposing hypotheses for the methods of manufacture provoked controversy, but did not lead to satisfactory solutions. They ranged from welding and soldering, metal-cutting with enormous loss of metal, chasing without any loss, to casting in open moulds. (Cutting a replica out of a massive copper bloc, using a modern metal-cutting lathe and a milling machine, but no conclusion relevant to the prehistoric process (Reinach 1912, 379, Fig. 3); fusion by pressure welding (Russel 1954, 71-73); soldering (Blanco 1957, 8, Fig. 3 Pl. 1); metal-cutting with a chisel from pre-formed bars (Cardozo 1959, 24, Pl. 1; Soler 1965, 19); chasing with bronze tools, no loss of material (Schüle 1976, 155-157); casting bars, cutting, perforating, filing (Nicolini 1990, 19-21); metal removal by cutting, great loss of metal (Perea 1991, 98 and 112, idem 1993, 24-25)). Confusion spread across the whole field. The spectrographic analysis of A. Hartmann (1982) include most of the Villena/Estremoz rings, but the technological studies have not profited from the results.

Within the scope of the technological study of Late Bronze Age goldwork from the Iberian Peninsula (programme "Archaeometallurgy", foundation Volkswagenstiftung), carried out by the author, forty-eight rings were re-examined. Optical examination identified tool-marks indicating the use of rotary tools in the production of Villena/Estremoz type jewellery. The craftsmen had developed a remarkable gold-working technique characterized by the incorporation of the principles of the lathe and drill into the production of lost-wax castings. This had the great advantage of allowing the formation of complex shapes with accurately parallel grooves, perforations and points on a cylinder of a free-machining modelling medium followed by the transfer of the fine details of the pattern from the wax-model onto massive gold-rings. The lathe was also used on cast metal rings during the finishing process. The drill, meanwhile, was used in the smoothing of conical, circular sectioned points. Its use is shown by concentric tool marks on the surfaces and bases of the points. This sophisticated modification of the cire-perdue process demonstrates the high level of metalcraft at the end of the second and the beginning of the first millenium B.C. The identification of tool and wear marks, as well as of repaired castings, defects and unfinished pieces, are all documented by macro-photographs to build up a detailed inventory of the complete manufacturing process and its component techniques. Tool-marks and surface texture on ancient metal relics can be observed with stereo binocular microscopes or the scanning electron microscope (SEM) and microprobe (Larsen 1987, 397). Regarding the closed, perfectly circular cylinders, in Estremoz and La Torrecilla examples, the use of a rotary appliance is also obvious (Fig. 1 + 17).

6. The manufacturing process: reconstruction and experiment

The manufacture of cylindrical rings is reconstructed from data collected from a comprehensive interdisciplinary study. The various stages are (Figs. 4-6):

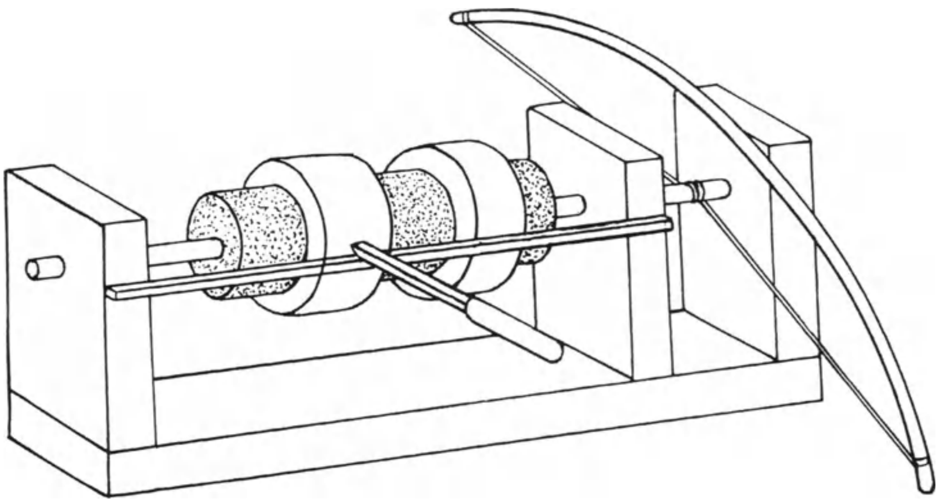

Fig. 4: Layout of a primitive lathe.

Clay-core: a wooden spindle is coated with a layer of clay. The clay is tempered with horse dung or other organic material and pulverised charcoal to avoid shrinkage. After drying, the spindle is attached to a manually powered lathe and the clay is turned with a cutting tool (probably of metal) to obtain a cylinder with an even surface. The clay cylinder serves first as a support for the wax model and finally as the casting core (Fig. 4).

Wax-cylinder: A layer of beeswax is then built up on the clay core and machined to a cylinder on the rotating spindle (Fig. 4). That is the basic form of all wax-models. Wax can be hardened by natural resins (collophony).

Profiled wax-model (Fig. 5): The desired shape, convex or with ribs and grooves, is cut into the surface of the wax with lathe tools such as scrapers or chisels. Then the grooved wax-model and its clay-core are detached from the lathe. For some rings, like "La Torrecilla" or "Colos" (Cat. B.1. and B.2.), this is the final state of the wax-model and the wooden spindle can be extracted from the core. For other types, with points and/or perforations work continues with knives and awls. The spindle might be retained to make the model easier to handle.

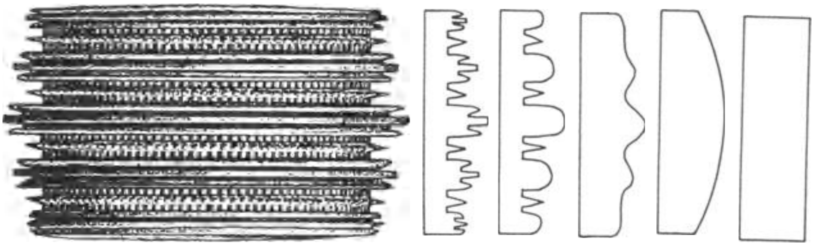

Fig. 5: Transformation of a wax-cylinder into a profiled model: cross-section and plan.

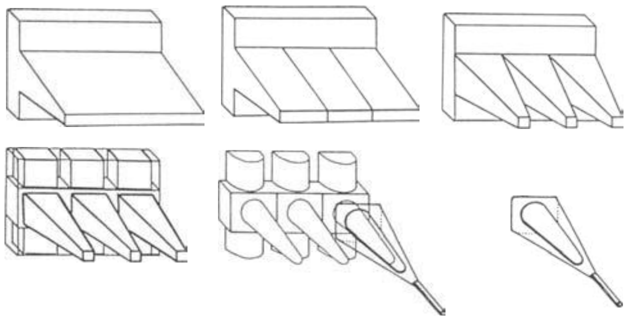

Fig. 6: 1-6. Conversion of a wax-rib into pyramidal and conical points.

Perforations: On pierced models, the rectangular perforations (Fig. 7) are cut in the wax with, possibly, a hollow tool with a rectangular cross-section, a knife or an awl. The material left between the rectangular holes is shaped with fine blades.

Points (Fig. 6, 1-4): The profiled wax-cylinder is then modified by cutting the wax ribs into pyramidal points with a knife. On the fragment of "no location" illustrated in Fig. 8 the pyramidal form of the cut points is obvious. The complex shape of the Estremoz bracelet is perfectly executed; nevertheless there are irregularities in the distribution of the points. The nearly equal distances between the points suggest some instrument for measuring. But the circumference of the ring could not be divided accurately into a whole number of complete elements. The distance between the last two or three points had therefore to be altered disproportionately (Fig. 9).

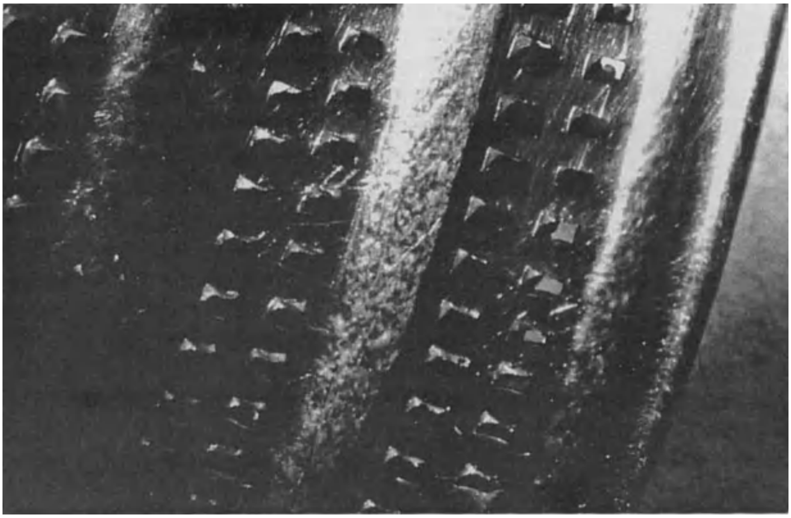

Fig. 7: Detail of the Estremoz bracelet, rectangular perforations and interior with remains of the cast surface.

Fig. 8: Detail of the fragment "no location", MAN Madrid, with pyramidal points.

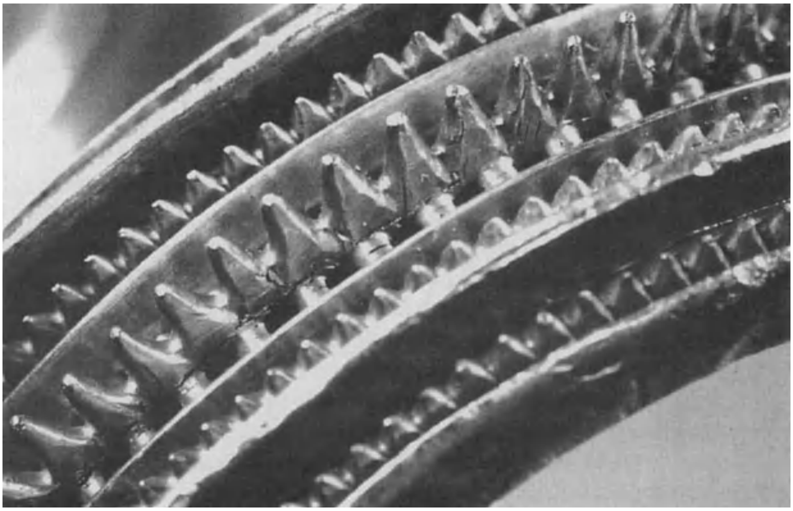

Fig. 9: Detail of the Estremoz bracelet showing the irregular distribution of the points.

Hollow cup-shaped punch (Fig. 6): After the basic cutting of the wax was complete the pyramidal points could be changed into conical points with a hollow, cup-shaped tool or punch first warmed in hot water. At the bottoms of the points marks from such hollow tools are visible (Fig. 10). Similar formations of conical points, worked in the wax model before casting, exist on bracelets of other Bronze Age types, such as Saint-Babel, Puy-de-Dôme (Eluère 1982, 96, Fig. 114-116).

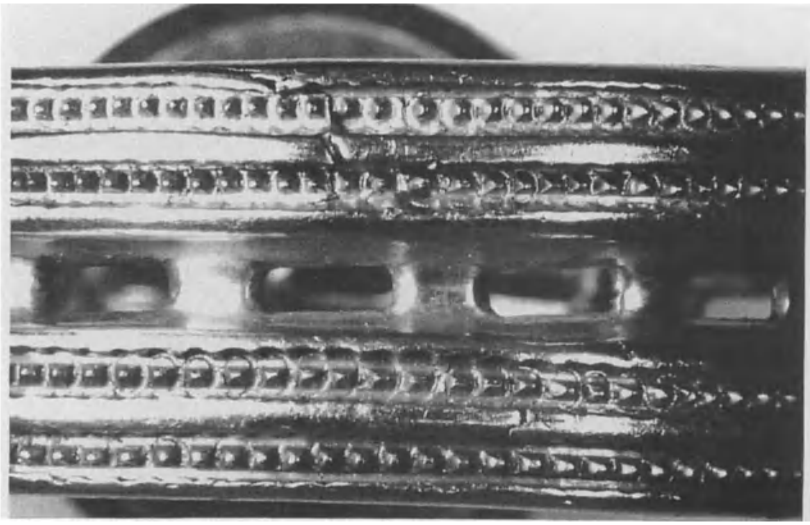

Fig. 10: Detail of one Villena bracelet: tool-marks from a hollow punch.

"Points" cut by chisel: There are seven rings with ribs and points worked with a chisel (Cat. F.). In these examples the cuts were applied directly to the metal after the profiled ring had been cast.

Runners and sprue: Finally wax runners and sprue are fixed to the model.

Mould: The wax-model with its complex shape and clay core are invested with several layers of finely levigated clay mixed with a high percentage of charcoal powder. This permits accurate reproduction of all fine details in the model surface, and a reducing atmosphere when the mould is fired. Coarser outer layers with organic temper are then applied. After drying, the wax is melted out, with some burning, and molten gold poured in to replace the wax, while the mould is still glowing. The clay mold is broken after cooling to extract the casting. Runners, sprue and other excess are removed with a chisel. A detailed description of the lost-wax process is not within the scope of this paper. For references see: gold casting in Ghana (Fröhlich 1981), historically (Hunt 1985).

Finishing with abrasives: The finishing process is carried out on the cast surface of the object while it rotates on the lathe. Fibres and abrasive powders were used.

Bow-drill with milling "cutter": On the conical points a bow-drill fitted with a hollow, concave, milling tool or cutter is employed to smooth the points' surfaces (Fig. 14, 3). The resulting tool-marks are often visible on the conical surface of the finished points (Fig. 11).

The inner surfaces of the rings are usually ground and polished; despite this there are always remnants left of the as-cast surface.

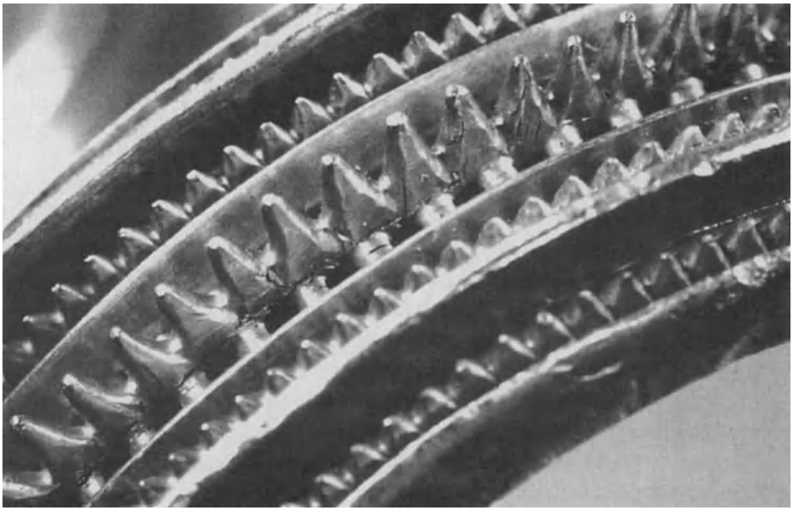

Fig. 11: Detail of one Villena bracelet: concentric marks from hollow milling tool.

Unfortunately all known rings, even the few incomplete examples, have such a high standard of surface finish that it is impossible to identify the position of the runners, neither do fragments of the clay investment moulds survive. All ornaments were cast as closed rings. At the end of the finishing process forty of the forty-six known bracelets were opened up. On the exposed cross-section of some unworn pieces tool-marks left by a cutting tool can be seen (Fig. 12), the tool could have been a fibre with abrasive, or a flint blade.

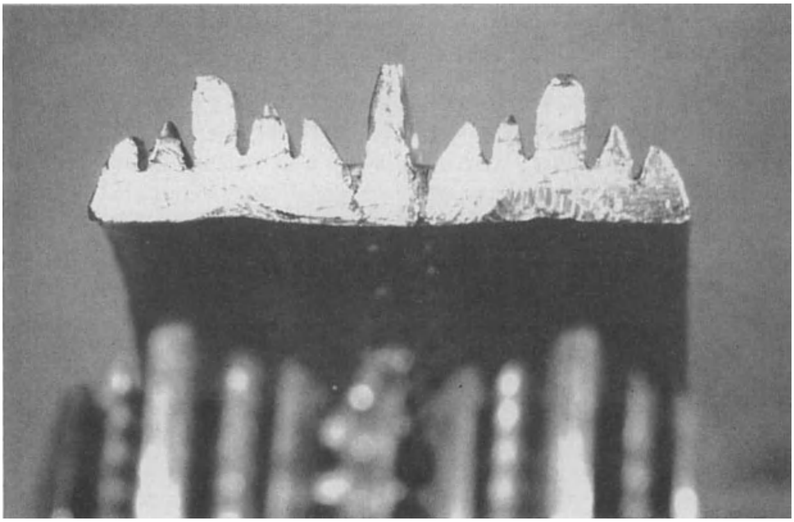

Fig. 12: Tool-marks in the cross-section of a Villena-bracelet.

7. Experiment

H. Drescher has reconstructed an antique lathe based on data obtained from ancient depictions and written sources (Drescher 1984, 124 Fig. 14). The conversion of a wax-cylinder to the finished model of Villena/Estremoz type with carving tools on a simple lathe as described above has been studied practically (Fig. 13) (Armbruster in press). The correct proportion of organic temper in the clay and the use of waxes of different hardness have been tested. There are basic constraints enforced by the natural, mechanical properties inherent in the working materials, wax, clay and gold, that must be considered in any reconstruction and experiment. The actual realisation of the experiment was carried out following the documented cylindrical forms and tool marks as well as by analogies with other craft traditions.

The use of experiment deals with testing models, in practical as well as theoretical terms. The reconstruction of rotary tools tests their functionality and their suitability to various possible solutions to the specific problem. In general, experimental archaeology provides a means by which some of the basic activities of ancient craftsmen can be empirically assessed in terms of their development and their competence empirically (Coles 1973, 18).

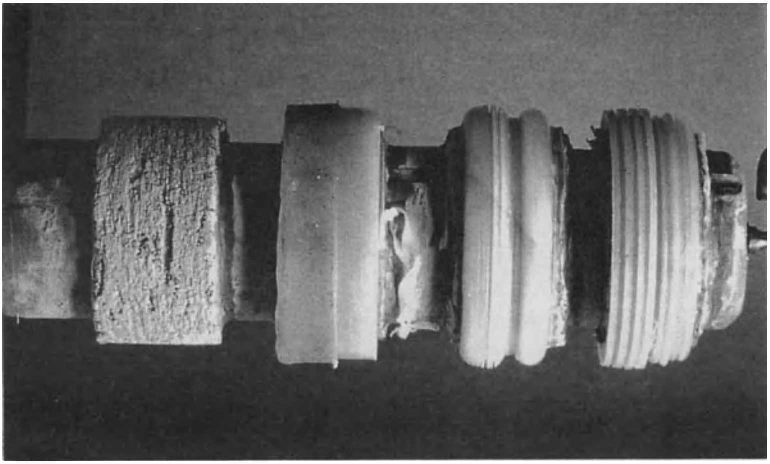

Fig. 13: Experiment: clay-core, wax cylinder and carved profiles.

8. Rotary-motion tools: ethno-archaeological and historical parallels

Lathe: The most primitive form of the lathe comprises a horizontal spindle, mounted on at least two wooden posts (Fig. 4). The spindle, on which the workpiece is fixed, has an alternating rotation, powered by a looped strip or a bow. Only one of the two phases of that reciprocal forward and backward motion is effectively used. The materials worked, as presently understood, were wood (Rieth 1956), amber, bronze (Drescher 1984, 122-123) and stone (Feldhaus 1965, 212, Fig. 147). Objects of cylindrical shape, hollow or solid, were worked with hand held carving implements.

Drill: The bow-drill consists of the bow, shaft and a handle for the upper end of the shaft in which one end of the vertical spindle can rotate freely (Fig. 14, 2). The head of the instrument, essentially a socket, is held by the driller and to press the drill onto the workpiece and to protect him from direct contact with the spinning shaft (Fig. 14, 1). This handle might be held by one hand, grasped with the mouth (Childe 1954, Fig. 145) or fixed on a waist-belt (Hugger 1963, Fig. 5). The spindle is moved by a looped cord attached at both ends to the bow. Another variation of instruments with a rotating, vertical spindle is the pump-drill, constructed of a shaft, a fly-wheel and a cross-piece serving to steady the spindle (Childe 1954, Fig. 114, Lenfant 1979, 213, Fig. 158).

Illustrations (Fig. 15): Depictions of metalworking in Egyptian tombs or on Greek vases are used as evidence for explanations of workshops, tools and their handling. Some scenes depict piercing and turning implements. The wall-paintings in the Egyptian tombs of Rekmire and Mereruka show various wood- and metal- working crafts (Scheel 1989). There, the bow-drill is applied to bead-working and to carpentry in the middle of the 2nd millenium B.C. (Drescher 1977/1978, 190, Fig 48 a-h). The earliest depiction of a primitive lathe comes from the tomb of Petosiris, 3rd century B.C. (Lefebure 1924, Pl. 10). Some Greek vase paintings show piercing tools like the bow-drill in use in metal working in the fifth century B.C. (Zimmer 1982, Born 1989).

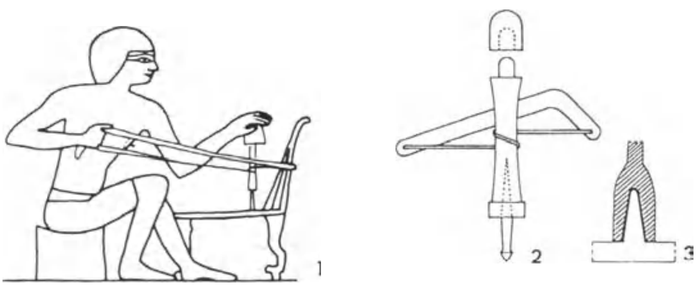

Fig. 14: 1. Use of the bow-drill depicted in the tomb of Rekmire, Thebes (after Scheel 1989, 52, Fig. 58a); 2. Egyptian bow-drill (after Untracht 1982, 95, Fig. 4-80,1); 3. Schematic section of hollow, milling tool fitted to drill.

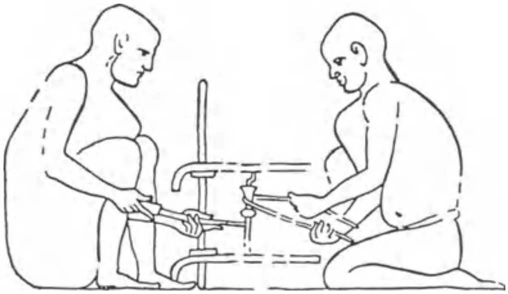

Fig. 15: Manually powered lathe: depiction from the tomb of Petosiris (after Lefebure 1924, Pl. 10).

Ethnographic analogies (Fig. 16): analogies from ethno-archaeological studies offer a comparative method for the reconstruction of ancient goldsmithing techniques (Gould et al. 1982, Armbruster 1993a). Ethnographical data obtained from recent handicrafts show the use of simple rotary tools of varied construction, with both vertical and horizontal spindles (Childe 1954, Feldhaus 1965). They have been recorded for fine woodwork (Untracht 1982, 482 Fig. 10-57), lapidary work (Lenfant 1979, 238) and bronze (Jacobsen et al. 1907). More usually used in the manufacture of wooden or ivory objects, the lathe is rarely used to turn wax models for the lost wax casting of bronze vessels, gongs or bells.

Literary sources: Technical references in antique and medieval literary sources give detailed descriptions of how to prepare materials like wax (Schönfeld et al. 1986) and of the construction and use of the primitive lathe. For instance, the Benedictine monk Theophilus Presbyter in the first half of the 12th century described a primitive lathe moved by a looped strip and another worked by a handle (Brepohl 1987, 181-182, Fig. 61.1 and 282-284, Fig. 88.1).

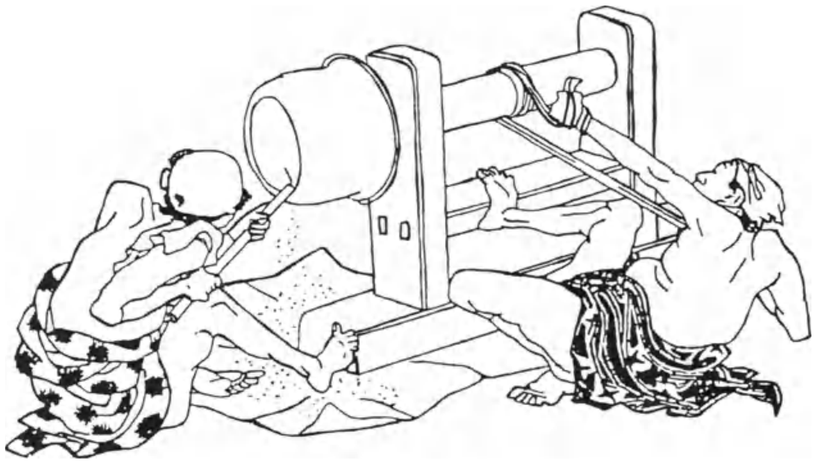

Fig. 16: Lathe, japanese drawing from Hokusai 1760-1849 (after Mutz 1972, 17).

Most of the tools characterised on the basis of these descriptions and functional analogies are manually powered and work by alternate rotary-motion. On the basis of these interdisciplinary data the reconstruction of the lathe and drill serves as an explanatory model. Early evidence for the use of rotary tools dates to the Neolithic, when the tubular drill was used to perforate stone blocks and implements. The earliest European lathework so far recorded was connected with Iron Age wood, amber and bronze work of the Hallstatt period (Drescher 1980, 58-62, Reim 1981, 213, Fig. 120). Recently a so-called "lathe", an instrument reconstructed for the realization of spiral decoration on circular-sectioned hard-wax bars, was established for the casting of bronze bracelets in Bronze Age Hungary (Born 1992).

9. Some selected Villena/Estremoz ornaments

Unfortunately, all the ornaments discussed below were found or acquired without contextual evidence. They are therefore classified as belonging to the Villena/Estremoz group by their style and corresponding manufacturing technique. There are five bracelets that are decorated only with parallel grooves and ribs of different depths (B. 1-7). Four of them are of closed, cylindrical form: the lost example from El Torrion, Navamorales, Salamanca (Delibes et al. 1991, 205, Fig. 1.3), La Torrecilla, Madrid (Priego et al. 1978, 17), Colos, Beja (Pingel 1992, Pl. 46, 2), and from "unidentified location" Museo Arqueológico Nacional (MAN) Madrid No. 16853 (Siret et al. 1890, Pl. 26,5). The macrophotographs of these items strongly support the idea that their very rectilinear execution could not have been performed without a turning spindle. The two last-mentioned ornaments have, so far, not been considered as Villena/Estremoz jewellery.

La Torrecilla (Fig. 17): The "masterpiece" from Torrecilla, Getafe, Madrid bears that name legitimately. Despite its solid design, it serves as a precise and polished example of the accuracy to be obtained with the technique. The form of the gold cylinder is completely circular, like that of the Estremoz bracelet. Tool-marks from the lathe in the grooves and remnants of the cast surface are inconspicuous but do survive even on this perfect work (Fig. 17, 2-3).

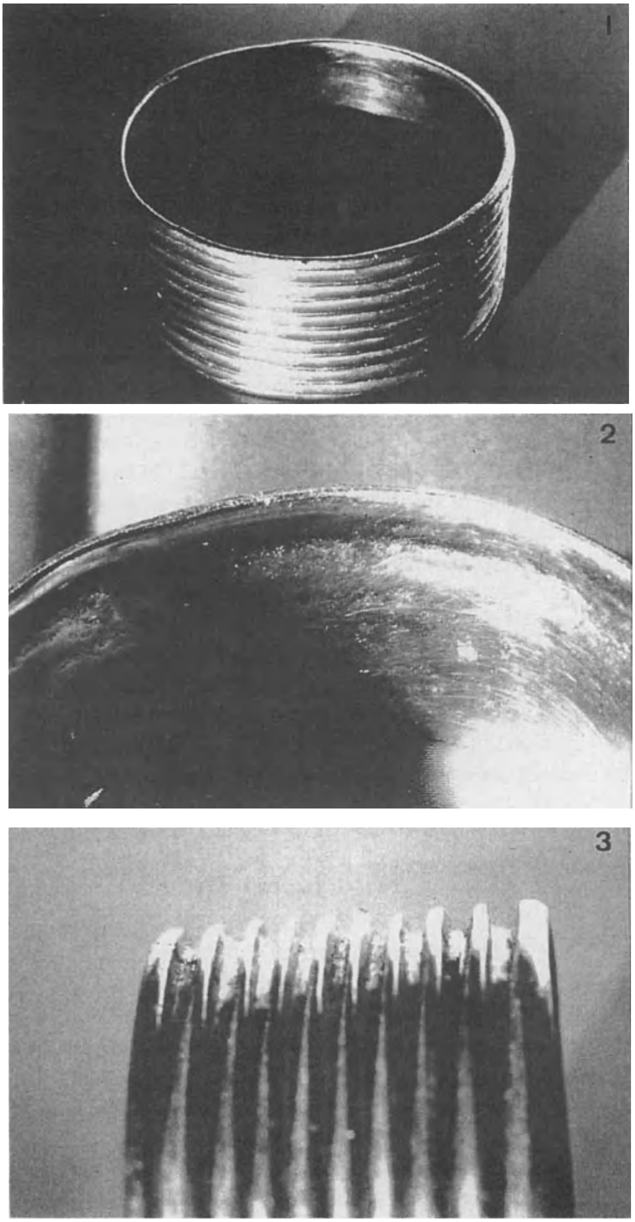

Fig. 17: 1. Bracelet from La Torrecilla (Madrid) (diameter 73 mm, L. 30,9 mm, 167,5 g); 2. residues of the casting surface; 3. regular grooves.

Colos (Fig. 18): The bracelet from Colos, Beja, an association with four simple bracelets being uncertain, has been dated to the Early and Middle Bronze Age (Parreira et al. 1980, No. 45-46, Perea 1991, 302, Pingel 1992, 52-53). Compared with the massive castings, it is an extraordinary piece because of its thinness. Even on the almost smooth, polished, interior surface, traces of the cast texture are visible. Tool-marks in the grooves, resulting from finishing on the lathe, indicate the use of the technique studied here (Fig. 18, 2).

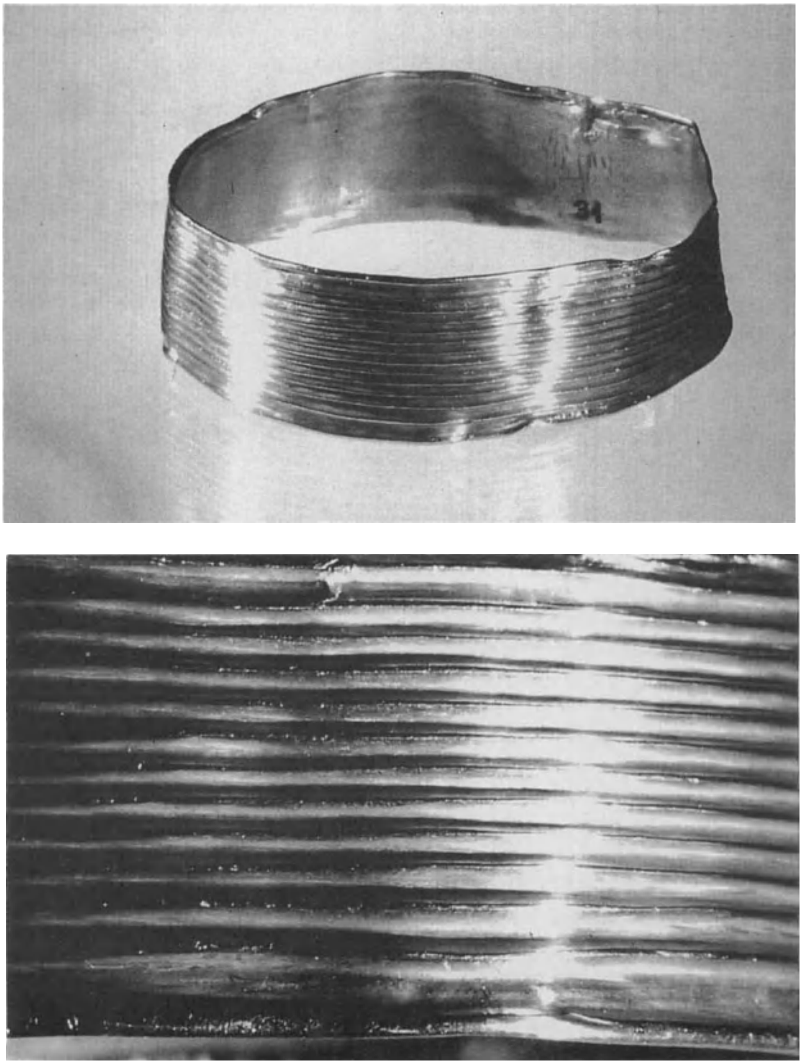

Fig. 18: 1. Bracelet from Colos (Odemira, Beja) (diameter 66,4 - 69,4 mm, L. 23 mm, 66,7 g); 2. regular grooves.

"No location": This bracelet from an "unidentified location" (Museo Arqueológico Nacional Madrid No. 16853) has been related to the goldwork from El Argar, Early Bronze Age (Perea 1991, 91), and has been thought of as gold sheet-work (Pingel 1992, 280). Its shape, with three ribs, is quite simple and it represents a rather crude and simple version of this group. Nevertheless, the tool-marks and surface texture observed indicate without any doubt its manufacture by the Villena/Estremoz technique (Armbruster 1993b, Pl. 3, Fig. 22-24).

Trindade (Fig. 19): The ring from Trindade, Beja (Nunes 1960/1961) is the only finger-ring known outside the ten rings in the hoard of Cabezo Redondo, Villena, Alicante. The decoration consists of two ribs along the edges and one line of points. There must have been difficulties during manufacture, because the points have a very irregular structure. In all probability this defect results from problems during the investment of the wax-model with the ceramic material displacing and deforming the points. One point was lost.

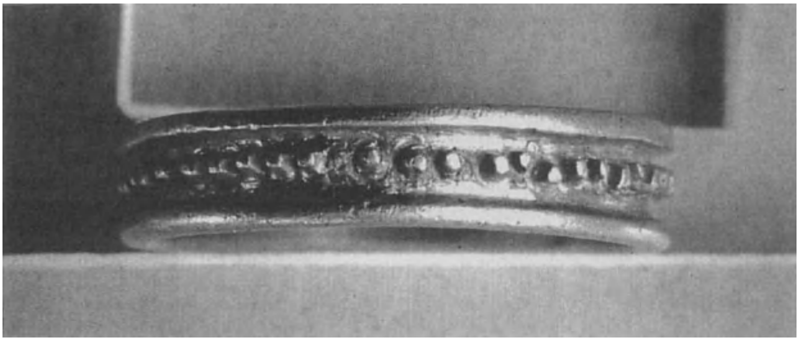

Fig. 19: Finger-ring from Trindade (Beja) (diameter 26 mm, L. 5,4 mm, 7,43 g).

Aljustrel (Fig. 20): The open bracelet from Aljustrel, Beja was thought to be sheet-work (Parreira et al. 1980, No. 45, Pingel 1992, 63). This piece is in fact not worked from sheet but with the lathe and cire-perdue. Some features of this unfinished bracelet are in distinct contrast to the other ornaments mentioned. The holes were not worked in the wax model; after casting, the perforations were pushed through the two broad grooves with a pointed instrument while the bracelet was still closed (Fig. 20, 3). Afterwards the ring was opened, probably by the use of a fibre and abrasive saw. Its cross-section resembles the one from a fragment (Fig. 8) of "unidentified location", Museo Arqueológico Nacional Madrid, No. 1962/7 (Almagro 1969, 284-287, Armbruster 1993b, Pl. 4, Fig. 32). This undulating, interior surface results from need to economize on the precious metal (Fig. 20, 2). It was prepared by shaping the surface of the clay-core before the wax model was constructed. Normally the interior surface of the rings is flat. The texture of the inside clearly shows the casting surface and the sharp edges resulting from the perforation (Fig. 20, 4). The outside bears evidence of polishing on a rotating spindle. As an unfinished workpiece the Aljustrel ornament offers interesting details of the manufacturing process. Indeed it is generally the case that the best technological information is obtained by the study of unfinished or defective pieces.

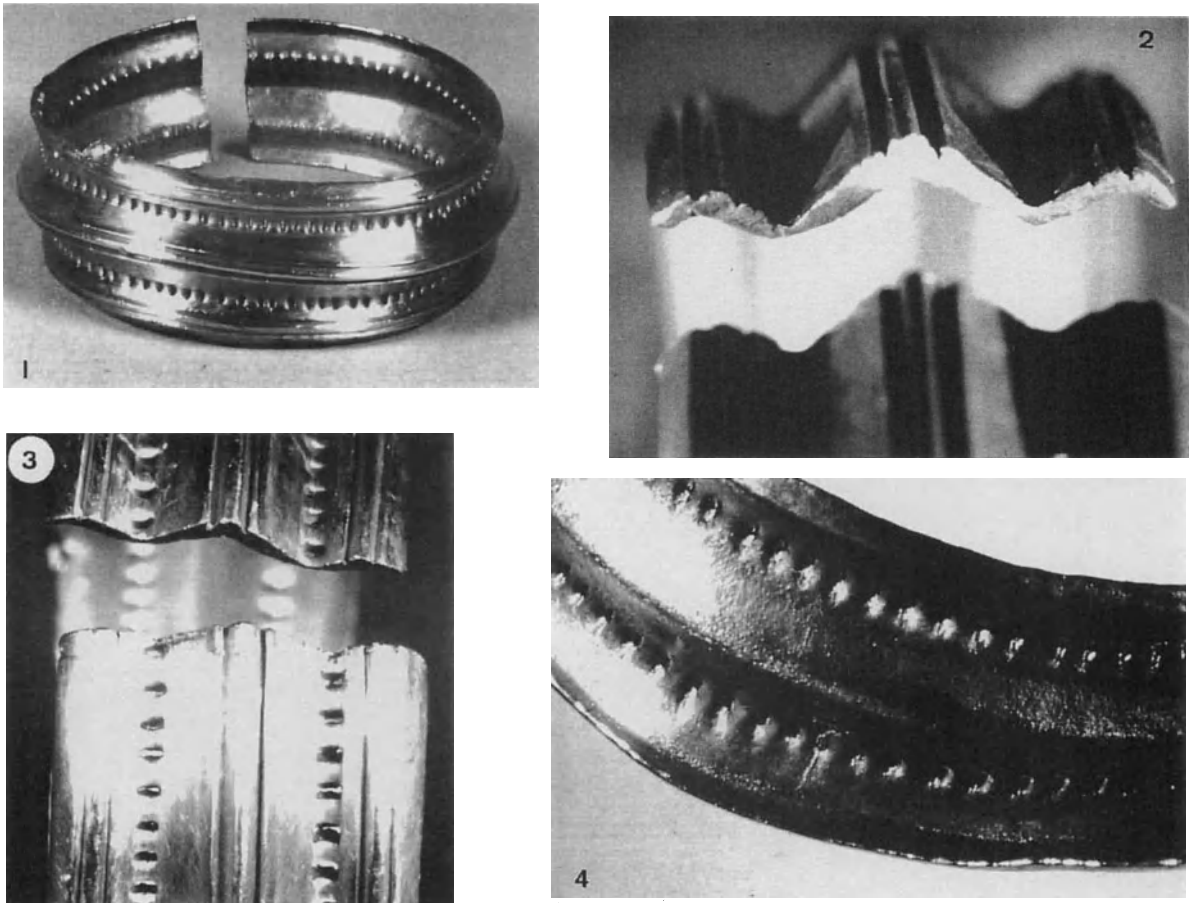

Fig. 20: 1. Bracelet from Aljustrel (Beja) (maximum diameter 72 mm, L. 24 mm, 110,5 g); 2. concave cross-section; 3. perforations pushed through; 4. casting-surface and sharp edges in the interior.

Cantonha (Figs. 21, 22): The composite bracelet from Cantonha, Guimarães, Braga, is composed of several elements: two massive, circular sectioned bracelets, decorated with a traced geometrical design and trumpet shaped terminals, a fragment of a Villena/Estremoz bracelet and six twisted wires (Heleno 1935, 252-254). These components were joined in antiquity: all were well-known during the Late Bronze Age, especially the circular sectioned rings (Kalb 1991). The connecting technique is believed to be "casting on", as the joints are filled with quantities of metal. This inundation with "solder" seems very unlike the true soldering process. Even the rectangular terminals of the inner part have been cast on, to cover the sharp edges and to fix the twisted wire (Fig. 22, 1 and 22, 4). The huge joint area was then decorated with a tracer to imitate the original geometric design (Fig. 22, 2). The artisan, who joined the elements, could not do this accurately, so the imitation is easily recognizable. Also it is obvious from the surface structure that the trumpet shaped ends of the two massive bracelets are cast on. The Villena/Estremoz component is no master-piece. Points and grooves are badly finished and parts of the casting surface-texture, as well as traces of the cup-shaped, hollow punch, still remain on the surface (Fig. 22, 3). Other Iberian Late Bronze Age ornaments assembled by casting-on are known, for example the double neckring from Sagrajas, Badajóz, and the bracelet from Alcudia, Ciudad Real (Perea 1991, 112, 138-139). The Cantonha bracelet is an extraordinary product of the recycling old, unused or defective pieces to create a composite ornament. Since there is no comparable item known, it may be interpreted as the inventiveness of an inividual craftsman. This unique bracelet, including various Late Bronze Age characteristics, leads on to the following period, and to the emergence of the new joining techniques of soldering and welding. Iron Age goldwork is characterized by the use of new methods like granulation and filigree-work. They permit economy of materials and the emergence of new designs. The Iron Age goldsmiths break with the massive ornament tradition and become influenced by oriental styles.

Fig. 21: Bracelet from Cantonha (Costa, Guimarães, Braga) (max. diameter. ca. 70 mm; L 34 mm; 230,9 g);


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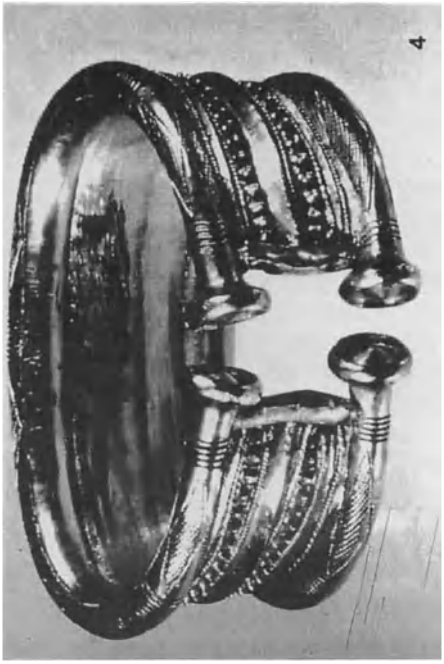
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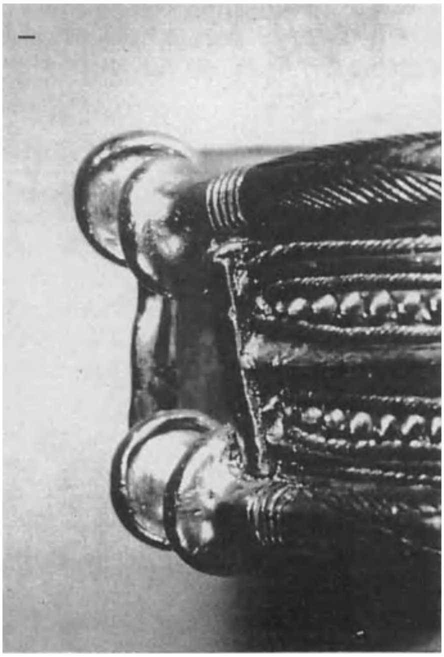
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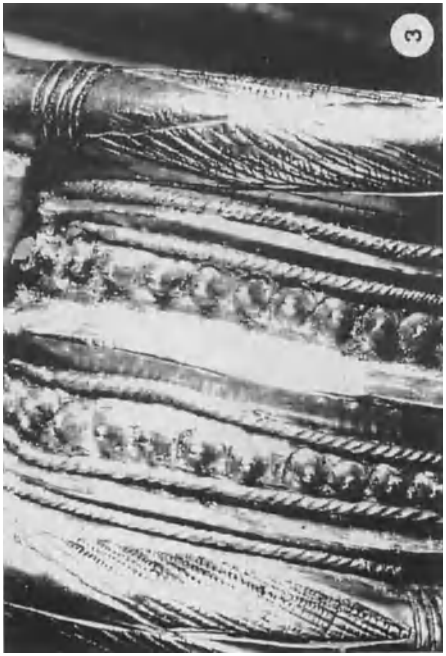
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10. Conclusions

There are two principal conclusions to be drawn from this study. Firstly, that there are features and traces on prehistoric gold objects that record the operations of the goldsmiths even where their tools have not been preserved. Secondly, that rotary tools and lost-wax casting were combined in the production of Villena/Estremoz type jewellery. This class of tool has not previously been related to Bronze Age metalworking practice. The particular process explained in this study confirms the exploitation of both lathe and drill in Late Bronze Age Iberia. It underlines the immense skill and inventiveness of the goldsmiths, as well as their specialization, producing ornaments of such an artistic and technical quality. Details of the materials and methods which seem to be unimportant for traditional study of material culture are precious sources of information for the interpretation both of gold objects and of broader patterns of ancient metal-working. There is a great need for a terminology and methodology for documenting the characteristic workmanship of gold and bronze objects for the archaeological literature in such a way as to integrate the techological and cultural aspects. The ideas suggested in this paper are designed to highlight the place of the technological approach in the study of ancient metalwork and metallurgy, and to encourage future interdisciplinary collaboration.

11. Catalogue of Villena/Estremoz rings from the Iberian Peninsula

There are 46 bracelets known so far, 6 of them of plain-convexe section and 39 with ribs/grooves, perforations and points. There are 11 closed finger-rings. 6 bracelets from the total 46 are closed (B.1., B.2, B.4, B.7, D.1, D.3), F.1 was closed when found, but opened afterwards. (Abreviations: brac = bracelet(s), fing = fingerring(s)).

A. Rings of plain-convexe cross-section: 1. Abía de la Obispalía, Cuenca (2 brac; Almagro Gorbea 1974, Fig. 1, 3-4). - 2. Villena, Alicante (4 brac; Soler 1965, No. 2-5).
B. Rings with ribs: 1. La Torrecilla, Madrid (1 brac; Priego et al., 1978, 17). - 2. Colos, Beja (1 brac; Parreira et al., 1980, No. 45; Pingel, 1992, Pl. 46, 2; No. 213). - 3. Abía de la Obispalía, Cuenca (1 brac; Almagro, 1974, 42, Fig. 1, 2). - 4. El Torrión, Navamorales, Salamanca (1 brac lost; Delibes et al. 1991, 205, Fig. 1, 3). - 5. Villena, Alicante (1 brac; Soler 1965, No. 7). - 6. Cabezo Redondo, Villena, Alicante (4 fing; Soler 1965, No. 9. 10. 29. 34). - 7. "No location", MAN Madrid Inv. No. 16853 (1 brac; Siret et al. 1890, Pl. 26, 5).
C. Rings with ribs and perforations: 1. Aljustrel, Beja (1 brac; Parreira et al. 1980, No. 54. - 2. Abía de la Obispalía, Cuenca (1 brac; Almagro 1974, 42, Fig. 1, 1). - 3. Villena, Alicante (18 brac; Soler 1965, No. 6. 8-24).
D. Rings with ribs, perforations and points: 1. Estremoz, Evora (1 brac; Reinach 1912; Alvarez 1941, Pl. 2). - 2. Portalegre (1 brac; Cardozo 1959, Est. 2). - 3. Toén, Orense (1 brac; Pingel 1992, Pl. 90, 2 No. 143). - 4. Villena, Alicante (3 brac; Soler 1965, No. 27-29).
E. Rings with ribs and points: 1. Evora (2 brac, melted; Heleno 1935, Pl. 9, Fig. 34). - 2. Cantonha, Guimarães, Braga (1 brac; Heleno 1935, 252-254, Fig. 2, Pl. 8, 32-33). - 3.

"No location", MAN Madrid, Inv. No. 1962/7 (fragment 1 brac; Almagro 1969, 284-287, Fig. 6, Pl. 6, 3). - 4. Trindade, Beja (1 fing; Nunes 1960/61, Fig. 2). - 5. Villena, Alicante (2 brac; Soler 1965, No. 25 et 26). - 6. Cabezo Redondo, Villena, Alicante (fragment 1 brac; Soler 1965, Pl. 54, 1-2).

F. Rings with ribs and points worked by chisel: 1. Chaves, Vila Real (1 brac; Cardozo 1944, Fig. 2). - 2. Cabezo Redondo, Villena, Alicante (6 fing; Soler 1965, No. 12-14. 28. 30. 35).

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Chapter 5

THE APPEARANCE OF BLACK PATINATED COPPER-GOLD-ALLOYS IN THE MEDITERRANEAN AREA IN THE SECOND MILLENNIUM B.C.
Material Characterisation and Problem of Origin

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ABSTRACT. Artificially patinated purple-black copper-gold-alloys, similar to some of the later Japanese *irogane*-alloys have been identified by the authors by analysing ancient objects belonging to the collections of the British Museum. The analyses have shown that the black metal is a very distinctive alloy of bronze with small amounts of gold, silver and occasionally arsenic, which after a patination treatment, acquires a permanent shiny and compact purple-black patina. Patinated items were mostly inlaid with other metals, for example gold, silver, electrum, but also copper and, later, brass. The earliest examples so far identified by scientific analysis are dated to about the mid 2nd Millennium B.C. and come from Mycenaean Greece and Egypt, but the material later spread throughout the Mediterranean. The authors identify this material as being the Greek kyanos and the famous Corinthian bronze mentioned by several classical texts. The presence of a similar material in other European regions is suggested.

1. Introduction

The aim of this paper is to acquaint prehistorians with a "new" kind of ancient material, which has been recently identified by the authors (Craddock and Giumlia-Mair 1993, Giumlia-Mair and Craddock 1993) and others (Ogden 1993) on ancient objects belonging to different civilisations and also to submit several problems connected with the material to other scholars. This is an artificially patinated purple-black gold-copper alloy.

The alloy was known and used for representative and sacred items already in Mycenaean Greece and New Kingdom Egypt of the second Millennium BC, it is mentioned and described in the Homeric texts, discussed, praised and denigrated as an exorbitantly costly status symbol in Roman times, and seems to have sunk into oblivion in Europe at some undetermined point in the Dark Ages.

However the knowledge of the process seems to have survived in the Middle East as testified by a Medieval Syriac translation of Zosimos' alchemistic work (approx. 3rd century AD) now in the Cambridge University Library. One of the recipes ascribed to Zosimos gives the instructions for producing "black metal sheets or the Corinthian alloy" by taking one mina of

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 425–434.

Cyprian copper (pure copper), 8 drachmas of silver and 8 of gold (approx. 6.5% of silver and gold in the alloy) (Berthelot 1967).

The history of the alloy becomes rather hazy in Asia, mainly because of the lack of analysis, but there are hints about a similar material in several ancient and also more recent literary and alchemistic texts from India, Tibet and China (Craddock and Giumlia-Mair 1993, Giumlia-Mair and Craddock 1993). Surprisingly enough, similar objects are still manufactured today in the Chinese region Yun Nan and in Japan and are considered typical examples of local handicraft.

The characteristics of the alloy do not seem to have changed much in the course of the centuries and in the different applications and styles of different civilisations. The most striking common feature is, perhaps, the presence of silver and arsenic. Both elements are not necessary for the achievement of the patina where only gold has a real function, but their presence is a common characteristic in many of the objects identified all over the ancient world. An explanation for this fact could be the connection of this alloy with the alchemistic world. The recipe could have been diffused by alchemists, who reproduced the ancient processes without variations for centuries out of their great respect for the sacred texts and for fear of failure in case any details of the procedure were missing. Another common feature is the representative or even sacred usage of the items made out of this material.

Up to this stage of the research, the technique seems to have come from the West, but too many links are still missing and too many time gaps have still to be filled out for us to be able to assert this as a fact. We are far from an accurate reconstruction of the history of the material.

2. The material: composition and properties

Some of the objects so far identified by scientific methods are rather well known by art historians (for instance examples of Mycenaean daggers or *hmty km* objects, see below) and have been repeatedly published and stylistically discussed by several scholars. However their very distinctive black decoration has been, even in recent publications, invariably described as "niello" (i.e. metal sulphides) without any support of scientific analysis. It is therefore rather important to define the real composition of the alloy and to discuss its peculiarities and properties.

The material is a copper-based alloy with small amounts of gold (1-3% weight in the alloy), of silver (1-2 %) and in some instances also of arsenic (> 1%) and presents a coppery appearance before the patination treatment. After careful cleaning and polishing of the surface and a treatment by means of some aqueous solution containing several mineral salts (which can vary), the metal acquires a black-purple, very shiny and compact patina. The black surface is then mostly inlaid with other metals of a contrasting colour to achieve polychromatic effects. The nature of the black patina and the reason for its compact structure have been studied by several scholars (Gowland 1894, 1910, 1915, Uno 1929, Oguchi 1983, Murakami et al. 1988, Notis 1988, La Niece 1990, Murakami 1993, Harris 1993) as the modern Japanese counterpart of the ancient material - the *shakudo* - is the most famous of the traditional *iro-gane*-alloys. These are different kinds of alloys and metals, which have been treated by the colouring method called *nikomi-chakushoku*, to obtain variously coloured artificially patinated surfaces. The gradation of hues, which can be achieved on the different materials covers several shades of black, beige, reddish-brown, green, blue, light brown and grey.

In the Japanese process the patinations appear after the objects - previously carefully cleaned, degreased and polished - have been boiled in an aqueous solution containing small amounts of verdigris, copper sulphate and alum (the actual *nikomi-chakushoku* bath), but the patination can be achieved with a number of other solutions (Uno 1929). If the alloy has the right composition a black surface layer is very easy to achieve. During some experiments it has even been produced in plain boiling water, and the Chinese blacken their black bronze (*wu tong*) by just holding the objects in sweaty hands (Mang Zidan and Han Rubin 1989). As already mentioned, the most famous and representative of the *irogane*-alloys is the *shakudo*, a black patinated alloy, which can acquire purple or deep blue shades, depending on the composition and of the mechanical and chemical treatment. Like the ancient items, *shakudo*, too, is mostly combined with precious metals or at least metals of different colour to produce contrasting effects. Fig. 1 shows an example of *shakudo* on a *tsuba*, a hiltguard of a Japanese sword (British Museum OA 3432, H: 6 cm). The water plants are depicted with gold inlays, the body of the birds is of silver and their heads of copper.

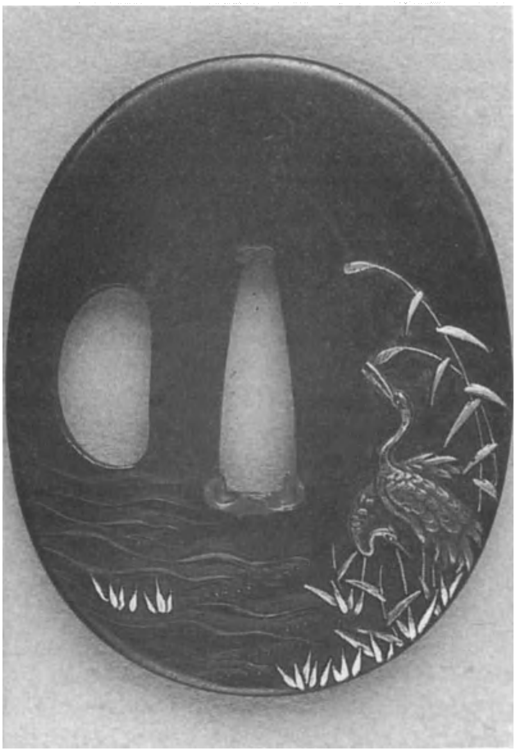

Fig. 1: Example of a shakudo object: tsuba (hiltguard) of a Japanese sword 19th century A.D. (H. 6 cm). Shakudo inlaid with gold, silver and copper. British Museum OA 3432. Photo: Tony Milton/The British Museum.

The most common *shakudo* is black-purple and contains 1-3 % of gold in the alloy. Larger amounts of gold (already by 5% of gold in the alloy) can give a bluish hue to the artificial patina. Other Japanese recipes also give about 1% of silver and small amounts of arsenic as components of the alloy (Gowland 1894, Lyman 1890-1). Furthermore the *shakudo* objects analysed by La Niece (1990) also show variable but consistent amounts of arsenic in the alloy.

Several studies on the effect of the *nikomi-chakushoku* bath on experimental *shakudo* have been carried out (Uno 1929, Oguchi 1983, Murakami et al. 1988, Notis 1988, Murakami 1993). The microstructure of the alloys is very similar to that observed in normal copper alloys, but the growth of the patina produced by the treatment on copper-gold-alloys differs from that found on other copper alloys. In both cases the crystalline compound observed on the surface is cuprite (Cu_2O), but in the *shakudo* patination there are dispersed tiny particles of metallic gold and the crystallite grows isotropically (i.e. equally in all directions). This renders the *shakudo* patina shock-resistant, while normal cuprite grows in one direction only and is very brittle. Prerequisites for the isotropical growth of the crystallite seem to be the presence of gold in the alloy and the careful mechanical cleaning and polishing of the surface before treatment. The reason for the particular black-purplish or -bluish hue of the patina is - after Murakami (1993) - the absorption of the red region of the incident spectrum by the gold particles dispersed in the cuprite. The analyses carried out on Mycenaean, Egyptian, Roman and ancient oriental pieces show the same characteristics encountered by analysing ancient *shakudo* objects and experimentally produced specimens (see Tables 1, 2, 3).

The body metal of the objects belonging to the collections of the British Museum have been analysed by atomic absorption spectrometry (AAS), where it was possible. The micro-analyser in the scanning electron microscope (EDS/SEM) was employed in cases in which drilled samples could not be obtained from the objects. All surfaces of the objects were also analysed by X-ray fluorescence (XRF).

Table 1. Body metal analyses of black bronzes (wt. %).

Object	BM Reg.N.	Cu	Pb	Sn	Au	Ag	As	Fe	Sb	Ni	Zn
Ptah	EA 27363	90.50	0.12	2.15	2.710	0.45	0.57	0.20	<0.04	0.032	0.010
Amun-Re	EA 63581	90.90	2.18	5.11	0.008	0.02	0.11	0.46	0.04	0.010	0.010
Montu-Re	EA 60342	82.10	8.93	6.63	0.013	0.06	0.45	0.13	0.13	0.040	0.010
Osiris	EA 24718	89.70	0.34	6.09	0.064	0.05	0.40	0.09	<0.04	0.040	0.007
Aegis of Re	EA 60637	84.80	7.40	5.20	0.005	0.05	0.70	0.20	0.50	0.080	0.020
Plaque	GR 1979. 12-13.1	92.00	1.90	1.40	0.600	1.20	1.10	<0.01	0.30	0.300	0.050
Inkpot body	GR 53-2-18.7	92.80	0.06	5.58	<0.008	0.03	<0.08	0.08	0.08	0.014	0.120
Dagger		92.3		0.52	1.72	0.53	1.72				

Precision of the figures for the atomic absorption analysis of the British Museum objects: ± 5-10% for alloying elements and ± 30% for minor and trace elements.
The dagger belongs to a private collection and has been analysed by J. Ogden.

Table 2. Surface analyses: EDS/SEM and XRF (wt. %).

Object	BM Reg.N.	Cu	Pb	Sn	Au	Ag	As	Fe	Sb	Zn
Necklace of Osiris	EA 64477	68.10	3.50	10.60	3.80	2.00	1.20	-	-	-
Inkpot-lid	GR 1853. 42-18.7	93.00	-	-	(0.80)	2.30	-	0.15	(0.3)	-
Inkpot-lid cleaned	GR 1853. 42-18.7	90.00	(0.90)	-	(0.90)	4.00	0.70	0.20	-	-
Side of inkpot	GR 1853. 42-18.7	43.00	1.90	35.50	-	0.50	-	0.50	-	-
Base of inkpot	GR 1853. 42-18.7	33.00	-	36.00	-	-	-	0.70	-	-
Forceps-decoration	GR 1814. 7-4.969	52.00	3.75	0.80	3.10	3.90	-	-	-	1.60
Forceps	GR 1814. 7-4.969	37.00	3.10	11.00	-	0.50	-	-	0.80	8.40
Triclinium-decoration	GR 1784. 1-31.4	83.50	1.10	13.80	<0.05	1.25	<0.30	0.10	0.04	<0.14
Dagger	Patras		traces		5 - 10	traces				
Dagger	Copenhagen		1 - 2		≈ 5	1 - 2				

Each analysis of the British Museum objects is the average of three separate determinations, where the figures are in parenthesis, the element was only detected once.
EDS-SEM detection limits are 0.6% for Pb and As, 0.5% for Au, 0.3% for Ag, Sb and Sn and 0.2% for Cu and Zn.
The dagger from Patras has been analysed by E. Photos-Jones.
The dagger from Copenhagen has been analysed by S. Dietz.

Table 3. XRD determinations of the principal crystalline compound in the patina (wt. %).

Object	BM reg.no.	Principal compounds identified
Ptah	EA 27363	Cuprite Cu_2O
Osiris' necklace	EA 64477	Cuprite Cu_2O
Amun-Re	EA 63581	no ancient patina
Montu-Re	EA 60342	no ancient patina
Osiris	EA 24718	no ancient patina
Aegis of Re	EA 60637	Cuprite Cu_2O
Plaque	GR 1979.12-13.1	Cuprite Cu_2O
Lid of inkpot	GR 1853.2-18.6	Cuprite Cu_2O + silver chloride AgCl + Ag
Forceps	GR 1814.7-4.969	Cuprite Cu_2O
Triclinium	GR 1784.1-31.4	Cuprite Cu_2O
Drapery		Cuprite Cu_2O + tenorite CuO
Dagger		Cuprite Cu_2O

The drapery has been analysed by Ch. Boube-Piccot and the dagger by J. Ogden.

3. Mycenaean *shakudo*

The earliest dated example, which has been scientifically identified is a Mycenaean bronze dagger, belonging to a private collection, analysed by Ogden (1993). The actual blade is of bronze and is inlaid with a strip of black patinated alloy containing 92.3% of copper, 5% of tin, 0.52% of arsenic, 1.72% of gold and 0.53% of silver. The black panel is inlaid with golden and silvery looking metal sheets, actually manufactured out of two different kinds of electrum, clearly man-made because of their high copper content (the golden ones contain 15.5% of silver and 8.6% of copper and the silvery ones 65.9% of silver and 10.7% of copper, the rest being gold). The fact that the dagger appeared on the antiquity market before any analyses of similar pieces of this highly unusual material were published and at a time in which the black decoration was considered to be niello, should put an end to any stylistic doubt about its authenticity. The more so as, since our studies and Ogden's analysis became known, two more similar daggers have been scientifically examined. One is the dagger in the National Museum of Copenhagen, which has been analysed by Dietz (quoted by Photos-Jones) and the other one is the dagger from Kataraktis - Ayios Athanassios, now in the Patras Museum, analysed by means of semiquantitative X-ray fluorescence by Photos-Jones (in publ.): both contain considerable amounts of gold, silver and lead.

It has to be emphasized here that the nature of the black decorations on the well known group of cups from Enkomi, Pylos, Dendra and other sites (Karo 1930, Blegen and Rawson 1966, Xenaki-Sakellariou and Chatziliou 1989), which have been believed to be of the same black decorative material found on the daggers, is insufficiently studied. The results of the analyses carried out on them do not give a straightforward answer to the question of the nature of this material. The problem of the use of early "niello" remains a challenge for archaeometallurgists.

The name of the material in early times is also still an open question.The authors have identified the material *kyanos* mentioned explicitly as a black decorative material by Homer in the description of the cuirass of Agamemnon and of the fabulous Shield of Achilles, as the Greek name of the *shakudo*-alloy found on representative Mycenaean daggers. A later use of the word in connection with the production of a black Egyptian statue made of bronze with gold, silver and other metals corroborates this interpretation of the word (Giumlia-Mair and Craddock 1993). Linear B texts from Pylos and Mycenae mention the correspondent word *kuwano* as a precious material listed together with precious metals - *kuruso* (i.e. gold) is mentioned in the same context - and *kuwanowokoi* as the craftsman who worked with this material (PY Ae 303 (.a); An 207.10; Ta 642.1; Ta 714.1 (.2); MY Oi 701 (7) -702. (4) - 703.2 - 704. (4)) (Reinholdt 1987). The word has been translated as glass, fayence or lapis lazuli, but also the Greek equivalent *kyanos* has been translated in the homeric texts as blue steel, blue glass and niello and can indeed also mean azurite, lapislazuli, the cornflower, a blue bird or simply the blue colour (Giumlia-Mair and Craddock 1993).

The smiths who manufactured the daggers in the Mycenaean centres must have been specialised handworkers and this is exactly what *kuwanowokoi* seem to have been. However at this stage of the study this interpretation of the word *kuwano* can only be a suggestion for further research.

4. *Hmty km:* the Egyptian black bronze

At roughly the same time in which Mycenaean *shakudo* appears, we encounter in Egypt the first examples of *hmty km* (pronounced "hemty kem"). The word means "black bronze" in hieroglyphic and has also been transcribed as *hsmn km*, the proper reading seems however to be *hmty km*. As it is evident from the tables of analysis *hmty km* is the same as the material found on the Mycenaean daggers. Fig. 2 shows an example of the use of *hmty km:* the necklace of the Osiris statuette is inlaid in the body of normal bronze and has been found to be of a patinated copper-based alloy containing 3.8% of gold, 2% of silver, 1.2% of arsenic, 10,6% of tin and 3.5% of lead. The black inlay was then in turn inlaid with three stripes of electrum (British Museum EA 64477, height of statuette: 16 cm).

Fig. 2: Example of hmty km on a ptolemaic statuette of Osiris. The body is of common bronze, inlaid with a necklace of a black patinated shakudo-type alloy, containing gold, silver and arsenic. The necklace is again inlaid with three electrum stripes. British Museum EA 64477. Photo: T. Milton/The British Museum

Cooney (1966, 1968) identified *hmty km* as black bronze, inlaid with precious metals and noted its affinity to the black Mycenaean decorations. Several hieroglyphic inscriptions give us good descriptions of ancient objects, similar to the ones, which have been analysed. The most ancient inscription mentioning *hmty km*, dated to the time of Thutmes I (i.e. at the beginning of the New Kingdom), describes, for instance, the podium of an Osiris statue made of silver, gold, lapis, *hmty km* and precious stones (Sethe 1906-1909, Urk IV,98).

Another interesting text underlines the use of "true" black copper as an inlay on a temple door (Urk IV,168), thus implying the existence of fakes or imitations. Some of the Egyptian objects analysed by the authors were indeed black patinated and inlaid with precious metals, but their bronze did not contain any gold. Three of the objects have a modern patination of black lacquer applied after conservation, but the Aegis of Ra still has the ancient patina. The black surface layer of the Aegis does, as a matter of fact, look different from the *shakudo* patina and is less homogeneous, but could nevertheless resemble the true *hmty km* and, in absence of an analysis, be taken for an authentic example. There are certainly ways to produce some sort of black patina on different alloys and we also know from the later literature that the Romans were aware of fakes and imitations on the market and worried about the authenticity of their Corinthian bronzes (Plinio Secondo, Plin. Nat. Hist., 34, 1988).

5. The problem of origins

The few scraps of information we can gather from the simple optical examination of the archaeological material and from the ancient literary sources are not sufficient to clarify the question of the origin of the alloy; on the contrary, they make us even more aware of the problem.

The famous paintings in the Tomb of Rekhmire (Davies de Garis 1922, Schoske 1984), dated to the time of Thutmes III, depict the presentation of items from Keftiu, which is today almost generally accepted as the name for Crete. One of the exotic looking vessels is described in the text as being of silver, gold and *hmty km*. In this case the object is imported from Crete or the Aegaean to Egypt, and we are already acquainted with the *shakudo*-like Mycenaean examples. Unfortunately the vessel described in Sethe (1906-1909, Urk. IV, 1090) is rather difficult to recognize on the painting and this single inscription is of course not sufficient basis to assume that the technique came from Mycenae to Egypt. The material found in archaeological contexts on the Greek mainland in Mycenaean times is very heterogeneous and reveals complicated trade patterns, but also intricate ethnic interactions - notably with Egypt and the Near East - which influenced all facets of life in the country (Bernal 1991).

Another hieroglyphic text, the annals of Thutmes III, narrates that the pharaoh, coming from Syria in the 23rd year of his reign, brought back all sorts of precious metals and materials, among other things, *hmty km* (Sethe 1906-1909, Urk. IV 744). Cooney (1966, 1968) considered the Egyptian black bronzes to be the direct descendants of some black decorated bronzes from Mesopotamia - the earliest dated about 2500 BC - and of later Syriac objects, for instance the black patinated axe from Ugarit (Schaeffer 1939). His opinion is shared by most scholars and the latest literature lists items from Byblos and Palestine as possible ancestors of the black material (Xenaki-Sakellariou and Chatziliou 1989). Regrettably no suitable objects from these regions could be found in the British Museum and not many analyses have been carried out on black patinated objects with this provenience. M. Leon Brun (Schaeffer 1939) analysed the famous axe from Ugarit, which has a black patinated socket inlaid with gold, but the technique must have been different because no gold and silver seem to have been present in the alloy.

Further, a qualitative spectral analysis by H. Kühn (1987) has been carried out on the sickle sword from Balata-Sichem in Palestina, dated either to the 12th or to the 18th Dynasty, which has been compared with the Mycenaean daggers because of its black decoration (Xenaki-Sakellariou and Chatziliou 1989). Kühn (1987) reports the use of electrum for the inlays and the presence of copper and silver as main elements, of smaller amounts of iron, gold, calcium, magnesium, tin, aluminium, lead, manganese, silicon and nickel and also of arsenic and titanium as trace elements. An X-ray diffraction analysis identified metallic silver and silver sulphide in the surface layer, which was therefore interpreted as a thin niello coating. From these results it is not quite clear which sort of material we are dealing with. Despite repeated statements to the contrary no real niello in the form of a coating has been scientifically ascertained, at least up to now. A new examination of the interesting find from Balata-Sichem would be highly desirable.

The hypothesis that the black decorations on the objects from the Near East are of the same material employed on Egyptian and Mycenaean finds - the *shakudo*-alloy - and that this area has been its birthplace can only be confirmed by more analyses on different objects and by further archaeological research. There is also no reason to exclude the idea that objects of this kind could have been produced in other European regions, or simply been exported to other places over long distances, as it happened with other goods, for example the amber from Baltic, the ostrich eggs from Africa and the rock crystals from the Alps found in Greece or the corals and ivories found in Northern countries. Examples of this particular black patinated alloy from other archaeological contexts could exist unrecognised among many other objects belonging to European Museum's collections as it was the case with the Corinthian bronze of the Romans.

Our final object is to awake the interest of other scholars in this subject and to promote a research on this remarkable and exquisite material in wider circles.

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Chapter 5

SINTERING, WELDING, BRAZING AND SOLDERING AS BONDING TECHNIQUES IN ETRUSCAN AND CELTIC GOLDSMITHING

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ABSTRACT. This article intends to describe the introduction of hot bonding techniques north of the Alps in the sixth century BC as a case of technology transfer from Etruria to the Celtic world. It further describes the independent development of the newly aquired techniques by Celtic goldsmiths.
North of the Alps, the earliest examples of hot bonding identified so far come from Burgundy and Upper Alsace and date from Hallstatt D. The first technique used by the Celts was reaction soldering in Hallstatt D1, followed by hard soldering (or brazing) with gold-silver-copper alloys in Hallstatt D3. A hybrid of reaction soldering and brazing was also current in Hallstatt D3. In La Tène A Celtic goldsmiths of the Saar-Rhine area introduced a liquid phase bonding process, at first without, later on with identical or nearly identical filler metal. This technique, which may be well described as "welding", was current in La Tène A and B.
Reaction soldering, which demands sophisticated knowledge, but is easy to manage, was obviously aquired by the Celts from the Etruscans. But the successve introduction of brazing and welding seems mainly to result from an independent Celtic development of higher levels of mechanical skill.

1. Introduction

In Europe, gold has been worked for ornaments and ceremonial objects since the very beginning of the European Copper Age in the fourth millennium. Apart cold welding no bonding techniques have been detected so far (Echt et al. 1991). The earliest European examples of hot bonding techniques date from the Aegean Early Bronze Age and are more than 1000 years later than cold welding. Very probably these techniques were adopted via Asia Minor from Mesopotamia, where high temperature bonding techniques were common since the Ur I-period in the middle of the third millennium. While Mediterranean cultures continued to use and develop hot bonding techniques, Bronze Age Europe produced a lot of cast and beaten gold objects, but took no part in the evolution of hot bonding techniques. Outside the Atlantic cultural complex, there is hardly a single golden item with traces of high temperature joining processes until the Early Iron Age.

North of the Alps, the earliest examples of gold ornaments joined together from different components or with applied granulation date from the Early Hallstatt period (Hallstatt C), roughly covering the 7th century BC. These come from graves at Kleinklein in Austria

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(Dobiat 1980, Taf. 95,8), Chaffois in France (Lerat 1970, Fig. 10) and Ins in Switzerland (Drack 1958, Taf. B3).

We do not intend to discuss here the question as to wether Hallstatt C is properly "Celtic". In our terminology, "Celtic" is neither an ethnographic nor a linguistic concept. For the purpose of this contribution, "Celtic" is simply a conventional label given to the Western Hallstatt and La Tène cultures. This reservation applies to the "Etruscans" too, who, in our terminology, are simply those responsible for the so called Etruscan civilization in middle and northern Italy.

There can be no doubt that the fragments from Kleinklein are of Etruscan origin (Frey 1989). For the Chaffois earring, the question has never been asked. The origin of the granulation-decorated bead from Ins, barrow 6, is much debated: currently it is not possible to decide whether this unique object is the product of an indigenous workshop or was imported from the Mediterranean world (Guggisberg 1991, Lüscher 1991). A Greek, Etruscan or even Phoenician/Punic origin is not totally out of question, and no analytical data have been published so far. To sum up the situation during the Hallstatt C period, we must admit that there are some finds of hot joined gold objects in temperate Europe, but we cannot say wether they are indigenous or were imported from technologically advanced regions south of the Alps.

Only in the following Late Hallstatt period of the sixth century BC (Hallstatt D) are there several examples of hot joined gold jewellery so closely related to types produced by the local bronze and gold industry, that we must accept their origin north of the Alps. The question is wether Celtic goldsmiths independantly invented thermal bonding techniques or if they benefited from a technology introduced from the south. In the first case one would expect the beginning of these new techniques to be marked by the hesitant attempts of an experimental phase; in the second case, we ought to be able to detect at a fixed point in time a sudden close technological resemblance between Mediterranean and Hallstatt gold objects.

To decide this question we cannot confine ourselves to comparing the formal resemblance between gold ornaments from the north and the south of the Alps, because similarity of forms can result from simple imitation. We have rather to compare the inner relationship of superficially similar goldsmiths' works from a strictly technological point of view. Thus we cannot argue, for example, on the basis of the presence or absence of filigree- or granulation decoration as proof of a kind of relationship between certain south and north Alpine items of gold jewellery. We must rather analyse how the filigree or granules were joined with their substrates in order to get an idea of the specific technological knowledge of the cultures under research.

To do so, we can in part lean on very useful analyses by Formigli (Nestler and Formigli 1993) on Etruscan and by Eluère on Late Hallstatt gold jewellery (Eluère 1987, Eluère et al. 1989). But, because not much Early La Tène gold jewellery has yet been analysed, we started in 1988 new investigations on this topic (Echt and Thiele 1994). Some major conclusions in this paper are drawn from these new investigations.

Because of the high museological value of the objects investigated, only non-destructive methods could be used: X-ray macro-structure analysis and EDS-spectroscopy with electron probe analysis. Polishing and etching in order to determine the micro-structure of the metal was strictly forbidden. Generally, the methods used gave enough information to identify the finger-prints of the bonding-technique used by the ancient goldsmiths. Only in a few cases we cannot reach a conclusion for lack of evidence.

Sophisticated joining techniques for gold and gold alloys were developed in the Near East from the late 4th millenium BC. We know about hard-soldered pieces from Chalcolithic and Early Dynastic times in Elam and Mesopotamia (Moesta 1983, Duval and Eluère 1986), about reaction-soldering for granulation and filigree work from Early Dynastic times (Moesta 1983) and about sintering for granulation from the Late Bronze age in the Levant (Thiele 1986). Although analytical data are yet too rare to elucidate the early history of joining techniques, we can state that in Early Phoenician times, i.e. the Late Bronze Age of the 15th to 12th centuries, hard soldering (or brazing) as well as reaction soldering and sintering were long developed standard techniques in the Near East.

2. Etruria

In non-Aegean continental cultures of the Late Bronze Age, hot bonding techniques are almost completely absent. It was in Greece, Italy, and, to some extent, southern Spain that these techniques gained a foothold during the Early Iron Age, when the Greek, Etruscan and Iberian cultures came in contact with the western spreading Phoenicians. Obviously, the beginning of the Orientalizing phase of Greek and Etruscan art in the 8th century falls in a time of intensive Phoenician activities in the eastern and western Mediterranean.

Suddenly, Etruscan gold jewellery reached the high technological standard to which we owe the most distinguished masterpieces of granulation work. From archaeological evidence, it is impossible to explain this progress by an evolution from initial stages in the Villanovian. We must postulate an external stimulus, and a lot of Phoenician style luxury goods in Early Etruscan princely graves allow us to imagine how far Early Etruscan arts and crafts may depend on Phoenician know-how.

A very rich heritage of Etruscan gold jewellery is at our disposal - but only a few analyses of Etruscan gold items have been published so far. Thus, from the little we do know, we are still far from able to paint the whole picture of the history of Etruscan gold jewellery but have to content ourselves with a very rough sketch.

As has been shown by various authors, in the 7th and 6th centuries BC reaction-soldering was a standard technique in Etruria, particularly for granulations (Parrini et al. 1982, Echt and Thiele 1987, Eluère 1989, Nestler and Formigli 1993). The technique has been described by Moesta based upon the results of his own experiments (Moesta 1983). According to Moesta, the goldsmith had to mix a powdered copper-oxide with a glue containing carbon and to coat the join with this mixture. When heating to yellow heat, the carbon will reduce the copper-oxide to pure metallic copper while producing carbon dioxide. When the heat reaches the temperature required (ca. 890 °C), the copper will diffuse into the gold and produce with the gold of the joining area a topographically very restricted gold-copper alloy, which fills the join and causes the bonding.

Very often, this technique can be detected by a certain copper enrichment in the join. Sometimes, when gold ornaments have been treated after joining in order to remove the copper from their surface, non-destructive methods will be unable to detect any copper enrichment. Then, only to some extent topographical traces will allow us to deduce the bonding technique.

Besides the traces of the well accepted reaction-soldering, we observed some indications of another bonding technique (Echt and Thiele 1987). A fragment of a fibula from Comeana, near Florence, shows a copper-enriched zone in the seam between foot and bow, but no copper at all in the joins between substrate and granules or between granules and granules. The partly flattened granules are joined together by necks with a grained surface (Fig. 1). The same surface-structure can be observed on a Sanguisuga-fibula from Vetulonia, prov. Grosseto (Fig. 2). Again, there is no copper in the joins, whilst the footplate's surface contains about 4.5% copper by weight (see Table 1). Obviously the goldsmith made no effort to remove the copper from the surface of the fibula after assembling it from several separate pieces. In both cases, neck-building and the absence of copper in the joins - not on the whole object! - leads to the conclusion, that the granules were joined to their substrate by sintering.

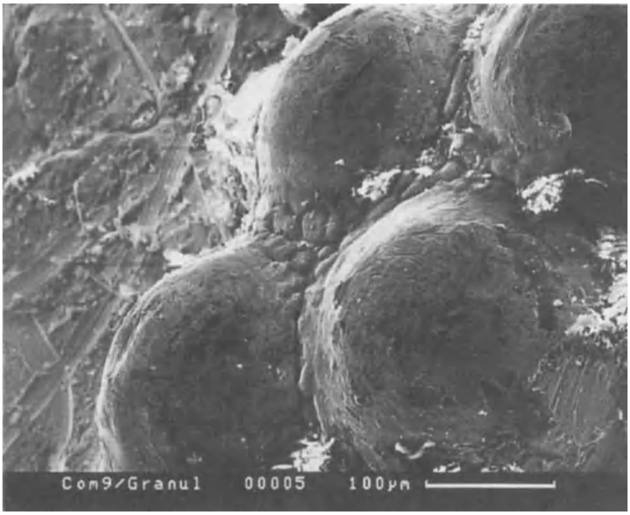

Fig. 1: Comeana (Italy), granules at the footplate of an Etruscan fibula.

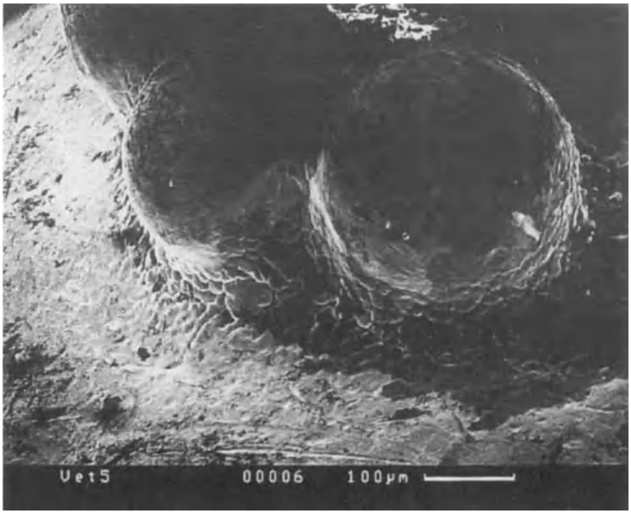

Fig. 2: Vetulonia (Italy), Etruscan Sanguisuga-fibula with granules very probably fixed by sintering.

Table 1. Selection of analyses of Etruscan and Celtic gold jewellery. If not specified, the analized points are on the objects' surface. The numbers are rounded, so that the total may be 99.99 or 100.01.

	Au	Ag	Cu	Zn
Early La Tène Celtic				
Worms-Herrnsheim, bracelet				
smooth surface	98.82	0.53	0.50	0.15
rough surface	97.71	0.45	1.23	0.61
crevice	94.47	3.10	2.27	0.16
seam	78.94	4.45	14.62	1.99
Rodenbach, bracelet				
smooth surface	98.78	0.78	0.44	
mask 3	98.79	0.77	0.44	
ram's figure	98.65	0.94	0.41	
outer volute	97.94	1.60	0.46	
outer balustrade	97.60	1.65	0.75	
stud	97.70	1.45	0.85	
torus	98.81	1.52	0.67	
tube, decorated part joins:	97.71	1.06	1.24	
joins: mask 1/stud	98.85	0.50	0.65	
ram/central mask	98.70	0.26	1.03	
torus/tubular part	98.21	0.52	1.26	
stud/balustrade	93.85	4.73	1.42	
central mask/cups	93.62	5.11	1.27	
torus/outer volute	92.02	5.52	2.45	
Waldalgesheim, decorated bracelet				
right end	99.84	0.13	0.04	
right torus	99.06	0.29	0.56	
plain segment	97.69	0.88	1.43	
crack, near surface	98.12	1.76	0.12	
crack, core	97.76	2.06	0.27	
join of Fig. 12	98.08	1.35	0.57	
Waldalgesheim, twisted bracelet				
wire 1	96.94	1.63	1.44	
wire 2	98.19	0.28	1.52	
longitudinal seam	97.87	0.78	1.35	
transversal join, w1	98.50	0.56	0.94	
transversal join, w1	97.55	0.21	2.24	
transversal join, w2	94.79	1.36	3.84	
Etruscan				
Comeana, fibula				
footplate	89.91	10.09	n.d.	
bow	94.87	5.13	n.d.	
footplate/bow	90.02	9.81	0.18	
granule	93.26	6.74	n.d.	
Vetulonia, fibula				
footplate	79.86	15.56	4.58	
bow	77.16	22.84	n.d.	
granule	90.59	9.41	n.d.	
granule/bow	73.75	26.25	n.d.	

Sintering is a solid phase bonding technique. If pressed metal powder is heated, usually to 65-80% of its solidus temperature, the powder grains will join together by diffusion, so that they finally build a solid body or, if they were not sintered under optimal conditions, at least a porous solid. It is evident that this technique can also easily be used to join golden granules or filigree to any piece of gold jewellery.

Thus, reaction-soldering and sintering have to be considered as standard techniques in the seventh and sixth century Etruscan goldwork. If until now neither brazing nor welding nor other techniques have been reported, we must bear in mind the small amount of investigation conducted so far.

3. Late Hallstatt bonding techniques

In Celtic Europe, we have no seventh or sixth century locally produced gold finds which can reasonably be compared with Etruscan gold. Even the famous mid sixth-century Hallstatt D2-grave at Eberdingen-Hochdorf in Württemberg contains only hammered sheet gold. The only composite pieces are two gold serpentine-fibulae, and these are not metallurgically joined, but stuck together (Biel 1985, 142)!

Clearly, the history of Celtic bonding technique started not in South-western Germany, but in Eastern France. The earliest metallurgically bonded indigenous gold products have been found in Burgundy in the Apremont princely grave, which must be dated early in Hallstatt D1 because of the associated long sword which still reflects the customs of the Hallstatt C period. The Apremont gold fragments, which may be part of a pair of fibulae, have been analysed by Eluère (1987). She has detected in the joins a significantly higher copper concentration, which enables our identification of the technique as reaction soldering. Reaction soldering is the oldest Celtic bonding technique so far established.

Traces of the same technique have been described by Eluère in the case of the golden earrings and armlets from the Hallstatt D2 grave of Butte Sainte Colombe, again in Burgundy (Eluère 1987). These pieces, too, must be considered as indigenous. They were produced at the time when the first wave of imported Mediterranean - i.e. Greek and Etruscan - luxury goods arrived. Particularly metal vessels were brought to the Celts via the Rhône and Saône rivers, and both graves, Apremont and Butte Sainte Colombe, contain bronze vessels from south of the Alps.

This is also true for the rich Hallstatt D3 grave at Vix, only 3 km from Sainte Colombe. The most remarkable gold item from this grave is the heavy penannular neckring, whose ends are decorated with winged horses, lion paws and pomegranate shaped spherical terminals (Fig. 3). As Eluère and others have demonstrated, the neckring is joined together from several separately worked pieces which are partly hammered and partly cast (Eluère et al. 1989). Noteworthy is the attachment of the hollow "pomegranates" at each end of the ring with a large pin in the centre of each terminal.

Analyses of the longitudinal seam of the ring's tube shows, apart from some impurities such as boron and nickel, a copper enrichment which is interpreted as an indication of the reaction soldering process. But other joins must have been hard-soldered, because the copper content as well as the silver concentration is significantly higher in these joins than on the surface of the ring. The solder must have been a gold-silver-copper alloy. In the seam between the two halves of the "pomegranates" Eluère detected mercury among other impurities.

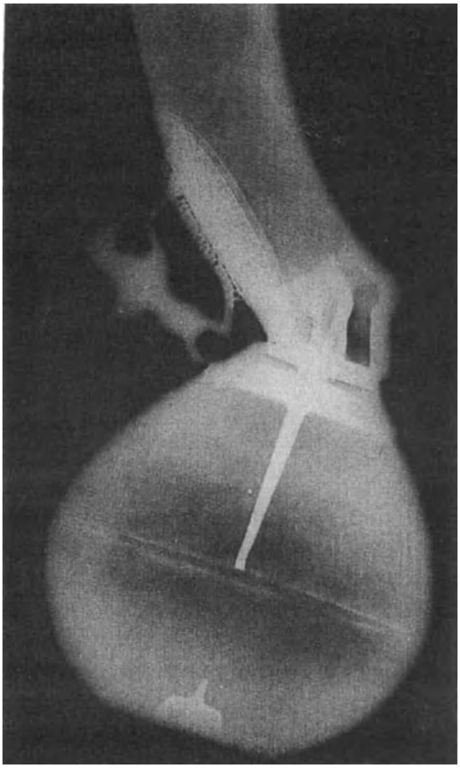

Fig. 3: Vix (France), Late Hallstatt penannular neckring. X-ray photography of one of the ends showing various joins (after Eluère et al. 1989).

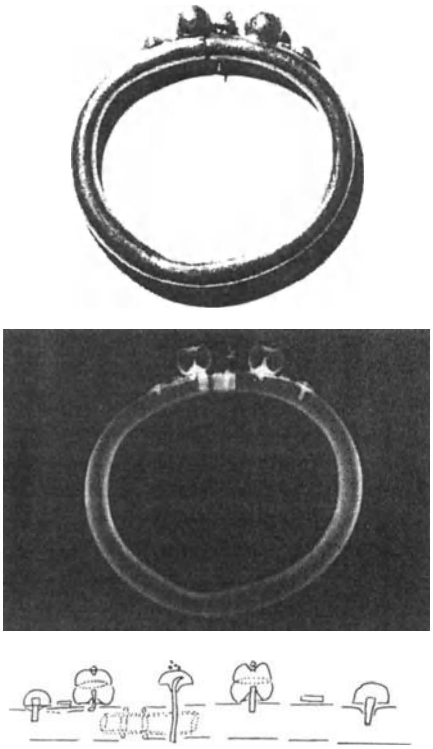

Fig. 4: Ensisheim (France), Late Hallstatt bracelet joined together from different pieces in a likelihood manner as Vix (after Eluère et al. 1989).

The Vix neckring is so different in form and technique from older as well as contemporaneous Celtic gold neckrings, that some scholars believe that it could have been imported from the South. But recently, Eluère was able to supply us with a very good argument for the indigenous origin of this extraordinary piece of jewellery. This argument is given by the bracelet from the Hallstatt D3 grave of Ensisheim in Upper Alsace, whose ascription to the Western Late Hallstatt culture has never been in doubt. This ring is decorated with two spheres and a pair of rams' heads.

X-ray photography shows that the two balls added near the ends of the penannular ring have been joined to the Ensisheim armlet with the aid of an internal pin in the same manner as the terminals of the Vix neckring (Fig. 4). And again, in the seam between the two hemispheres of the globes traces of mercury have been detected (Eluère et al. 1989, 23).

There can be no doubt that both pieces of jewellery have been produced in the same manner, and it is very probable that identical auxiliary material has been used as a flux. Although stylistically different, both pieces obviously originate from the same workshop. This workshop took over from the South not only symbolic forms such as winged horses, lions' paws, rams' heads and perhaps even pomegranates, but also at least the reaction soldering technique. Only personal contact between Celtic and Mediterranean goldsmiths can explain such an exchange of iconographical and technological elements around 500 BC.

4. Early La Tène bonding techniques

Intensive contacts between Etruscans and Celts led to a considerable alteration of Celtic culture in the second and third decades of the fifth century BC when wide areas of the western Late Hallstatt culture gave way to the emergent La Tène culture. In the early phase of the La Tène period (La Tène A and B), the Celts adhered to the old custom of burying their élite with rich gold ornaments. Thus, there is sufficient material from the fifth and fourth centuries to trace the next steps in the history of the Celtic bonding techniques.

One of the very earliest La Tène A graves with gold ornaments was found in 1969 at Worms-Herrnsheim (Schaaff 1971). A pair of plain hollow bracelets has been beaten up from two gold sheets. A longitudinal seam runs along the inner circumference. The two edges of the seam are very carefully joined and the join is well polished (Figs. 5, 6). Semi-quantitative electron probe analyses demonstrate that the seam has been closed with an especially prepared solder. The silver concentration on the surface of the seam is 2.3 - 4.4 % by weight against 0.2 - 0.5 % on the plain surface, and the copper concentration in the seam is 14.6 % against only 0.5 - 2.0 % on the surface. In the join, zinc has also been detected in a concentration from 1.2 to 2.6 % by weight (see Table 1). From these data we deduce that the solder has been prepared from a mixture of gold, silver or a gold-silver alloy and a copper ore containing zinc. Such minerals are not only known from Etruria, but are also found in the Wallerfangen copper deposits in the Saarland. And a gold plated copper neckring and hollow gold armring from Wallerfangen, which is contemporanous with Vix and Ensisheim and hence a little bit earlier than Worms-Herrnsheim, were also soldered with a zinc-containing copper mineral and silver (Echt and Thiele 1994). We interpret this procedure as an intermediate experimental stage between reaction soldering and hard soldering, and might make sense to suggest that a hard solder was prepared from gold and silver- or from a gold-silver alloy- and copper-zinc ores.

A little bit younger than the Worms-Herrnsheim bracelets is the heavily ornamented armlet from Rodenbach near Kaiserslautern (Linden-Schmit 1881). Backward-looking rams and human heads are composed in an allegorical group. Again the Celts probably were inspired to produce such compositions by the Mediterranean civilizations, especially the Etruscans. The hollow ring consists of at least 28 separate parts and groups of parts (Fig. 7). In fact, the Rodenbach ring is the most complicated example of Early La Tène gold jewellery. Its components, partly cast and partly hammered, were joined together using different methods.

Traditional reaction soldering has been used to join the plain tubular part of the ring to the adjacent cast protuberant parts. This is demonstrated by copper enrichment of the join and standard silver concentration. Less significant traces of the same technique have been observed in the join between the central human mask and the flanking elements of the ring.

The relatively "modern" hard soldering technique, with a gold-silver-copper alloy as solder, has left significantly higher silver and copper concentrations in the joins between the torus and the outer volute, between the human heads and the cup-like ornaments above them and between the "cup" of the left mask and the adjoining balusters.

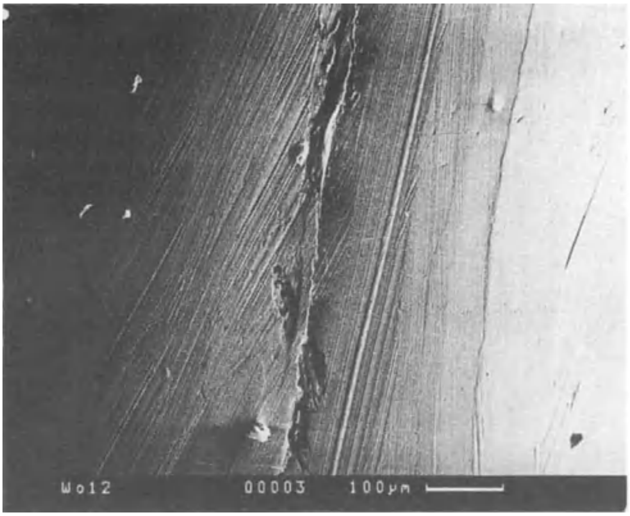

Fig. 5: Worms-Herrnsheim (Germany), grave 1, Early La Tène plain bracelet, longitudinal seam with filled-in solder.

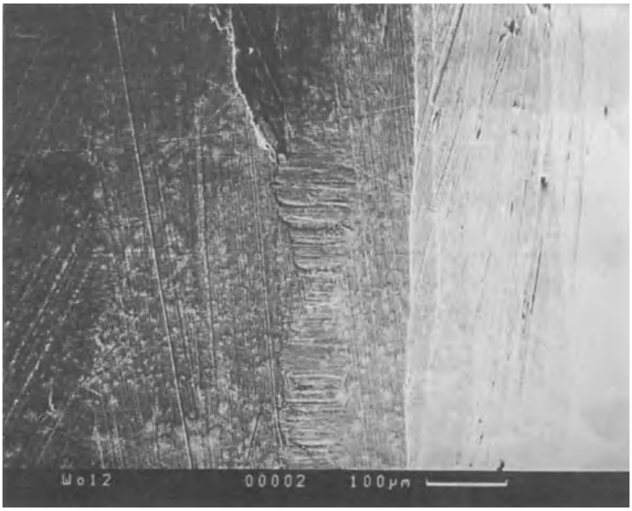

Fig. 6: Another part of the seam shown in Fig. 5, but polished in transverse direction.

Reaction soldering seems then to have been used to assemble the armlet proper, while hard soldering has been used to fix the outer applications. There are some other joins showing gold, traces of copper and impurities like C, O, Mg, Al, Si, Ca, Fe in a dendritic or lumpy structure. Most of these elements are typical for sandy and clayey soils and because they have

Fig. 7: Rodenbach (Germany), Early La Tène bracelet consisting of a plain tubular part, two adjacent swelling parts, two volutes, four rams' figures, four balustrades fixed on the rams' backs, three human masks, ten baluster- and cup-shaped ornaments above the masks and the two protuberant horns of the rams besides the central mask (photo by courtesy of the Historisches Museum Speyer).

Fig. 8: Rodenbach (Germany), Early La Tène bracelet. Join between a torus (right) and the neighbouring ram's figure (left), very probably achieved by welding.

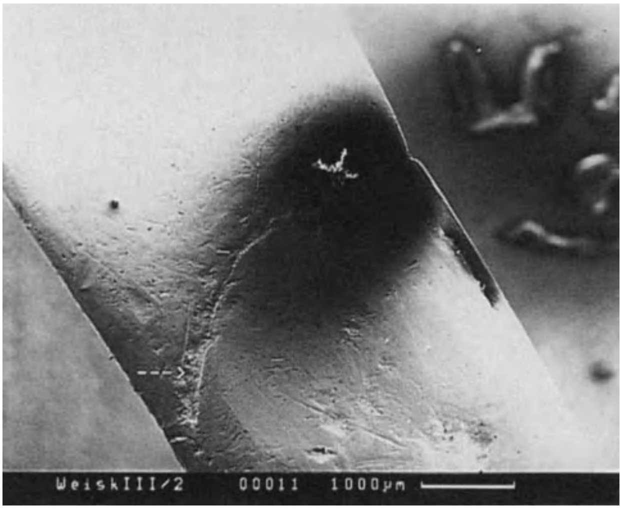

Fig. 9: Weiskirchen (Germany), grave 3. Early La Tène finger ring with an oblique welded join subsequently worked by hammering.

The join between the torus and the neighbouring ram's figure shows a narrow zone with a porous grained surface (Fig. 8). The structure indicates that the metal in this zone solidified from the liquid state. The solidification structure of molten metal demonstrates that joining took place in the liquid phase. This could be achieved by soldering or by heating the join up to melting temperature, i.e. by welding. Because the silver and copper concentrations in the join do not differ from the standard surface values, there is no evidence in favour of any kind of soldering and a welded join cannot be excluded.

As a result of our research we can in fact state that since Early La Tène times welding was in use in the production of small finger rings. Examples from Dörth near St. Goar on the river Rhine, Theley in the central and Weiskirchen in the northern Saarland region show oblique joins with typical porous and grained solidification structure and an unaltered alloy composition (Fig. 9). The joins were invariably subsequently worked by hammering; traces of tooling are clearly visible.

One of the most impressive pieces of Early La Tène gold jewellery is the famous torque from Reinheim in Southern Saarland (Keller 1965). It dates from the very end of La Tène A at the beginning of the 4th century BC. The torque consists of a twisted triple flanged penannular ring and two plastic terminals decorated with humans' and animals' figures (Fig. 10). Each group shows an beardless human being, most probably a woman, wearing on her head a kind of Phrygian helmet with a peak in the shape of a predatory bird and cheek-pieces looking like the bird's wings. Behind each figure are two beasts' heads which can be identified as felidae. Each carries a long stud resembling in shape the smaller studs on the Rodenbach bracelet (see Fig. 7).

The Reinheim-torque consists of at least 25 hammered and cast parts. Multiple joining was therefore necessary to assemble the whole piece. The joins are relatively large and some of them are clearly visible to the naked eye. SEM-microscopy reveals that all these joins have a porous and grained dendritic structure, which proves that the metal in the joins was heated to its liquid state. In most joins the filler stands out sharply against the adjacent parts (Fig. 11).

The only element detected by electron probe analyses on the torques' surface is gold, and this is also true for most of the joins. Again, neither the analytical data nor the surface topography gives any evidence of soldering. We have therefore to consider whether bonding could not have been done by means of welding.

Fig. 10: Reinheim (Germany), Early La Tène penannular neckring, one of the two similar decorated terminals, assembled from various separate parts (photo M. Zorn).

In any case, the joins have been filled with additional material, which, according to the analyses, is either identical with the bulk material or is at least very near to the latter's composition. No copper could be found on the torque's surface, and in a few joins only a little amount of silver, which could not have significantly lowered the melting temperature. The mostly sharp border between the dendritic surface of the filler and the smooth surface of the adjacent parts indicates that only the filler melted - although its melting temperature is the same or nearly the same as that of the bulk material.

As one possible interpretation of our findings, we suggest a bonding process such as the following: The join was filled with gold dust and glue. When it was heated, the glue burned and the gold dust could be slightly sintered. If then a blow-pipe was used to direct a very hot flame to the join, the little dust grains, with their greater surface relative to their volume, began to melt before the bulk material. The goldsmith had to stop heating as soon as the filler liquefied; the re-solidifying filler closed the join and bonded the adjacent parts together. But only the metallography of a cross section through a join could confirm this hypothesis, because we cannot entirely exclude that the surface composition could have been altered by depletion gilding.

Fig. 11: Reinheim (Germany), Early La Tène neckring. The surface of the porous, grained filler in the join shows the same composition as the adjacent parts.

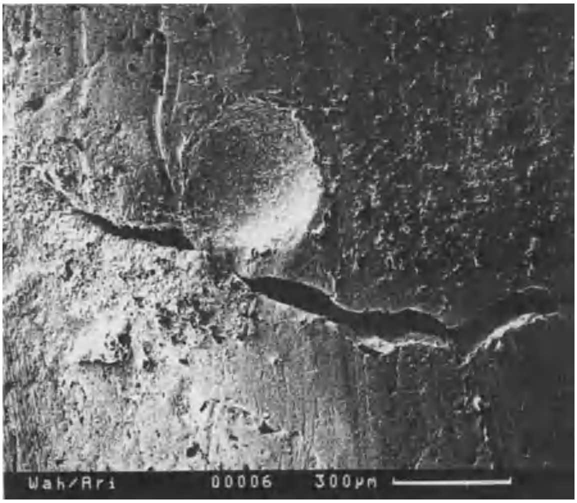

Fig. 12: Waldalgesheim (Germany), Late Early La Tène penannular bracelet. Friable crack near the welded join between a massive and a hollow part.

Reinheim is the latest La Tène A example of Celtic gold jewellery. The most recent items analysed come from Waldalgesheim near Bingen and are eponymous for the Waldalgesheim-style of the La Tène B-phase. They date from the last third of the 4th century BC (Driehaus 1971, Jacobsthal 1944).

The great Waldalgesheim-torque, like all the heavily decorated La Tène-torques and -bracelets, was assembled from different parts. The assembly-groups of the two endings are cast, the tubular part of the neckring is hammered. As with the bonding-techniques, the traces of brazing with differently composed gold-silver-copper-alloys as solders can be identified. Such a solder has also been used to repair a casting flaw.

One pair of penannular bracelets was produced differently. Apparently each bracelet consists of three relief-decorated protruding parts, separated by two smooth tubular segments. All the ornamented parts were cast, bearing the decoration in rough; they were finished by punching, scraping and engraving. The plain segments are hammered. The massive hammered and the hollow cast parts are joined together by hammer-welding. In other words, the parts were heated until red heat and hammered together without reaching a fluid state. The traces of hammering are clearly visible. One of the bracelets shows a crack near the bonding area running in transverse direction (Fig. 12). This crack may well have been caused by shrinkage as a result of stress - a phenomenon, which would not fit with any bonding technique other than welding.

Finally, the Waldalgesheim grave contained a twisted bracelet, assembled from three thick wires which were joined together with a lot of filler metal (Fig. 13). The composition of the filler alloy does not differ significantly from the gold alloy of the three wires. It can be regarded as practically identical. Thus, the bonding technique is almost the same as observed on the Reinheim gold torque: bonding has been done in the liquid state with the aid of additional material, which is identical or nearly identical with the base material. A liquid phase bonding technique has also been used to make the transverse join (Fig. 14). In our opinion "welding" is not an inappropriate term by which to designate this technique.

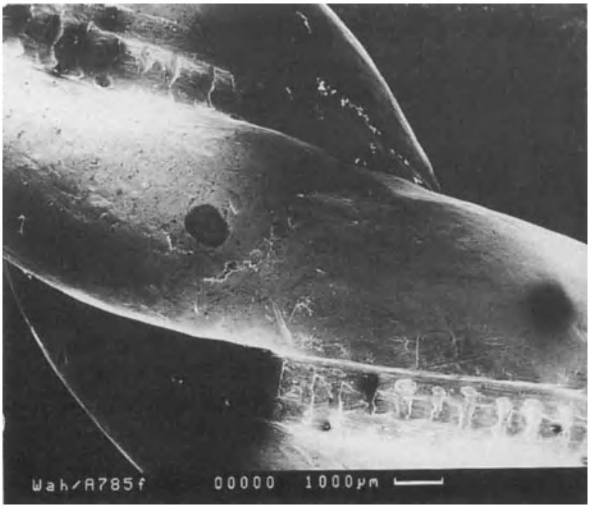

Fig. 13: Waldalgesheim (Germany), Late Early La Tène twisted bracelet. Three twisted wires are joined together by welding, the protuberant seams are incised. Transversal join in the middle of the photography.

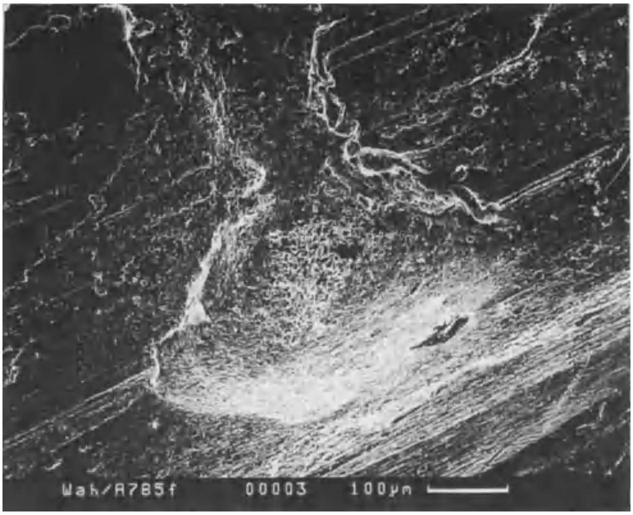

Fig. 14: Interior of an incision showing the porous grained structure of the filler metal.

5. Historical conclusions

To sum up, we can state that in the manufacture of Celtic gold jewellery high temperature bonding techniques played no role until the Late Hallstatt period, when many imported objects - and techniques (like the famous clay-brick baskin walls of Heuneburg IV) - reflect the increasing contacts between the Celts and the Mediterranean world. According to Eluère's results, the earliest technique used by the Celts is reaction soldering with one Hallstatt D1 example. Hard soldering was used from Hallstatt D3. The earliest traces of welding identified date to the beginning of La Tène A on the middle Rhineland, and a developed welding technique with filler metal occurs from late La Tène A until La Tène B in the Saar-Rhine region.

The introduction of hot bonding techniques to the Celts north-west of the Alps took place in a relatively short span of time from Hallstatt D1 to Hallstatt D3. Burgundy with Upper Alsace seem to have been the first centre to produce gold ornaments using these new techniques. The goldsmiths worked for the Celtic upper class, which surrounded itself with South Italian Greek and central Italian Etruscan luxury goods. Celtic cart wrights supplied this élite with luxury vehicles following Italian models. It seems plausible then to postulate that Celtic craftsmen went on trips to Italy and brought back a collection of new technologies. But there is a strong alternative interpretation.

In Etruria various bonding techniques were in use simultaneously. A travelling Celtic goldsmith would have been able to learn them all and to bring them back on one and the same occasion. But as we know, in the Celtic world reaction soldering, hard soldering and welding were successvely introduced. Reaction soldering is the easiest to manage, but demands sophisticated knowledge. The later introductions - hard soldering and welding - occur in increasing order of difficulty.

It would be illogical to conclude from these facts that Celtic goldsmiths acquired all their technological knowledge from the Etruscans. Rather, the data suggest a technology transfer early in the sixth century BC, which brought reaction-soldering to the Celts, followed by an independant development of higher levels of mechanical skill such as brazing and welding. Only the fourth century BC more sophisticated welding technique with additional material may be suspected of being the result of new contacts between Celtic and Etruscan craftmen during the time of the Celtic migrations into Italy. In support of this should be mentioned that style and iconography of the Reinheim torque and bracelet reflect Etruscan models of the fifth century, while the whole repertoire of the Waldalgesheim style could not have been created without intimate knowledge of fourth century Italo-Greek tendril patterns. But this hypothesis of a new technology transfer in the fourth century must remain unproven in our current lack of technological knowledge of Etruscan gold jewellery of this time.

Acknowledgments
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Chapter 5

GOLD WIRE TECHNIQUES OF EUROPE AND THE MEDITERRANEAN AROUND 300 B.C.

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ABSTRACT. The period around 300 B.C. is of the greatest interest for a review of the evolution of gold wire techniques in Antiquity. Such a study reveals many things about the dissemination of technical knowledge in the ancient world, about the levels of development of different jewellery traditions and design centres, and about the sometimes surprising distribution patterns of individual techniques. It is not possible to deal with all categories of gold wire in the space of this paper; only the most characteristic and frequently used types of wire of the period are presented.

1. Plain round wires

Plain round wires are the commonest of all the types; they are of three kinds. The oldest way to make a round wire was probably to cut strips from sheet gold, and then to hammer them gently or to roll them between two flat surfaces, perhaps of stone or fired clay. The process was discovered by Egyptian goldsmiths about the end of the fourth millenium (Aldred 1976, 85-87; Ogden 1982, 46-52; Nicolini 1990, 100). Solid gold wire was still employed in 300 B.C. all around the Mediterranean and Western Europe, particularly when the craftsman needed solidity, for instance for the pins of fibulae, hooks, links, and all kinds of rings. There is no evidence for the making of any such gold wire in ancient times by drawing as would be done today. Specialists believe that parallel, longitudinal scratches on the plain wires are the result of modern manufacture in a die. On the other hand, some of these wires appear faceted by the hammering, with the facet edges blunted by a smoothing process (Fig. 1) (Hackens 1976; Formigli 1985, 92-97). How this smoothing was done is still unknown; the use of bored stone beads or pierced clay or bronze plates remains to be proved. Smoothing implies only a hole with a diameter equal to or slightly larger than the wire section pulled through it, unlike the one in a (modern) drawplate which is always smaller (Nicolini 1990, 108-109).

In the Mediterranean area, the type of plain round wire most used is hollow strip twisted wire, invented around the middle of the second millenium B.C., probably also in Egypt where examples are known from the New Kingdom (Nicolini 1990, 110-112; Aldred, 1976). The technique is very simple: a narrow strip is coiled around a rod to produce the basic hollow strip twisted wire (Fig. 2a); the rod is then removed (Fig. 2b). The wire is then further twisted to tighten so as to reduce the visibility of the helical seam (Fig. 2c), and finally threaded through a drawplate. The result is a hollow round wire with the advantage of a light

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weight, and characterised by a regular section and an irregular helical seam bent out of shape by the drawing process (Fig. 2d). The section of such a wire shows a more or less tight spiral (Fig. 2e). This type wire was often used in the decoration many kinds of jewels, for example on an earring from Ptolemaic Egypt (Fig. 3a-b). A wire wound rightly around a rod forms the body of the piece.

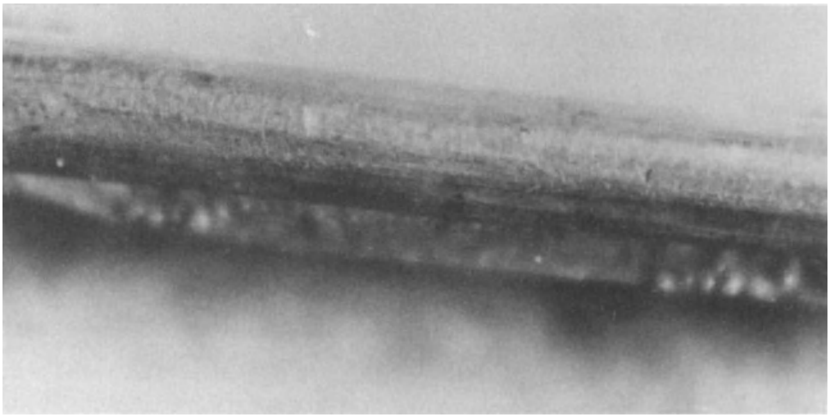

Fig. 1: Detail of an Etruscan fibula pin showing facets formed by hammering and probable effects of smoothing. 1.4 mm section. After Hackens 1976, Pl.iv.

The third way of making round plain wire is to twist a strip or a wire of square or rectangular section about its own length. This block twisted wire (in French *fil plat tors* or *fil carré tors*) is one of the oldest types in the history of gold filigree with examples from Early dynastic Ur dated to about 2700 B.C. (Ogden 1982, 49, Figs. 4-27, 4-28; Nicolini 1990, 109-111, Pl. 14a, 221a-c). In all probability about the middle of the second millenium B.C., goldsmiths hit upon the idea of drawing or smoothing this kind of wire to convert it into a round plain wire. By the 4th century B.C. this block twisted wire is widely used. It also shows a helical seam, but this is usually narrower than in the previous type. A good example is given by some Iberian earrings (Fig. 4) (Nicolini, 1990, 287, No. 54, Pl. 40a-b). However, it is very difficult to appreciate the difference between hollow strip twisted wire and block twisted wire without examining a cross-section. Block-twisted wire has an H-shaped cross section when starting with a flat or rectangular section strip, and in a section in the shape of cross *moliné* when the original wire has a square section. The reproduction of this wire is also very easy (Fig. 5); it is heavier and more solid than the strip twisted wire. It is used, for example, in the period considered, for chains or hooks (Ogden 1982, 57-59; Nicolini 1990, 126-128, Pl. 223). Sometimes both kinds of wire are used for filigree in the decoration of the same piece, without any apparent reason for choosing them. In the head of a bracelet from Greece at the Louvre Museum, it is very clearly seen that both techniques are present (Fig. 6): block twisted wire and hollow strip wire have been used to make the spiral and curls. It can also be noted the poor quality of the work despite its Greek origin but, because of this low quality, the two classes of wire can be recognized.

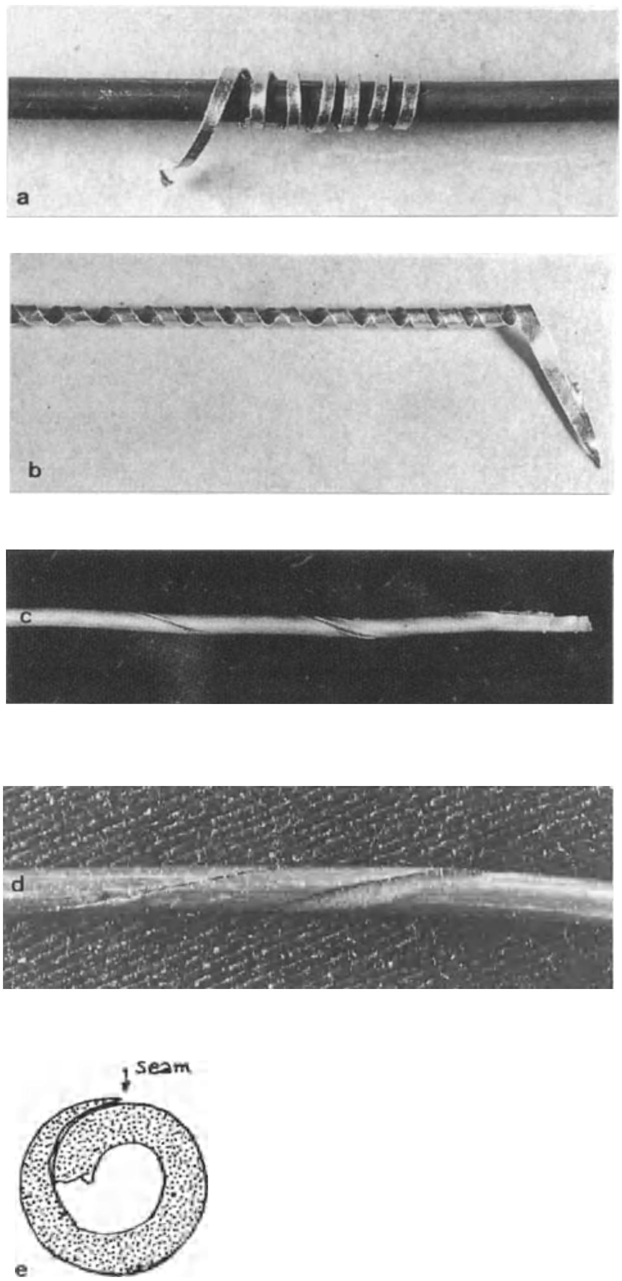

Fig. 2: Reproduction of hollow strip twisted wire making. a) strip rolled around a rod; b) the same before tightening; c) tightened wire; d) the same drawn with a characteristic irregular seam; e) section.

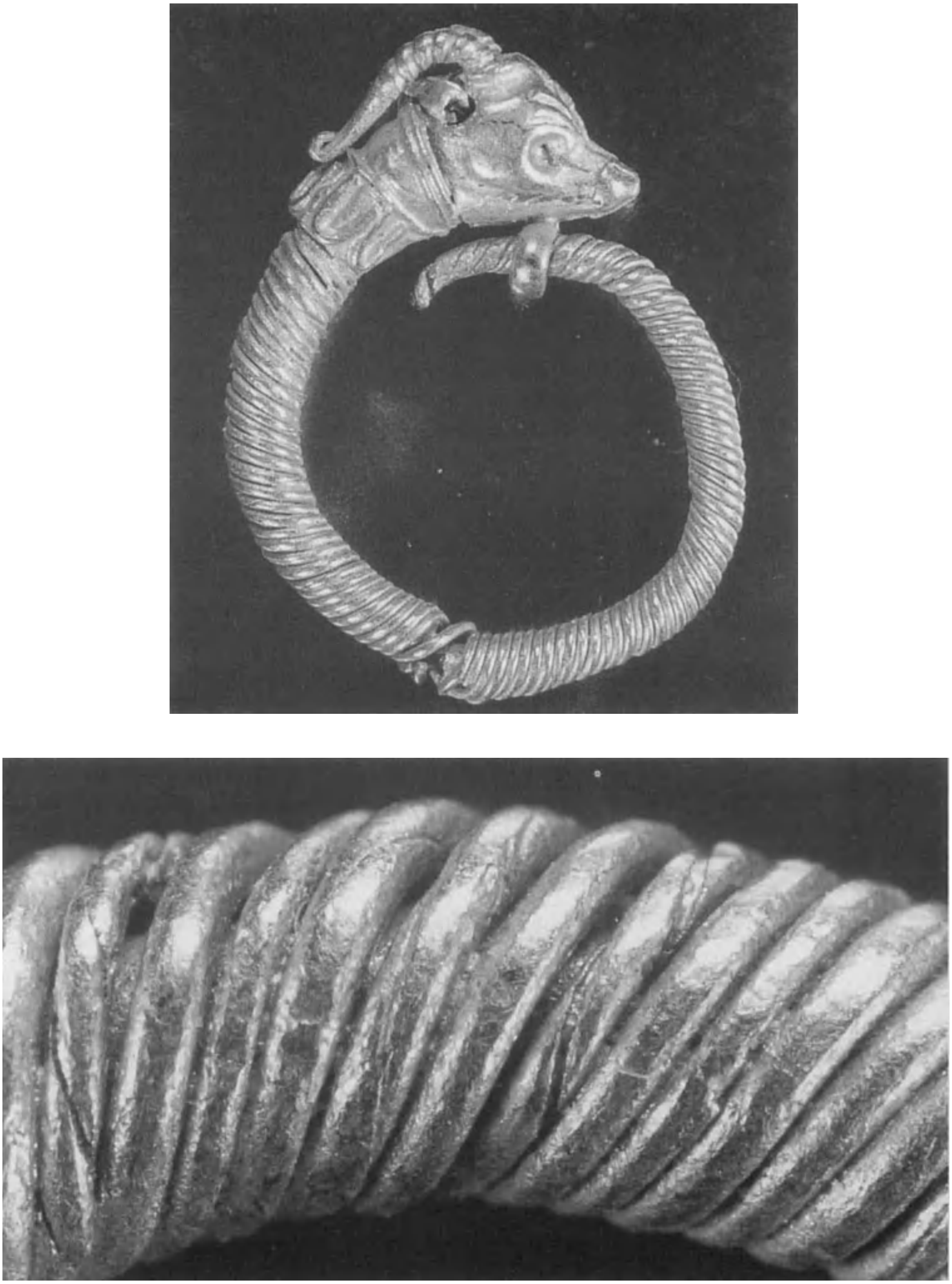

Fig. 3: a) Egyptian earring. 3rd century B.C; b) detail showing a drawn hollow strip twisted wire with irregular helical seam. Musée du Louvre.

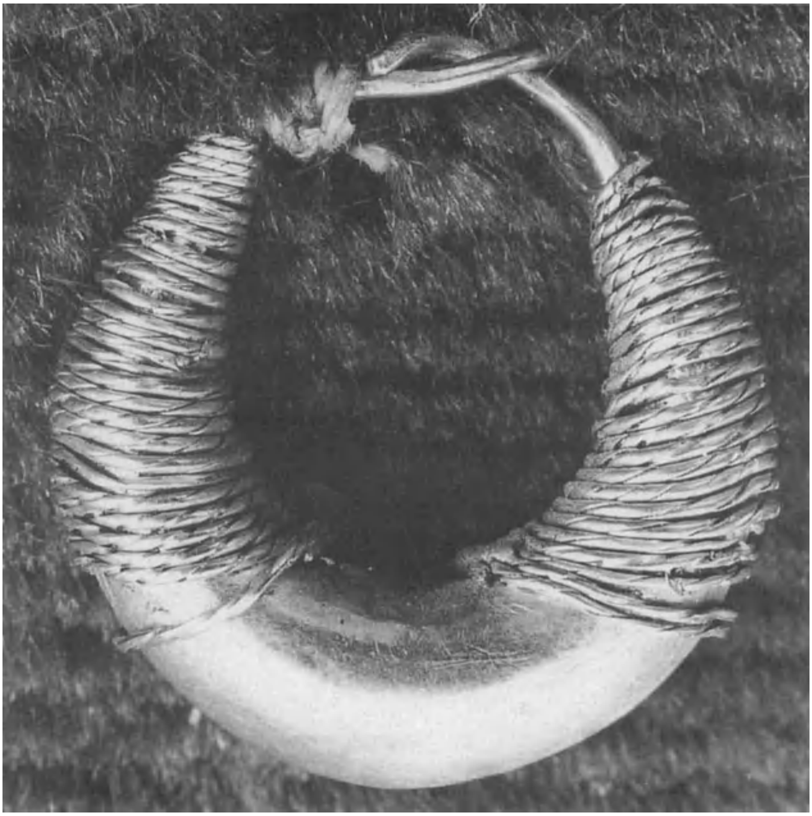

Fig. 4: Iberian earring from La Guardia. 4th century B.C., Museo de Jaen.

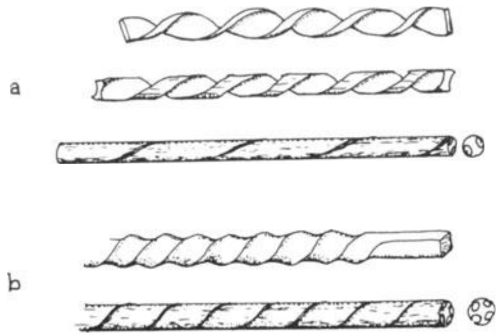

Fig. 5: Reproductions of block twisted wire a) from a block twisted strip; b) from a twisted square section wire.

Fig. 6: Greece. Ferrule of a bracelet head. 3rd century B.C. Louvre, Paris.

2. Wrought round wires

More interesting are round worked and decorated wires, usually "spooled" and "beaded" types (Fig. 7a-e).

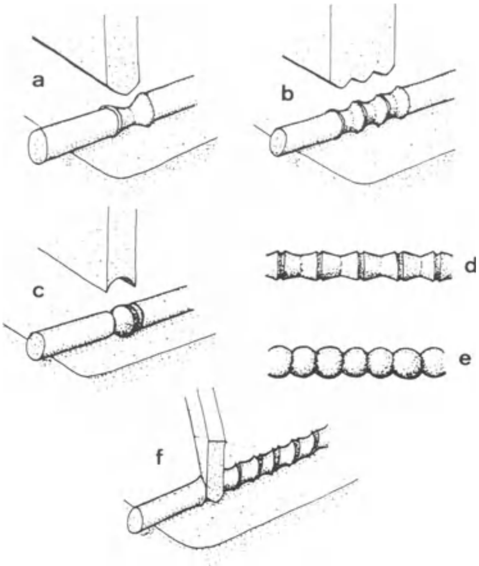

Fig. 7: Schematics of spool and beaded wires. a) process using a single edge tool; b) a triple edge tool; c) making a beaded wire with a fluted tool; d) spooled wire; e) beaded wire; f) oblique spooled wire.

The methods of making them are now well-known. Spool wire is produced by rolling a wire of round section - solid or block twisted wire - under a sharp or blunt edge tool, to produce around the wire a groove with a V- or U-section between two ridges (Fig. 7a). A rib of variable width appears between the ridges flanking neighbouring grooves or "spools" (Fig. 7b, d). The use of a multi-edged tool was one means of improving efficiency (Fig. 7b) (Ogden 1982, 52-55; Nicolini 1990, 120-21, Pl. 221). It was also possible to roll the wire obliquely under a single-edged tool (Fig. 7e). This technique, perhaps invented by the Etruscans at the end of the 6th century B.C., was most used in the second half of the 4th century B.C.. Particularly prominent are the jewels of Tarentum, in which very tiny oblique spool wires form palmettes or foliate patterns (Fig. 8) (Ogden 1982, describing it as a "spiral groove wire", 52-55; Nicolini 1984, 118-121; 1990, 120-21).

Fig. 8: Tarentum. Detail of a diadem. Around 300-280 B.C., Museo Nazionale Taranto 22.406.

In some pieces the spool wires appear unfinished. Very light spiral marks made with a single edge tool next to sections of finished wire, are further evidence of the methods described above (Fig. 9). In the same way, it was possible to produce beaded wires with a tool with a longitudinal flute between two sharp edges (Fig. 7c, e). However, various combinations of these wire types occurred and were perhaps made with hybrid tools as well as with flute and edge tools. The most elaborately ornamental wires are also to be found on Tarentine jewellery. Among many other varieties it may be distinguished "olive-shaped" wires made with a double groove/triple edge tool producing an olive shape between two lentoid beads. The result is a kind of rosary where "olives" alternate with pairs of lentoid beads can be seen on a diadem from Canosa near Tarentum (Fig. 10) (Nicolini 1984, 122-25, No. 54).

Fig. 9: Greece (?). Brooch. 3rd century B.C. Detail showing unfinished spooled wire, bottom left and right.

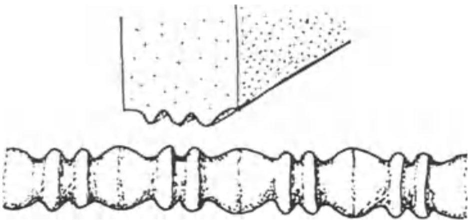

Fig. 10: Tarentine olive-shaped wire, from a diadem from Canosa (Puglia). A seam resulting from the making of the wire is visible on each "olive", Museo Nazionale Taranto 22.437.

Certain wrought wires are hollow. In a finger-ring of the 4th century B.C. from Thespiai (Boeotia), the bezel is held on each side by a short length hollow spooled wire (Musée du Louvre, No. Bj 1131, see Coche de la Ferte 1956, Pl. XVII.2-3). These very rare hollow ornamental wires are perhaps a Mycenean invention of around the middle of the second millenium B.C. (for a discussion of an example from Tutankhamun's tomb and possible earlier Mycenean types, see Nicolini 1990, 121). They can be found on Etruscan jewellery of the orientalizing period, in the first half of the 7th century B.C. (Cristofani and Martelli 1983, 594, No. 28), and later (see Quillard 1987). It is not very easy to find an explanation for such a technique. Some might be made from a hollow strip-twisted wire, which remained hollow after rolling under the edge tool. But the Egyptian one (and Celtic examples, see below) seem to be made from a strip worked into a die, perhaps of ceramic impressed with a spooled wire. It was then possible to make a half- or full-section wire by progressively working the strip into the die with a blunt cushion punch, moving the tool from one edge to the other so that the metal curls up (Fig. 11). Tubes with a diameter of about 7 mm seem to have been made this way on a bracelet from the burial at Psusennes at Tanis, 21st Dynasty, ca. 1000 B.C. (Andrews 1990, 156, Fig. 137).

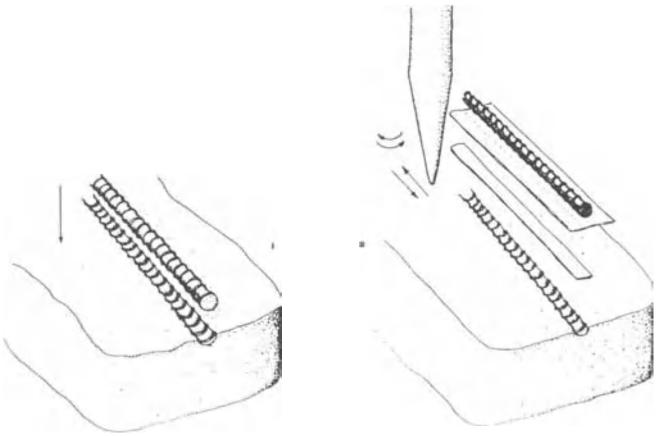

Fig. 11: Hypothetical method for manufacture of hollow spooled wire. A narrow strip is used for half wire, broad strip for full wire.

This kind of hollow wire in fact often has a rather large cross-section, usually more than 1 mm in diameter: 1.6 mm on the Thespiai ring, 1.5 mm on the Etruscan pin, 1.3-1.5 mm on the Celtic torc mentioned below (Joffroy 1969, Duval 1977).

The author has not yet placed much emphasis upon the Celtic areas of Europe around 300 B.C. Wires are seldom to be found in the gold Celtic jewellery at this time. It seems that the Celts did know all the kinds of round plain wires mentioned above from Greek, Etruscan or Iberian jewellery (Eluère 1987). However, their own ornamental wires raise some questions. On the torc from Vix, nowadays held to be a Celtic production of about 500 B.C. (Eluère, 1990, 21, Pl. 13; Eluère et al. 1989), a good example of beaded wire can be found, which is among the oldest in the Celtic world (Fig. 12a).

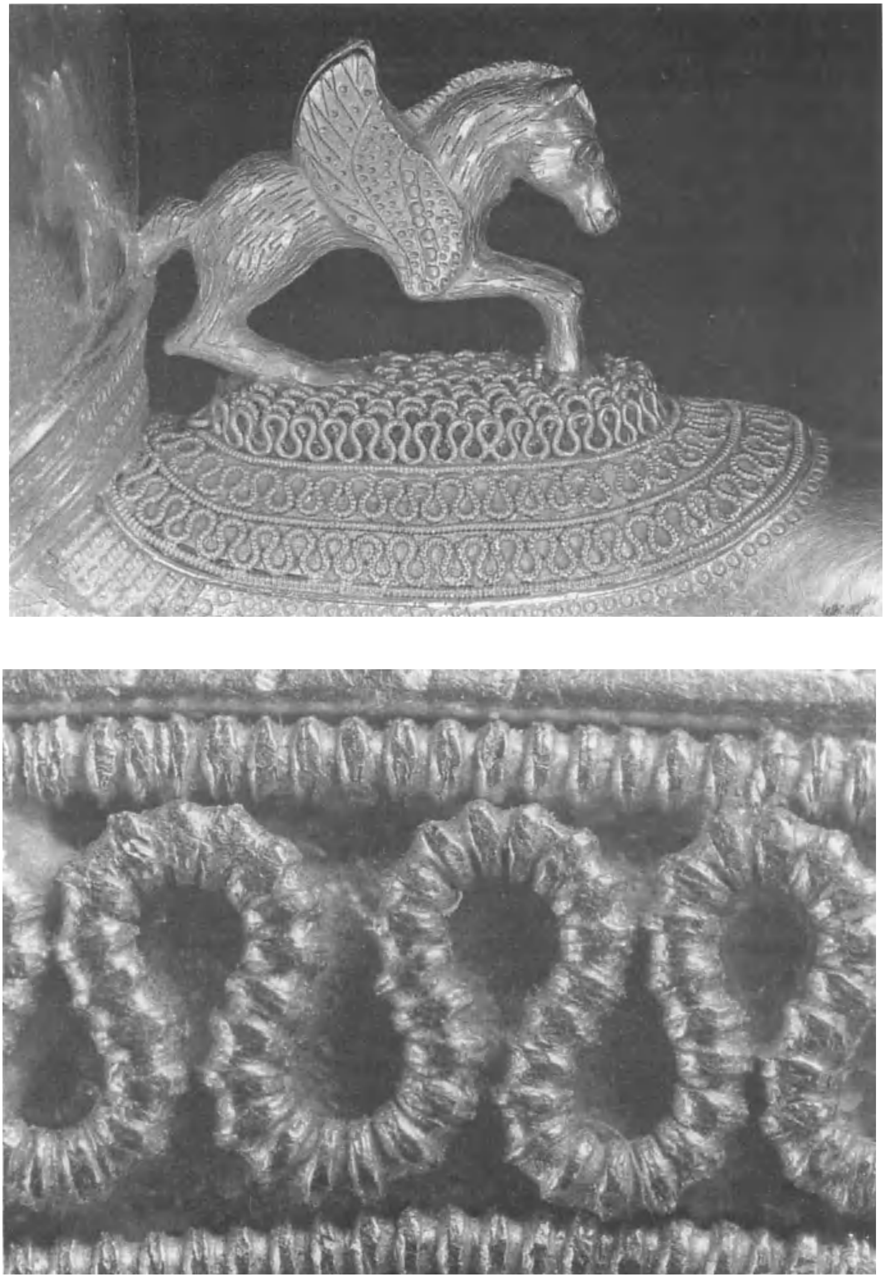

Fig. 12: Vix (Cote d'or, France). Torc, around 500 B.C. a) detail. b) detail of beaded wire, diameter 0.4 mm. Repair in the upper left corner is evidence for use of a triple edge tool. Musée de Châtillon-sur-Seine.

This wire, 0.4 mm in cross-section, is probably made with a triple edge tool: various repairs here and there show that this sort of tool was indeed used (Fig. 12b). Celtic goldsmiths, and therefore their customers, were fond of this unusual wire, termed *fil a pirouettes* in French. It is found on the 4th B.C. century helmet from Agris, in the filigree work of the *paragnathis* (Fig. 13) (Eluère et al. 1987), and, with a somewhat looser treatment, on a 1st century B.C. torc from Mailly-le-Camp (Joffroy 1969, Duval 1977, 180, 273, Fig. 398) (adjacent to the spooled wire) (Fig. 14). From the 4th century B.C. onwards, or even earlier, skeuomorphs of the same kind of wire rapidly grow in number on Celtic objects. Such imitations occur in relief on the same helmet from Agris (Fig. 15), and in intaglio on the torc from Mailly-le-Camp. In the case of the Agris helmet, the process is noticeably more complicated. Reliefs produced by wire imprints on the reverse side are rectified with a tool to isolate each bulge of the wire imitation. Tool marks are visible inside the patterns (cf. Eluère et al. 1987).

Hollow spooled wires are also present on Celtic jewellery. The oldest known example is perhaps on the Vix torc, around the terminal stud (cf. Eluère 1987). It seems to be a half-section wire. It is impossible to find any explanation for using of this hollow wire so close to the solid one around the base of the winged horse (Fig. 12a). Inexplicably, it is later found on a torc from Civray-en-Touraine (Duval and Eluère 1987), with a 1.3-1.5 mm section, soldered around each terminal (Fig. 16).

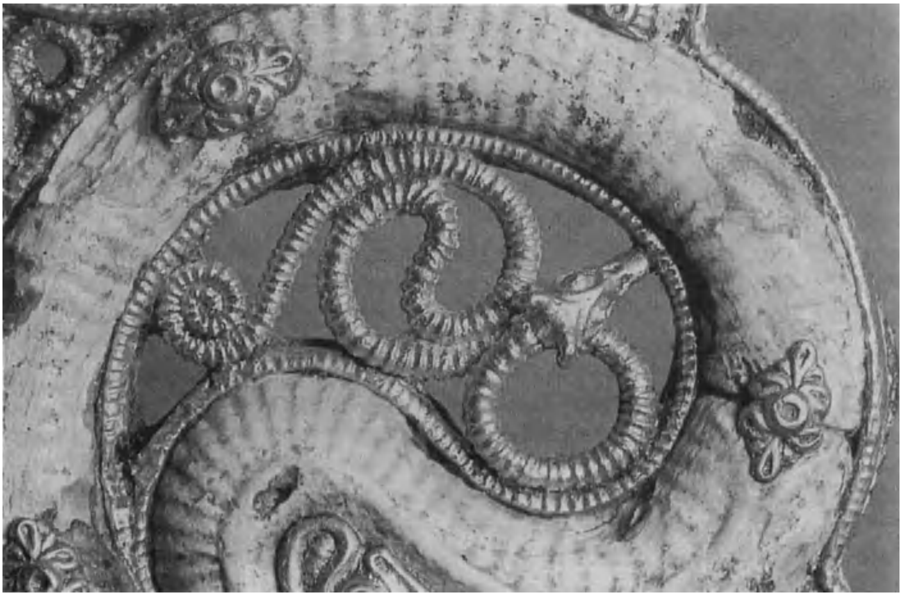

Fig. 13: Agris (Charente, France). Helmet, 4th century B.C. Detail of paragnathi. Beaded wire/fil a pirouettes, 0.6 mm diameter section. Musée des Beaux-Arts, Angoulême.

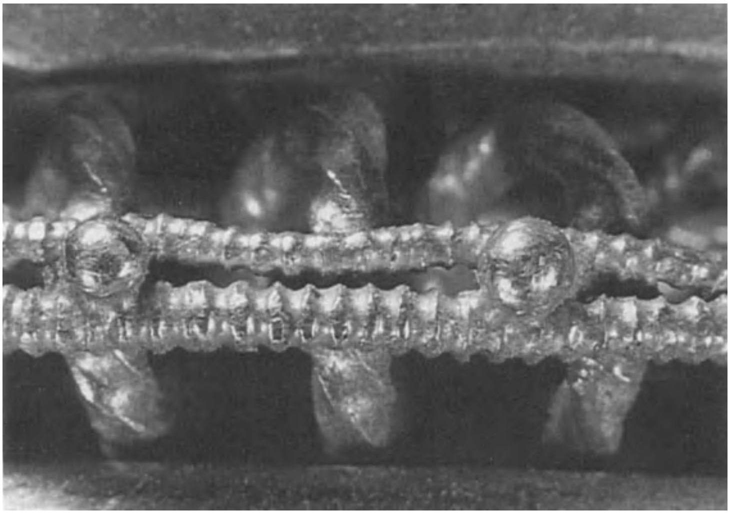

Fig. 14: Mailly-le-Camp (Aube, France). Torc, 1st century B.C.. Fil a pirouettes with spooled wire close by; 1.0 and 0.7 mm diameter sections. Musée des Antiquités Nationales, Saint-Germain-en-Laye 82988.

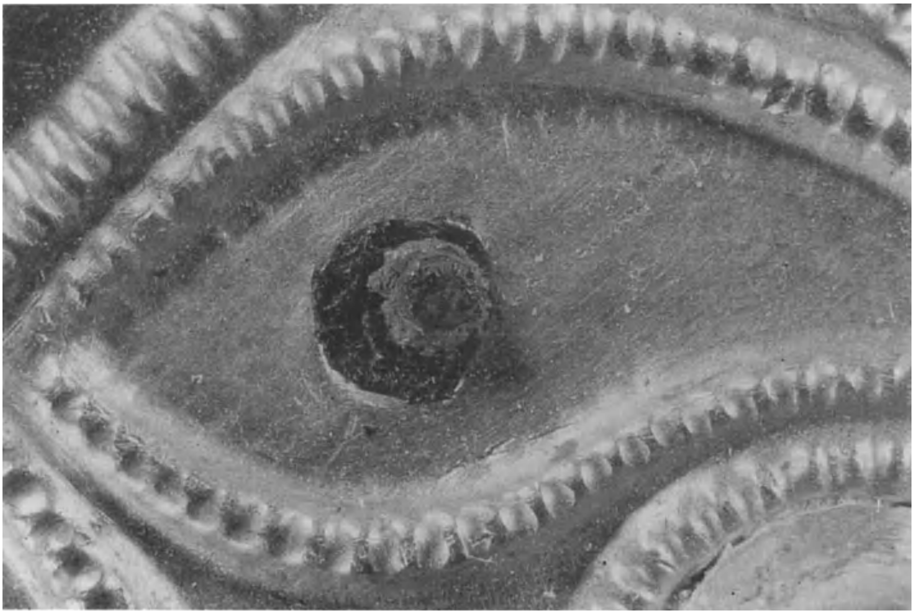

Fig. 15: Detail of the helmet from Agris (cf. Fig. 13). Embossed imitation of spool wire.

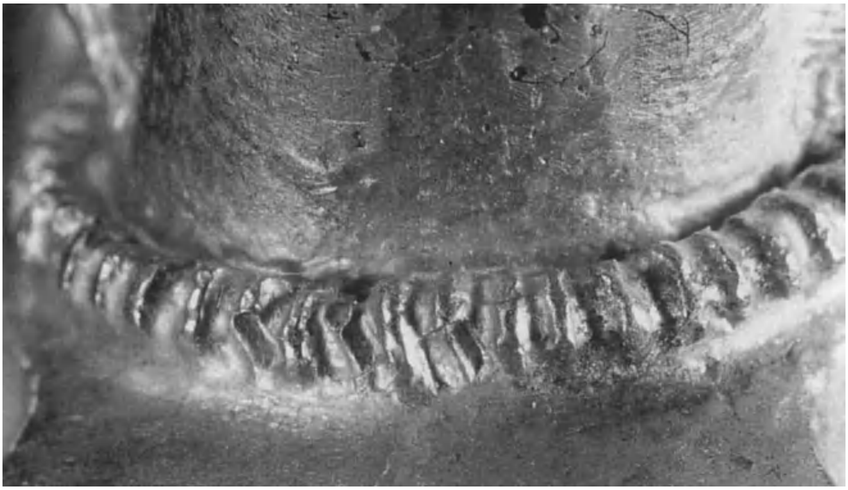

Fig. 16: Civray-en-Touraine (Indre-et-Loire, France). Torc, around 200 B.C. Detail, hollow spooled wire, 1.3-1.5 mm cross-section, around a terminal. Musée des Antiquités Nationales, Saint-Germain-en-Laye.

3. Flat wrought wires

The last section in this short paper is about a rather strange category of wire: flat, wrought wires. This expression is used to denote a flat wire or a very narrow strip with diagnostic marks at the edges, normally used for stone settings such as bezels or collets (terms taken from Untracht 1985, 599-603). However, there is a problem of vocabulary about the term, as with many terms relating to ancient jewellery. The author has coined in French the expression *bate ouvragée* (Nicolini 1990, 117, 123-4, Pls. 220k, 222f-h; 1993). This can be translated into English as "wrought bezel" or "wrought collet" (for other terms see Untracht, 1985, Fig. 13-40), but the expression "flat wrought wire"- *fil plat ouvragé*, is preferred here for both technical and historical reasons.

The first known example of flat wrought wire is Iberian, but it was not used as a bezel or collet around a stone; it is simply a filigree ornament on the rim of an articulated diadem (Fig. 17) in the Evora treasure, dated to the second half of the 6th century B.C. (Nicolini 1990, 483-486, No. 240, Pl. 209a-b; Perea 1991, 154, 165). Several pieces of the same treasure have flat wrought wires as collets around settings of enamel or glass paste from the same period or a bit later (Nicolini 1990, 23-24, Pl. 113a-b; Perea 1991, 146-47, 162). In the absence of earlier examples from Iberia or elsewhere, it is possible to say that the Iberians were the first to use these flat wires, and therefore that they were their inventors. The process is very simple, consisting of the flattening or hammering a block twisted wire. The oblique fluted marks on the edges are the remains of the original form of the block twisted wire (Untracht 1985, 599-603). On the flat faces of the wire oblique residual seams appear (Fig. 18a). Two hundred years later, during the 4th century B.C., the same Iberian goldsmiths at Cadiz hit upon the idea of producing flat wrought wires from beaded or spool

Fig. 17: Evora, Sanlucar de Barrameda. Diadem. 6th century B.C. Detail of triangular point showing a flat wrought wire soldered onto the rim. Museo Arqeologico de Sevilla.

wire (Fig. 18b). They then systematically used this type of wire for bezels for enamel settings on medallions or earrings, where it can be seen both the original spooled wire and flat wrought wire made by hammering the same wire (Nicolini 1990, 304, No. 77a-b, Pl. 53a-c; 460-65, Nos. 218-19, Pls. 145d, 147a, Colour Plate 7) (Fig. 19). Modern reproductions of these flat wires are very instructive. Better results are obtained with a regular square section block twisted wire or a beaded wire made with multiple edge tool (Fig. 20).

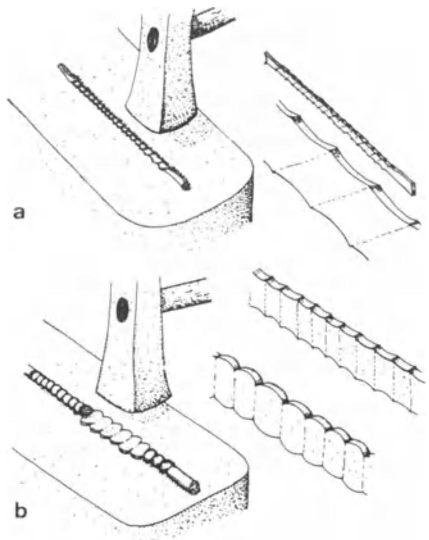

Fig. 18: Manufacture of flat wrought wire. a) from a block twisted wire, b) from beaded and spooled wire.

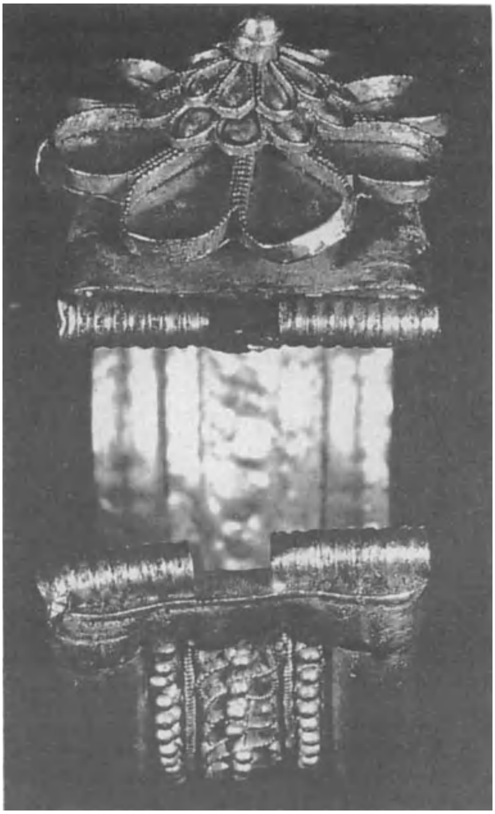

Fig. 19: Cadiz. Earring. 4th century. Flat spooled wires used as bezels forming petals of a triple rosette; results of hammering a spooled wire visible at the bottom, parallel to the lines of granules. Cadiz, Museo de Bellas Artes.

Knowledge of these flat wires was disseminated across the Western and Eastern Mediterranean, except in the Celtic countries, from the 4th century B.C. onwards. Generally, they were used as bezels. In Carthaginian jewellery, some pieces of the end of the 4th century imitate the Iberian disposition of flat wrought wires to make rosette bezels on certain earrings in the same way as at Cadiz (Quillard 1987, 34-37, 153-57, Nos. 250-53, Pl.s XII-XIII). At the same time also examples of a method are found very similar to the Iberian one in Etruria. In a 4th century B.C. Etruscan earring from Chiusi they form a line of S's soldered edgewise on each side of the piece (Cristofani and Martelli 1983, 312, No. 243). This can be compared with opposed S and spiral patterns on an Iberian earring from Cadiz (Nicolini 1990, 303-4, No. 77a-b, Pl. 49a-b). On a bezel from a 3rd century B.C. earring from Vulci (Fig. 21) the same piece of wire can be found with both whole and flattened sections. In south Italian jewellery there are numerous examples of bezels made in this way. Important examples include settings in shape of a "Crown of Isis", with a mounted cabochon and two granulated doves on a base, on earrings from the Cabinet des Médailles (Nicolini 1993, 32, Figs. 14-15, n.19), at Tarentum (Nicolini, 1984, 167 No. 82), and at the Louvre (Coche de la Ferte 1956, 66, Pl.XXIV-2; De Ridder 1924, 21, 232-233, Pl. VIII), all probably from the 2nd century B.C.

Fig. 20: Scanning electron micrograph showing the edge of a flat wrought wire (modern reproduction), made from an oblique beaded wire. Separations between beads are still visible; parallel black lines are the remains of the original separations from before hammering.

Fig. 21: Vulci. Earring. 3rd century. Detail of ivy-leaf shaped bezel made from an oblique spooled wire visible on the jewel rim. Musée du Louve, Paris, Bj 298 C-118.

4. Conclusions

As a tailpiece to this survey, the importance to gold jewellery of technical studies should again be emphasized. Observation by macro- and microphotography, experimental reproductions in the workshop and compositional analyses are necessary for the understanding of the wide diversity of styles, each using specific techniques and excluding others. In turn, these styles reflect the different tastes of ancient peoples. However one should not assume, as others often do, that the technical style of one region is intrinsically superior to an other. As an example, there are very few gold wires in the Celtic world comparable with the Greek, Etruscan, Iberian ones, but the Celtic sheet jewellery is truly outstanding. Likewise, it is known for certain that Iberian goldsmiths were the first to invent or develop techniques which were later adopted by the Carthaginians, the Etruscans, and the Greeks, etc. The problem of diffusion routes and agents, of the identity and nationality of the goldsmiths remains real (For reviews of this question see Coche de la Ferte 1956, 66, Pl.XXIV-2; De Ridder 1924, 21, 232-233, Pl. VIII) in the absence of significant inscriptions. At the beginning of the 3d century B.C., a community of techniques and workshops appears with varied tastes according to their respective regions, linked by diffusion currents in many directions instead of perpetual influences from eastern workshops on western ones, or from the Mediterranean on central or western Europe. Things were more complicated. One may recognize some production centres or regions, and through a chronological approach, deduce a pattern of influences, but, above all, this must be done without any prejudice in favour of the superiority of any region or civilization. Everything has to be observed and then described without bias.

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Chapter 5

THE GOLD FROM ARRABALDE

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ABSTRACT. This paper shows a hoard of jewels, little known outside Spain, of great importance in the study of the Celtiberian peninsula society. Three characteristics make it an unusual find:
- It is one of the largest groups of gold and silver found in the Celtiberian area of the Duero river basin, where concealing of jewels and coins is frequent, and it is the one which contains the largest number of gold pieces.
- It represents a fairly complete range of the forms and techniques which define the gold and silver work of this geographical-cultural sphere.
- It contributes new data on the use and significance of certain adornments already known.

1. INTRODUCTION

The Arrabalde group is in fact made up of two treasures hidden, probably in the same circumstances, inside the same fortified dwelling: the Castro or Oppidum of Labradas (Zamora). The first treasure was found by chance in 1980, and its pieces scattered, although, fortunately, they were later recovered by the State. The rescue excavation performed some months afterwards was certainly unfruitful due to the vandalism of illegal treasure hunters who destroyed that part of the site in search for other treasures. It is only known that the context must have been the subsoil of the interior of one of the houses. It comprises about fifty gold and silver objects, without counting the 20 coins which, it seems, accompany them inside a rough pottery vessel. The total weight of the metal was 5 kilogrammes (Martin Valls and Delibes 1981, Delibes and Martin Valls 1982, Fernández Bolaños et al. 1982, Esparza 1986).

Seven years later, and at some distance from the earlier one, a second small treasure appeared, also by chance, i.e. not systematically searched for by the illegal treasure hunters. In this case the rescue excavation did not reveal any new structure which could connect the hoard with a habitation zone. It comprises

19 pieces of gold and silver, with a total weight of rather more than 2 kilogrammes. Among them a small silver crucible ingot must be highlighted.

This type of small treasure, composed of pieces in use, fragments, coins and raw material is fairly frequent in the peninsula, and all too easily there is a tendency to connect them with

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moments of social and economic insecurity during the wars between the Romans and the indigenous people (Raddatz 1969, Delibes and Esparza 1969).

The problem in the chronological study of Celtiberian gold and silver work in Spain is precisely this absence of archaeological context for this type of find.

2. ANALYTICAL METHODS

Quantitative analysis of the alloys has been executed with a Kevex Model 7000 X-ray fluorescence spectrometer (energy dispersive) in the research laboratory of the Museo de América (Madrid). The characteristics of the equipment and the methodology followed are described in detail in Rovira (1990 and forthcoming). For the statistical treatment of the data, the STATGRAPHICS V5.0 was used.

3. METALS AND ALLOYS

The group is formed of objects of gold, silver and composite pieces in which gold and silver parts are combined. Seventy-six pieces of the treasure have been analyzed. Of these, 46 are gold alloys and the rest silver (see the list in the Appendix).

As has been indicated, two hoards exist (Arrabalde I and Arrabalde II), but they can perfectly well be placed in one single group because no statistically significant differences exist in their central tendencies for gold, silver and copper, borne out by the study of their variances. Fig. 1 shows the main characteristics of the totality of the Au-Ag-Cu ternary alloys from Arrabalde. There are few examples with a purity of more than 95% Au, barely 4% of the total.

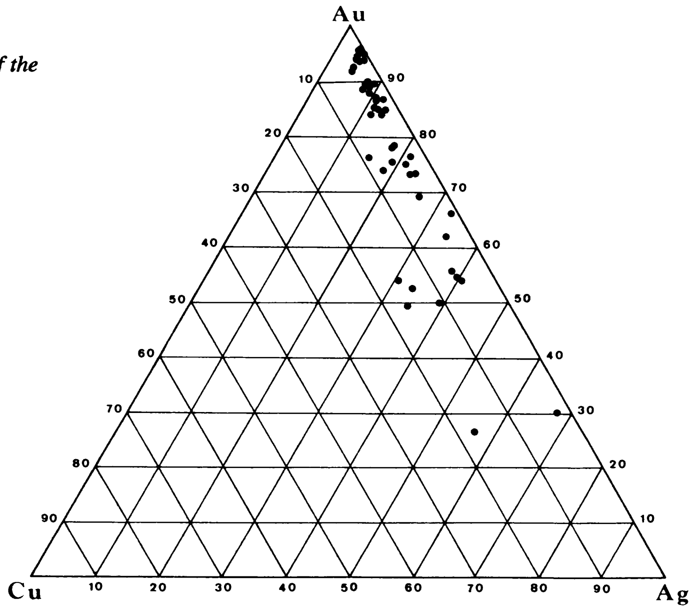

Fig. 1: Ternary diagram of the goldwork of Arrabalde.

The largest group, with 63.05%, is formed by the alloys which contain between 75% and 95% Au (18 to 22.8 carat). Finally, 8.7% of the analyses are of alloys with less than 50% Au.

With regard to the silver content, in no case are there values of less than 1% Ag. Most of the cases fall into the 1%-15% Ag range (56.5% of the cases), with a few disperse values of over 60% Ag.

With regard to the copper content, nearly 11% of the analyses give figures of under 1% Cu; 80.4% of the cases are in the 1%-5% Cu range and none exceed 20% Cu.

The cluster analysis of the ternary alloys of Arrabalde makes it possible to establish 8 groups according to the euclidian distance from their respective centroid (Fig. 2), having been confirmed by means of discriminant analysis that this is the best possible cluster from the statistical viewpoint. Table 1 summarizes their characteristic parameters.

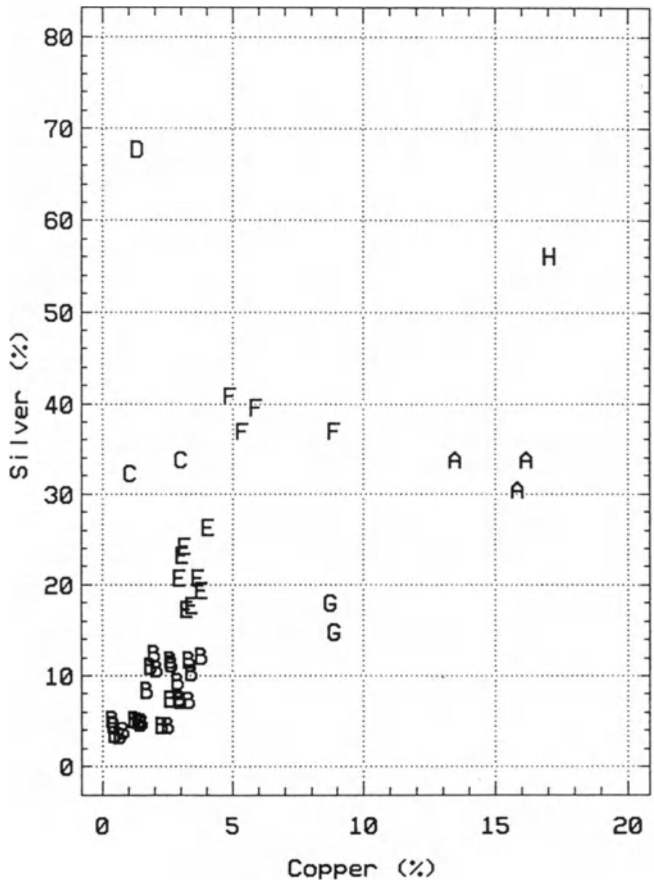

Fig. 2: Cu vs. Ag plot of the ternary alloys of the Arrabalde goldwork. The signatures refer to Table 1.

Table 1. Statistical values resulting from discriminant analysis. Letter in brackets in the group row refers to cluster in Fig. 2.

Group	1(B)	2(E)	3(F)	4(A)	5(C)	6(G)	7(D)	8(H)
Observations	25	8	4	3	2	2	1	1
Means:								
Gold	90.0	75.0	53.2	51.8	63.8	74.2	30.2	26.1
Silver	7.6	21.2	38.7	32.7	33.1	16.4	67.8	56.2
Copper	2.1	3.4	6.3	15.1	2.0	8.8	1.3	17.0
Std. Dev.:								
Gold	3.8	3.2	3.0	1.9	2.9	2.3	1.0	1.0
Silver	3.1	3.1	1.9	2.0	1.1	2.2		
	1.0	1.0						
Copper	1.0	0.4	1.8	1.5	1.4	0.1	1.0	1.0

Before entering into the evaluation and technological meaning of these groups, one must look at the raw material with which, at a certain moment, the gold craftsman started: the native gold. At present the fineness of this gold is not known for there is no analysis of its composition. On another occasion, the analyses of Chalcolithic objects and those from the early Bronze Age in the Peninsula were used as a reference parameter, it being understood that these were objects made with native gold (Montero and Rovira 1991, 9-10). According to the data cited there, the native Spanish gold does not surpass the limiting values of 25% Ag and 1% Cu.

According to this, only three pieces from Arrabalde would be made with native gold (PA1018, PA1023, PA1026) and all of them are in Group 1. To this group the pieces of greatest purity belong. Nevertheless, the high copper contents clearly indicate that it is not native gold in all the cases. Group 2, with a higher range of silver, although it is lower than 25%, does not include objects of native gold, by virtue of the copper contents. The rest of the groups, barely represented, but of great technological interest, are made up of artificial alloys.

Copper therefore becomes the key element in the discussion regarding the ternary alloys in Celtiberian gold and silver work in Arrabalde. Various hypotheses to explain the small amounts of copper in Groups 1 and 2 can be established:

a) The copper was added deliberately to compensate for losses in casting, or to increase the goldsmith's profit. Certainly, the addition of amounts of copper under 5% produces barely perceptible changes in the gold, either in its appearance or in its physical and mechanical qualities, but it meant a substantial saving in precious metal.
b) The copper passed into the alloy unnoticed (or in an uncontrolled way) due to the remelting of pieces in disuse together with native gold. The recycling of precious metals must have been then, as now, an important activity (see the composition of the PA1012 ingot), and the impossibility of refining the gold without silver loss made it necessary to re-use alloys of very variable quality. Thus, for example, the melting of a particular amount of native gold with low silver content with another amount of metal, like the ingot mentioned, could result in a Group 2 alloy.

c) The copper is the result of the mixture of high purity gold with another Ag-Cu alloy prepared beforehand. This makes it necessary to revise, even if only briefly and in a very partial way, the compositions of the numerous pieces of silver in the Arrabalde treasure (see the Appendix). As can be observed, the metal used in the silversmith's workshop is always a Ag-Cu alloy, in many cases also containing gold and lead impurities. The use of alloys of this type to reduce the gold content would bring as a result the low concentration of copper observed in the gold pieces.

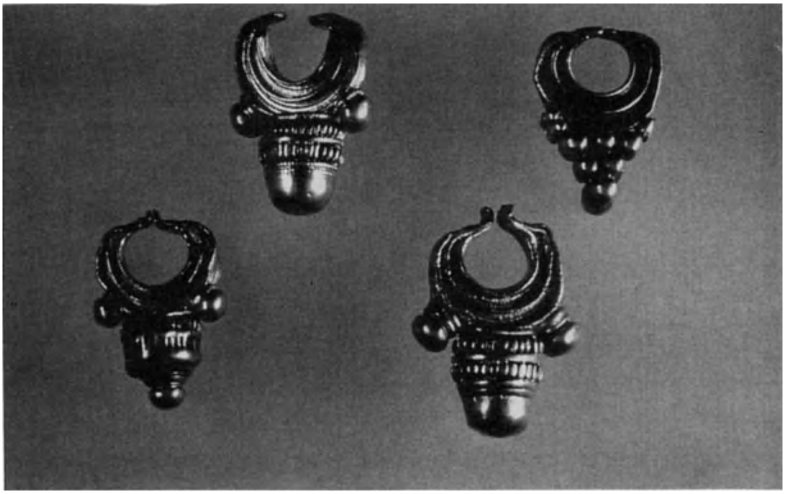

Fig. 3: Drop earrings.

At present, it is impossible to decide which of these hypotheses is the most likely or if all three of them occur, depending on individual circumstances. Further analyses of the gold and silver work of other regions are necessary in order to establish reliable comparative models. For the moment, and within the Peninsula, Hartmann's analyses (1982) of Celtic goldwork from the northwestern region of Galicia, show differences with respect to Arrabalde in the gold, silver and copper contents, the most outstanding being that approximately half the Galician jewels show a copper content of less than 1%. If we make comparisons with the series of Voûte (1991) of Swiss material, it results that, there too, more objects are probably made with native gold.

Perhaps the apparent singularity of the Arrabalde group rests more on the way in which its owner selected the pieces to form the treasure more than 2,000 years ago, than in the purely technological aspects of metals and alloys.

4. SHAPES AND TECHNIQUES

The Arrabalde group stands out for its gold jewellery, both from the technical viewpoint, and from that of design and ornamentation. Tackling its study, one should bear in mind that in the genesis of Celtiberian gold and silver work both the Mediterranean and Iberian components appear with great force. For example, the drop earrings with spindle-shaped body and pendant in the form of a bunch of grapes (Fig. 3) are shapes of old Mediterranean origin, but if one pays attention to their voluminous lateral development, one can see the baroque style of a new concept for a jewel (Fig. 4). The same happens with the acorn shaped pendants.

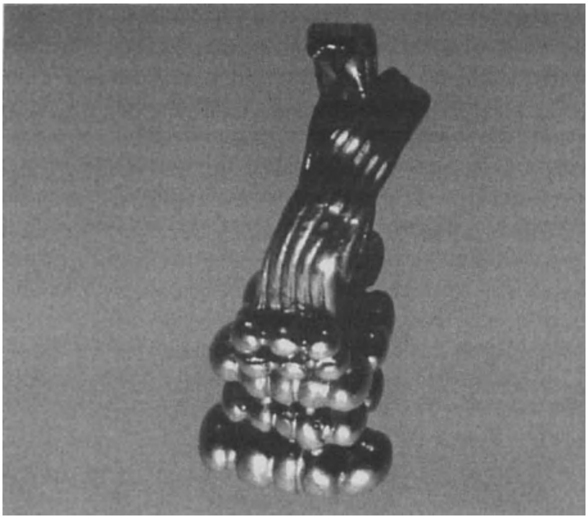

Fig. 4: Side view of a drop earring with a pendant in the form of a bunch of grapes.

Another ornament of Mediterranean origin and which was always somewhat timeless, is the spiral. In the case of Arrabalde these were made by plaiting three wires, either smooth or twisted. The ends are finished in a very rough shape of a horse's head: the muzzle is a rolled wire finished in a lenticular globule and the eyes a double spiral with two small spheres (Fig. 5).

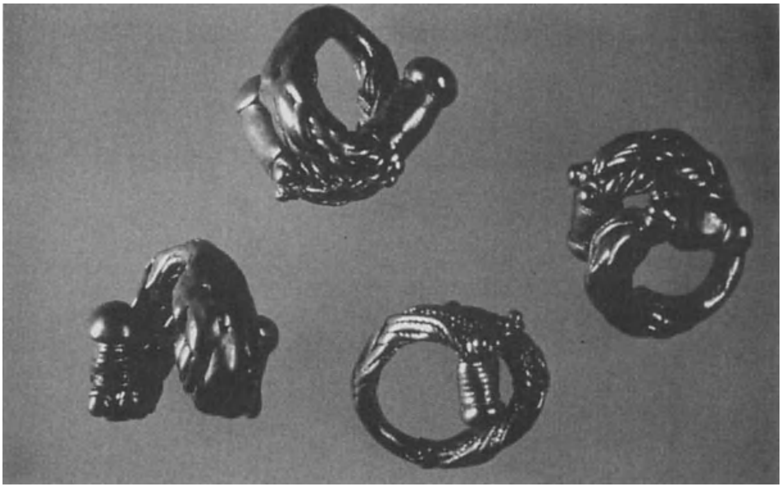

Fig. 5: Spirals with ends as a horse's head.

Completely new shapes also exist, such as the sheet ribbon rings with spiral development and the ends turned back (Fig. 6). Their characteristic is the simplicity of technical solutions with a maximum impact; any technique other than the beating of sheet has been avoided, and all the creativity is concentrated on the design. This same concept is repeated in another example where the gold sheets are interwoven as in basketwork.

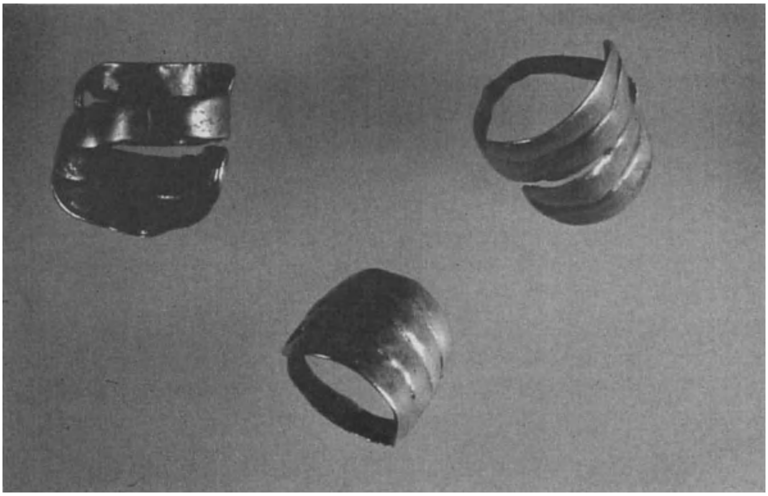

Fig. 6: Sheet ribbon rings with spiral development.

Celtiberian goldwork is one of contrasts. Together with sobriety, there is ostentation. The ring fibulae are pieces of a type which extends over the greater part of the Peninsula, from the 6th century B.C. to Romanization, although the variant which is of interest today restricts its chronology to between the middle of the 3rd century and the 1st. Century B.C. (Cuadrado 1960). They are very exceptional in gold. Those of Arrabalde stand out, first because of their size, second because of their original and baroque ornamentation, and third because they are manufactured in gold over a silver core (Fig. 7). None of the most sophisticated techniques known in that period has been spared in its decoration, in addition to other new ones such as that of covering a metal object with gold thread. The decoration in filigree and granulation is concentrated on some plates which hide the join between the ring and the bridge.

Another three fibulae of gold and gilded silver were found: two of symmetrical type, with ends turned back in acorn shape, and one of the hinge type.

The last characteristic which the authors wish to emphasize is conceptual, the rendering of figures in a schematic way. Two examples are given. The piece originally described as a belt, although, by its size, appears rather more like a bracelet, is made up of two plates articulated by means of hinges, and it is finished with a zoomorphic clasp (Fig. 8), probably a bovid, shown in face on. The anatomical volumes, perfectly conceived, were achieved by means of the die stamping of a plate, and it was highlighted with filigree wires and decorative granules. Although not frequent, the face on perspective is known on painted pottery from Numancia and in some other metal pieces which can be placed chronologically between the 2nd and 1st centuries B.C. (Esparza 1988-89), but the technical-conceptual perfection of the Arrabalde clasp is surprising.

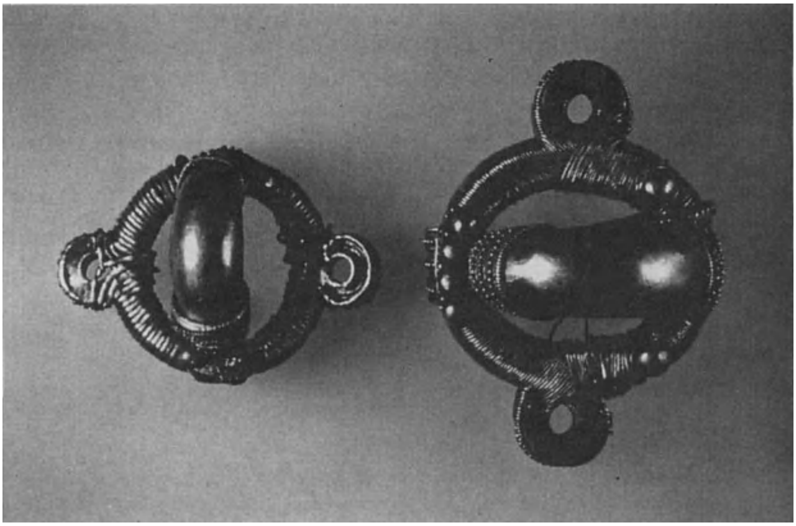

Fig. 7: Two ring fibulae.

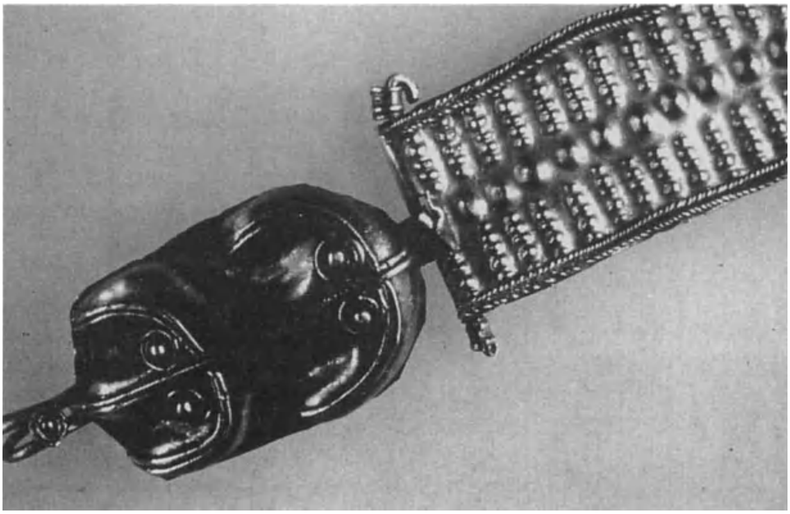

Fig. 8: Zoomorfic clasp shown in face on.

The second example of schematization is a pendant which in this case shows a head in round volume (Fig. 9). The general shape seems that of a bovid's skull. The muzzle is separated by means of a beaded wire; on the sides two circles of wire appear like eyes or horns, and also serve as suspension elements; and the front part is divided vertically by a motif of filigree very worn by use.

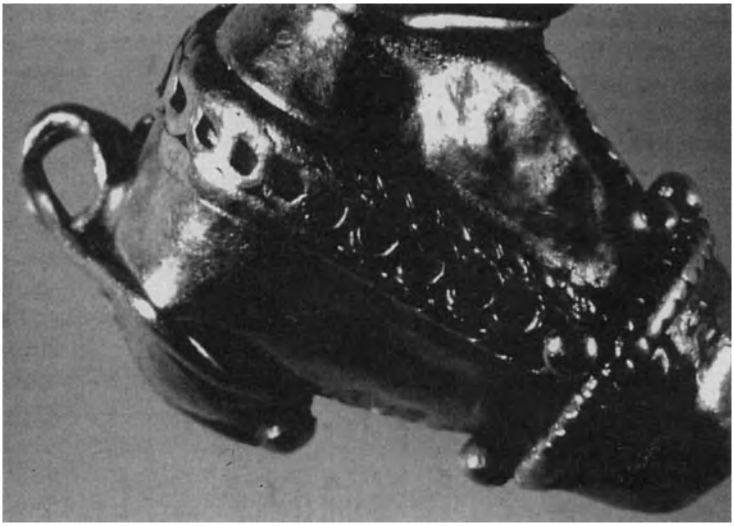

Fig. 9: Pendant in the form of a bovid's skull.

Limited space prevents here from examining the silver objects in detail, although they make up the bulk of this treasure's weight, but one can see some of the most representative types. The twisted rod torc is the type best represented, with 15 examples (Fig. 10). A twisted wire was usually intercalated between the rods, and the ends, finished in acorn shape, having a small object inside which serves as a rattle.

Fig. 10: Silver, twisted rod torc.

The second most characteristic type is the spiral shaped bracelet (Fig. 11). These are very voluminous pieces, made in thick sheet, generally of convex-flat section, whose ends are once more finished with very rough serpent's or horse's heads. The ornamental resources are limited to combinations of different punches, such as "half a pearl" in a space or in relief, chevrons or zig-zags filled with dots, St. Andrew's crosses, etc. (Fig. 12B).

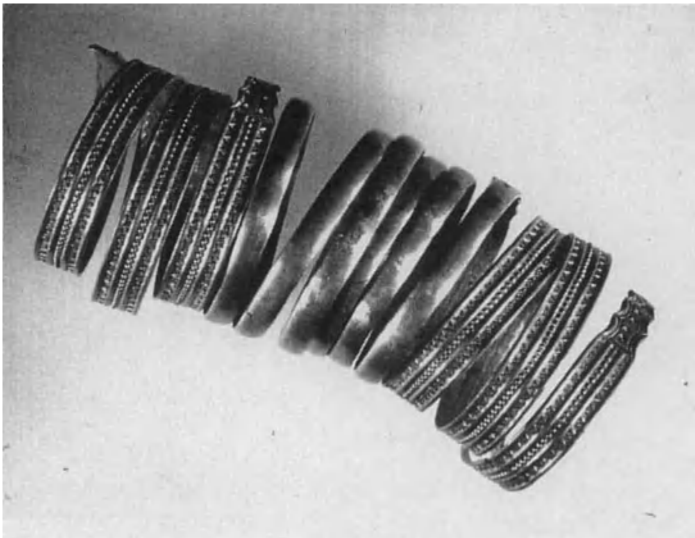

Fig. 11: Silver, spiral shaped bracelet.

Silver plate objects were also found. Two carinated vases, with the same type of decoration: a cord at the angle-change and a finish of dots on the edge.

The Arrabalde gold and silver work is a compendium of the technological resources of the time. The use of hollow and massive cast pieces is attested, although it is difficult to determine whether or not the lost wax technique was used in any of them. The shaping of the gold sheet was performed by means of beating and die-stamping, in those pieces of certain volume.

The gold wrapping of silver pieces is another resort which was solved in three ways:

- By means of wrapping with wire.
- By means of covering with plate.

The manufacture of pieces with low gold alloy is recorded, which look as if they were slightly gilded, but the analyses neither show amounts of mercury (usual in fire gilt processes) nor other surface enrichments. The white-yellowish colour is the natural one of this kind of alloy.

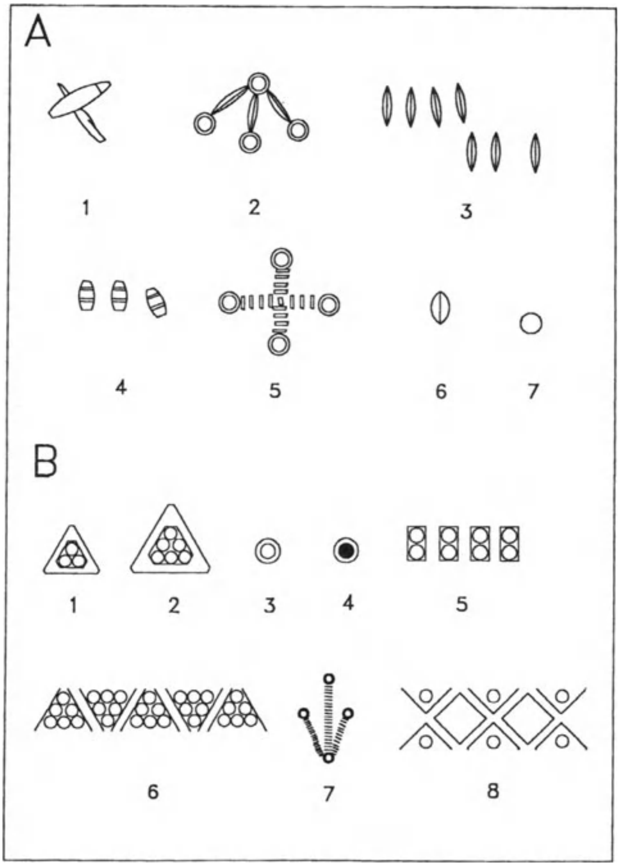

Fig. 12: A: Different marks stamped in the torcs;
B: different ornamental punches.

With regard to the ornamental techniques, filigree is used more than granulation, the latter almost always as an isolated motif. The use of large lenticular spheres, which cannot really be classified as granules, is frequent. Filigree is executed with various types of wire:

- Wire with round, hollow, section, made by means of the twisting of a strip; it has a fine helicoidal seam line all along its length. A characteristic arrangement of this wire is in the form of a spring, hollow or flattened; it also appears in the shape of a cord, and in that of an ear of wheat, formed by placing several of them together in parallel twists, on the surface to be decorated.
- Massive round section hammered wire; this has no marks showing the use of a drawing plate; its section is usually thicker than the previous type.
- Twisted quadrangular section wire.
- Beaded wire, of segments made with great regularity.
- Flattened strip or ribbon shaped wire.

Soldered joints are usually clean, although in certain cases, necks appear rather over-filled, for example in the union of the granules which form the bunch of grapes in the drop earrings.

Finally, the method used almost exclusively in the decoration of the silver pieces, such as torcs and bracelets, is stamping by means of different types of punches.

Possibly the most interesting feature of the group presented in this paper is the appearance of a series of marks stamped in some of the torcs (Fig. 12A). It has been possible to identify as many as seven, one of them repeated in two examples. Some are very basic, such as the careless tracing of a simple cross, or a notch (Figs. 13-14); but others are more elaborate and are made with several punches (Figs. 15 to 19). Their meaning is as yet undetermined, for it is the first time that this feature has been identified. Two hypotheses can be offered; that they were the silversmith's mark; or that they were property marks. Against the first option, is the fact that the gold or silversmith's mark would imply a craft organisation of guild type, or at least the status of a highly considered craftsman with the capacity of individualized artistic creation, the existence of which the authors consider would be very unlikely in pre-Roman Celtiberian society. Therefore, the authors are inclined, to think that these marks, while not an indication of the private property of an individual, at least could refer to possession by a family or "kin" group; it is also possible to consider a relationship which is not of blood but rather local, for example, that of a particular dwelling or territory.

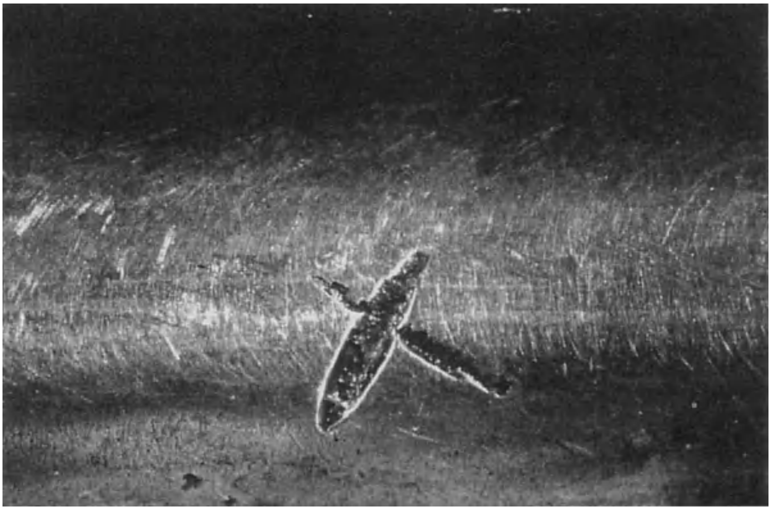

Fig. 13: Goldsmith or owner's marks.

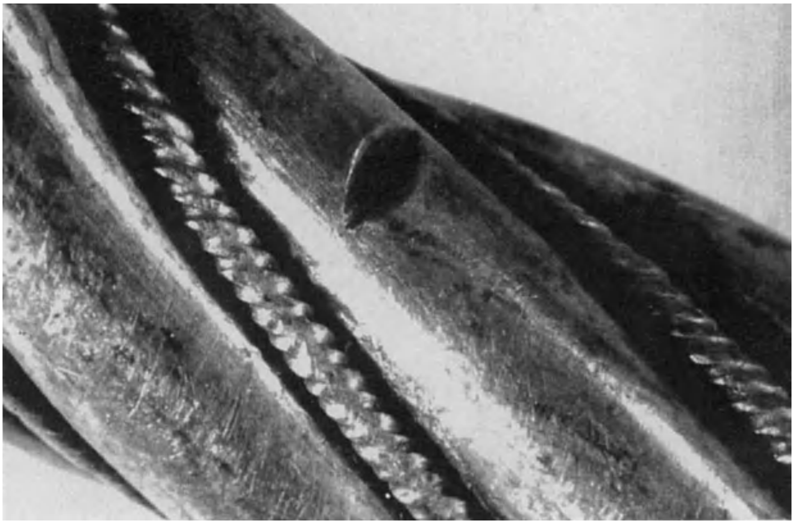

Fig. 14: Goldsmith or owner's marks.

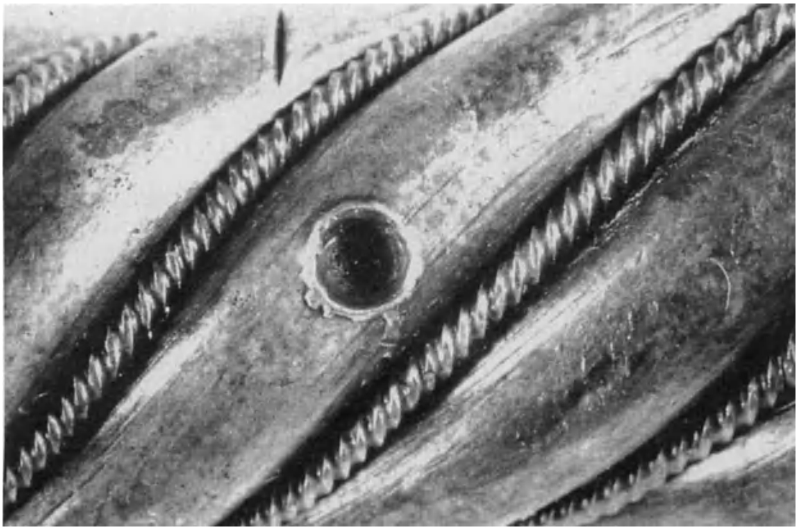

Fig. 15: Goldsmith or owner's marks.

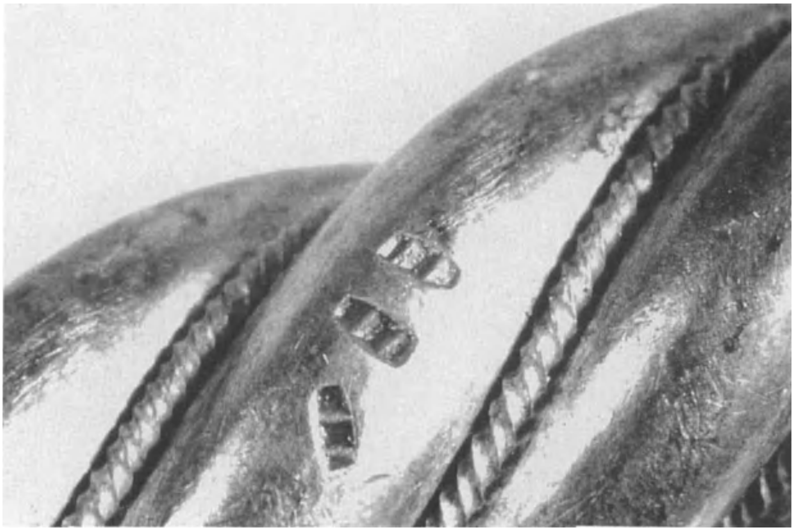

Fig. 16: Goldsmith or owner's marks.

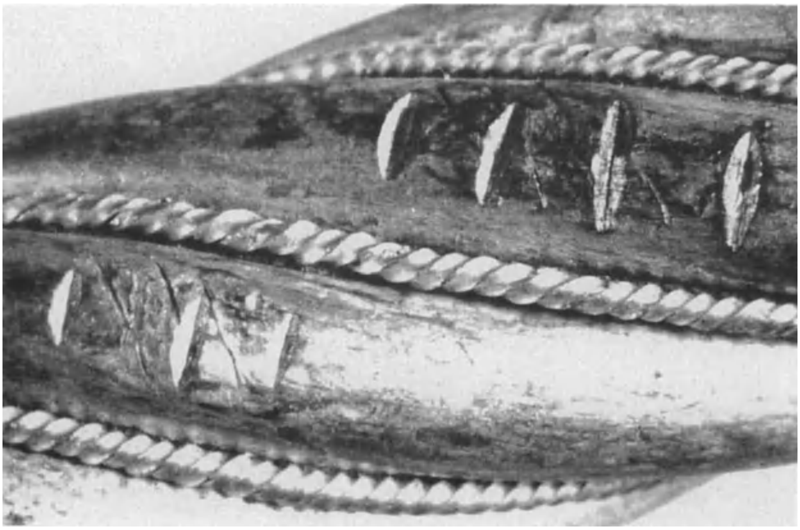

Fig. 17: Goldsmith or owner's marks.

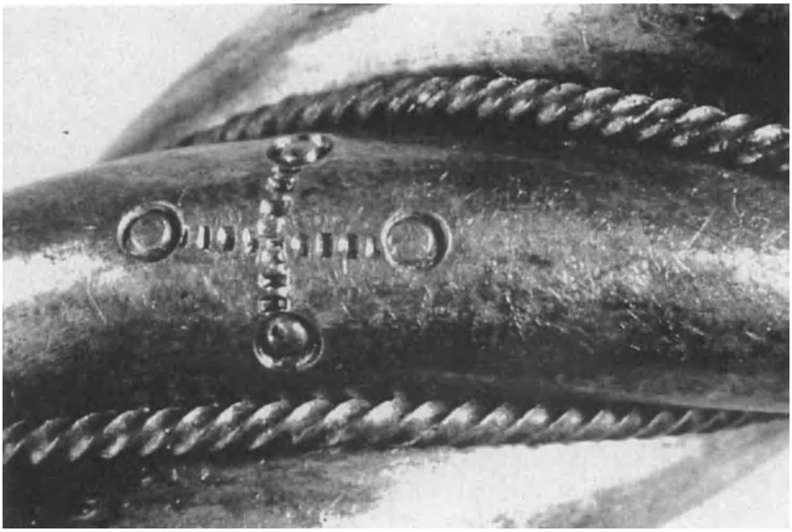

Fig. 18: Goldsmith or owner's marks.

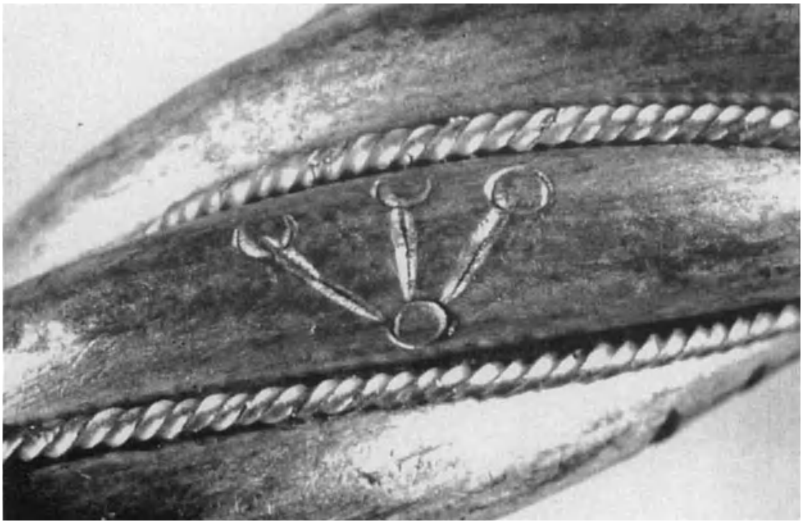

Fig. 19: Goldsmith or owner's marks.

Finally, the ticklish problem of chronology remains. It is known with some degree of certainity that the two hoards were buried at the end

of the 1st Century B.C. Together with the treasure found in 1980, 20 coins were recovered; 16 Iberian denarii and 4 Roman Republic ones, which vouch for that date (Sanchez de Arza 1984). It has been suggested that the reason for making the hoard was the state of insecurity created in the zone due to the wars between the Cantabrians and the Asturians against the Romans between the years 29 and 19 B.C. (Delibes and Esparza 1989).

Regarding the time of their manufacture, there are no data other than those from the technical and typological study, with all the inconsistencies which this implies. It must be presumed that there was a technical-stylistic synchrony among most of the pieces, with the possible exception of the drop earrings and the gold spirals which show older, Mediterranean traditions. This possible greater age of some of the gold pieces is also deduced by the very considerable signs of use which can be observed in some examples. Both the drop earrings and the spirals show wear on the lateral part which has gone as far as "reducing" the filigree and granulated surface to the point of leaving a smooth and compact mass of gold. This is also observed in the two rings and the pendant. Other pieces, such as the larger ring fibula, and some of the torcs and bracelets also show signs of wear, but never such deep ones. It can be believed that the gold adornments must have been used for several generations for this effect to have been produced.

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APPENDIX

ANALYSIS	OBJECT	Invent. No.	Au	Ag	Cu	Sn	Sb	Pb
PA1001A	Belt (band)	87/6/19	73.6	23.2	3.1	0.015	nd	nd
PA1001B	Belt (end)	87/6/19	75.5	20.7	3.6	0.067	nd	nd
PA1001C	Belt (back fastener)	87/6/19	72.5	24.2	3.1	tr	0.007	nd
PA1001D	Belt (obverse fastener)	87/6/19	75.9	20.7	3.0	0.041	tr	nd
PA1002	Torc (necklace)	87/6/1	85.9	10.5	3.4	0.049	0.009	nd
PA1003	Torc (necklace)	87/6/2	72.6	18.0	8.7	0.221	0.018	nd
PA1004A	Torc (necklace)	87/6/3	76.0	19.4	3.8	0.043	tr	nd
PA1004B	Torc (end piece)	87/6/3	86.9	10.8	2.1	0.031	0.012	nd
PA1004C	Torc (end piece)	86/7/3	85.3	11.8	2.6	0.070	0.011	nd
PA1005A	Torc (necklace)	87/6/4	nd	96.3	3.6	nd	nd	nd
PA1005B	Torc (end piece)	87/6/4	0.8	93.4	5.8	nd	nd	nd
PA1005C	Torc (end piece)	87/6/4	nd	96.5	2.5	nd	nd	0.7
PA1006A	Symmetr. brooch (lining)	87/6/5	83.7	12.2	3.8	0.022	nd	nd
PA1006B	Symmetr. brooch (bow)	87/6/5	nd	97.8	2.1	nd	nd	nd
PA1006B	Symmetr. brooch (pin)	87/6/5	nd	94.7	4.5	nd	nd	nd
PA1007	Brooch (spring knob)	87/6/6	nd	91.5	8.2	nd	nd	nd
PA1008	Symmetrical brooch	87/6/7.1	nd	95.5	2.4	nd	nd	1.1
PA1009	Fingerring	87/6/17	5.6	85.0	8.1	0.385	nd	0.8
PA1010	Brooch frag. (knob)	87/6/7.2	nd	96.7	2.2	nd	nd	0.6
PA1011	Symmetrical brooch	87/6/8	nd	96.2	2.0	nd	nd	0.9
PA1012	Ingot (cake shaped)	87/6/9	26.1	56.2	17.0	0.093	0.075	nd
PA1013	Bracelet fragment	87/6/10	1.5	93.3	4.8	0.022	nd	0.3
PA1013A	Bracelet (soldered joint)	87/6/10	1.6	94.1	3.8	0.063	nd	0.4
PA1014	Bracelet fragment	87/6/11	1.3	91.6	6.4	nd	nd	0.7
PA1015	Pin	87/6/13	nd	97.6	2.3	nd	nd	nd
PA1016	Bracelet	87/6/12	0.9	94.4	3.9	nd	nd	0.6
PA1017	Pendant earring (down side)	87/6/18	85.1	12.5	2.0	0.034	0.012	nd
PA1017A	Pendant earring (top side)	87/6/18	86.5	11.1	1.9	0.050	0.015	nd
PA1018A	Pendant (body)	82/6/25	94.6	4.7	0.4	nd	0.017	nd
PA1018B	Pendant (ring)	82/6/25	94.9	4.1	0.8	nd	0.018	nd
PA1019	Ring	82/6/33	93.3	4.9	1.5	nd	0.013	nd
PA1019A	Pendant (body)	82/6/26	87.5	9.4	2.9	0.026	0.011	nd
PA1019B	Pendant (ring)	82/6/26	89.4	7.4	3.0	nd	0.014	nd
PA1020A	Pendant (body)	82/6/27	93.3	5.3	1.2	nd	0.018	nd
PA1020B	Pendant (ring)	82/6/27	93.2	5.0	1.5	0.026	0.017	nd
PA1021A	Pendant (body)	82/6/28	89.8	7.4	2.6	0.018	0.003	nd
PA1021B	Pendant (ring)	82/6/28	89.1	7.7	2.9	0.022	0.014	nd
PA1022	Fingerring	82/6/29	88.6	7.3	3.3	0.094	0.016	nd
PA1023	Ring	82/6/35	94.1	5.3	0.4	nd	0.016	nd
PA1024	Pendant	82/6/37	79.0	17.4	3.2	0.128	0.006	nd
PA1025A	Ring (twist)	82/6/36	84.7	11.8	3.3	0.028	0.005	nd
PA1025B	Ring	82/6/36	85.6	11.4	2.7	0.085	0.006	nd
PA1026A	Fingerring (flat front)	82/6/32	95.6	3.6	0.5	0.053	0.014	nd
PA1026B	Fingerring (ring)	82/6/32	95.3	3.5	0.7	0.058	0.031	nd
PA1027	Vessel	82/6/23	1.3	92.0	5.4	nd	nd	1.3

Appendix continued:

PA1028	Ring	82/6/34	93.1	5.2	1.4	0.035	0.022	nd
PA1030	Fingerring	82/6/30	89.5	8.5	1.7	0.048	0.096	nd
PA1031	Fingerring	82/6/31	65.9	32.3	1.0	0.204	0.024	nd
PA1032	Vessel	82/6/24	1.5	96.4	2.1	nd	nd	tr
PA1034	Torc	82/6/11	nd	91.6	7.7	nd	nd	nd
PA1035	Bracelet	82/6/17	0.6	91.6	7.1	nd	nd	0.5
PA1036A	Torc (necklace)	82/6/16	0.8	90.8	7.5	0.228	tr	0.6
PA1036B	Torc (broken end)	82/6/16	0.6	89.7	8.6	0.340	tr	0.6
PA1037	Torc (necklace)	82/6/12	0.2	90.7	8.1	nd	tr	0.3
PA1037A	Torc (solder)	82/6/12	1.2	80.4	17.5	nd	nd	0.5
PA1038A	Brooch (knob)	82/6/40	92.5	4.6	2.5	nd	0.029	nd
PA1038B	Brooch (pin)	82/6/40	91.9	4.6	2.3	nd	0.044	nd
PA1039A	Ring brooch (bow)	82/6/38	30.2	67.8	1.3	0.543	nd	nd
PA1039B	Ring brooch (bow filigree)	82/6/38	53.3	39.7	5.9	0.242	nd	nd
PA1039C	Ring brooch (ring knob)	82/6/38	53.1	40.9	4.9	0.137	0.013	nd
PA1039D	Ring brooch (coating wire)	82/6/38	56.9	37.0	5.4	0.299	0.016	nd
PA1039E	Ring brooch (pin)	82/6/38	61.8	33.9	3.0	0.116	0.044	nd
PA1039F	Ring brooch (braided str.)	82/6/38	49.6	37.0	8.9	0.218	0.105	nd
PA1040	Bracelet	82/6/22	0.9	90.6	7.4	0.043	nd	1.0
PA1041A	Bracelet (spiral)	82/6/20	1.7	88.9	8.9	nd	nd	0.2
PA1041B	Brazelet (end)	82/6/20	1.5	91.3	6.7	0.024	nd	0.5
PA1042	Bracelet	82/6/19	tr	92.1	6.5	nd	nd	0.8
PA1043A	Bracelet (spiral)	82/6/21	0.7	93.8	5.0	nd	nd	0.4
PA1043B	Bracelet (end)	82/6/21	1.1	94.9	3.5	nd	nd	0.4
PA1044C	Double spring brooch (pin)	82/6/41	5.0	91.3	3.5	nd	0.15	tr
PA1047	Torc	82/6/14	53.2	30.4	15.8	0.068	0.009	nd
PA1048A	Torc (necklace)	82/6/8	2.7	82.6	13.1	0.270	0.035	0.3
PA1048B	Torc (ring joint)	82/6/8	1.8	92.4	5.5	0.024	nd	0.2
PA1048C	Torc (end)	82/6/8	0.9	94.3	4.6	nd	nd	0.2
PA1049	Torc	82/6/13	nd	98.9	0.8	nd	nd	tr
PA1050	Bracelet	82/6/18	0.7	86.7	10.4	0.052	nd	1.9
PA1051	Torc (end fragment)	82/6/49	1.1	81.8	15.9	0.121	nd	1.7
PA1052	Torc (end fragment)	82/6/50	1.3	88.6	9.0	0.129	nd	0.6
PA1053	Bracelet (end fragment)	82/6/51	2.8	87.1	8.8	0.013	nd	1.2
PA1054	Fingerring	82/6/47	0.7	87.2	10.0	nd	nd	1.7
PA1055	Fingerring	82/6/48	1.4	87.3	10.4	nd	nd	0.8
PA1056	Returned foot brooch	82/6/42	1.0	90.9	7.0	0.19	nd	0.7
PA1057	Bracelet	82/6/46	0.9	88.9	10.1	nd	nd	nd
PA1058	Bracelet	82/6/44	0.6	65.6	32.4	0.339	nd	0.6
PA1059A	Torc (necklace)	82/6/15	52.5	33.9	13.5	0.157	nd	nd
PA1059B	Torc (end knob)	82/6/15	49.6	33.9	16.2	0.065	nd	nd
PA1060A	Torc (necklace)	82/6/2	0.3	90.3	8.3	0.092	nd	0.6
PA1060B	Torc (ring joint)	82/6/2	0.7	95.2	3.9	0.014	nd	0.1
PA1060C	Torc (end)	82/6/2	1.1	95.6	3.1	nd	nd	0.2
PA1061A	Torc (necklace)	82/6/5	nd	89.9	8.1	nd	nd	1.7
PA1061B	Torc (ring joint)	82/6/5	0.1	88.3	7.2	nd	nd	3.4
PA1061C	Torc (end)	82/6/5	nd	90.1	7.4	nd	nd	2.4
PA1062A	Torc (necklace)	82/6/3	0.5	88.0	9.5	nd	nd	2.0

Appendix continued:

PA1062B	Torc (ring joint)	82/6/3	0.6	91.4	7.0	nd	nd	1.0
PA1062C	Torc (end)	82/6/3	0.5	90.5	7.9	nd	nd	1.0
PA1063A	Torc (necklace)	82/6/1	0.7	89.1	9.5	0.073	nd	0.6
PA1063B	Torc (ring joint)	82/6/1	1.1	95.3	3.3	0.014	nd	0.3
PA1063C	Torc (end)	82/6/1	1.5	95.1	3.1	0.005	nd	0.2
PA1064A	Torc (necklace)	82/6/4	0.9	90.4	7.3	0.018	nd	1.4
PA1064B	Torc (ring joint)	82/6/4	0.9	95.1	3.7	0.007	nd	0.2
PA1064C	Torc (end)	82/6/4	0.9	95.1	3.7	0.005	nd	0.2
PA1065A	Torc (necklace)	82/6/6	0.5	96.3	1.9	0.036	nd	0.7
PA1065B	Torc (ring joint)	82/6/6	1.0	93.2	5.0	0.267	nd	0.4
PA1065C	Torc (end)	82/6/6	2.0	92.8	4.9	nd	nd	0.2
PA1066A	Torc (necklace)	82/6/7	0.8	90.9	7.2	0.018	nd	1.0
PA1066B	Torc (ring joint)	82/6/7	0.9	93.3	5.6	0.006	nd	0.2
PA1066C	Torc (end)	82/6/7	1.0	92.3	5.9	0.003	nd	0.8
PA1067A	Torc (necklace)	82/6/9	1.5	88.3	8.1	0.185	nd	1.5
PA1067B	Torc (ring joint)	82/6/9	0.8	93.6	5.3	0.012	nd	0.2
PA1067C	Torc (end)	82/6/9	0.9	92.9	5.8	nd	nd	0.4
PA1068	Torc	82/6/10	1.4	89.1	8.9	0.233	nd	0.3
PA1069A	Ring brooch (bow)	82/6/39	69.2	26.4	4.0	0.239	nd	nd
PA1069B	Ring brooch (knob)	82/6/39	78.4	17.8	3.4	0.073	nd	nd
PA1069C	Ring brooch (coating wire)	82/6/39	75.9	14.9	8.9	0.053	0.008	nd
PA1069D	Ring brooch (pin)	82/6/39	0.8	90.4	8.2	nd	nd	0.4
PA1070	Bracelet	82/6/43	1.3	88.6	9.6	0.016	nd	0.4
PA1071	Bracelet	82/6/45	0.9	89.0	9.3	0.035	nd	0.5
PA1072	Torc (end fragment)	82/6/52	0.5	89.1	9.3	0.032	nd	0.3
PA1073	Torc (end fragment)	82/6/53	2.4	87.6	7.9	0.051	nd	1.2
PA1074	Bracelet (fragment)	82/6/54	1.8	85.7	11.3	nd	nd	0.7
PA1075	Bracelet (fragment)	82/6/55	2.8	85.3	10.2	nd	nd	1.3
PA1122	Worked sheet	87/6/14.1	7.0	81.5	10.7	0.323	nd	0.4
PA1123	Worked sheet	87/6/14.2	8.2	82.3	8.8	0.631	nd	nd
PA1124	Wire	87/6/16	7.4	83.0	9.5	nd	nd	nd
PA1125	Brooch (pin fragment)	87/6/15	3.5	85.6	8.6	nd	nd	1.7

NOTES: Analysis results in weight %; nd: not detected; tr: traces, usually <0.001 for Ag, Sn, Sb; <0.1 for Au, Cu, Pb

Chapter 5

CELTIC GOLDWORK IN THE IBERIAN PENINSULA

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ABSTRACT. A general overview of the "Celtic" goldwork of the Iberian Peninsula necessitates a review of the concept of "Celtic" in Hispania, avoiding the traditional identification with elements from Hallstatt and La Tène cultures, and based on a palaeo-ethnological interpretation of the Hispano-Celtic peoples.
This research identifies six groups of Celtic jewellery in Iberia:
1) "Protoceltic" of the Late Atlantic Bronze Age (XII-VIII B.C.);
2) Engraved and stamped of the Early Iron Age (VII-V B.C.);
3) Celtic "orientalizing" jewellery (V-IV B.C.);
4) Lusitano-Galician jewellery (IV-I B.C.);
5) Vacceo-Vettonian jewellery (II-I B.C.);
6) Celtic jewellery with La Tène influences (IV-II B.C.).
In conclusion it can be said that all these groups confirm the importance and the variability of Hispano-Celtic jewellery from the Late Bronze Age to the period of Romanisation in I B.C. This new interpretation gives a good idea of one of the most characteristic elements in the complex material culture of the Hispano-Celtic peoples and enlarges the current view of Celtic goldwork in Europe.

1. Introduction

In order to offer a view of the present situation of the "Celtic" goldwork of the Iberian Peninsula it is necessary to reconsider what is meant by "Celtic" in Art and Archaeology (Renfrew 1987). The classical texts provide numerous references to the Celts in Hispania which were evaluated in the last century (d'Arbois de Juvanville 1893-4). The traditional solution to their archaeological identification has been to relate them to elements of the Central European Hallstatt and La Tène cultures (Duval 1977, Megaw and Megaw 1989), as a natural result of the evolution of research (Ruiz Zapatero 1993).

Around 1920 Bosch Gimpera (1932, 1974) linked the Celts with the Urnfield cemeteries discovered in the northeast of the Peninsula, explaining their arrival in terms of a complex series of invasions. This tradition of identifying the Hispanic Celts in terms of the archaeological material culture used to define the Celts in Central Europe, a consequence of the priority of Central European research in that field, has hindered interpretation by introducing a typology, terminology and an invasionist model that are inappropriate for describing Celtic elements in the Iberian Peninsula (Bosch 1974, Almagro 1952, Sangmeister 1960, Schüle 1969, Lenerz-de Wilde 1991, etc.). This has led to the inaccurate use of ethnic, linguistic and archaeological terms, with confusion arising in the field of Celtic archaeology.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 491–501.

In order to overcome the problems arising from this view, it is necessary to bear in mind that the Celts in the Iberian Peninsula assimilated numerous Mediterranean elements that enriched and transformed their culture, especially from the Tartessians and the Iberians, such as wheel-made pottery, urban planning, writing, laws, etc. (Almagro-Gorbea 1993). Such processes of assimilation also affected the typology and technology of goldwork, one of the main items of social prestige, which explains why the Greeks and Romans called them **Celtiberi** (Koch 1979), to distinguish them from other Celts beyond the Pyrenees.

These differences between their material culture and the Hallstatt and La Tène cultures of Central Europe traditionally identified with the Celtic world explain the difficulties that exist in the archaeological identification of the Hispanic Celts. Therefore, in the Iberian Peninsula this identification of "Celtic" elements should, rather than searching for elements of presumably Central European origin, be based on adequate palaeoethnological research (Almagro-Gorbea and Ruiz Zapatero 1993). This should allow us to identify Celtic populations and define their material culture.

In keeping with this new interpretation, this paper describes the various groups of Celtic goldwork identified in the Iberian Peninsula. They are of interest because they help to confirm the varied material culture of the Hispanic Celts which developed out of their capacity for acculturation, and at the same time contributes to shaping a better and more comprehensive view of Celtic goldwork in Europe.

2. The main groups of Celtic gold jewellery

Six main groups of gold jewellery can at present be identified with certainty in the Celtic Hispania.

2.1 GROUP 1: "PROTO-CELTIC" GOLDWORK FROM THE ATLANTIC FINAL BRONZE AGE (12TH-8TH CENTURIES B.C.)

For the discussion of this Late Bronze Age group the fact that the linguists document two or three Hispano-Celtic strata must be taken into account (Tovar 1961, de Hoz 1983, Villar 1991). The oldest of these can be identified because it preserves the initial Indo-European "P", and can be associated with the language of the Lusitani, which other linguists (Untermann 1987) include amongst the Celtic languages, as their onomastics and the names of their deities would seem to confirm (Albertos 1983, id. 1983a). These very archaic linguistic elements are attested in the western Atlantic regions, leading to their association with an Atlantic Late Bronze Age cultural substratum, which, as a result, should be considered "proto-Celtic" (Almagro-Gorbea 1993). As indirect evidence of "proto-Celtic" goldworking one can include the terminology of gold-mining referred to by Pliny (Nat. hist. 33, 76-77, 34, 157), with characteristic words such as palaga, palacurna, baluces, arrugia, agogas, alutia, etc., which certainly correspond to a pre-"Celtic" linguistic substratum (Tovar 1983: 276 f., Domergue 1974).

Some of the finest and best-known gold ornaments of the Iberian Peninsula correspond to this cultural substratum. Their distribution is explained by the rich gold deposits of the western regions (Almagro-Gorbea 1977: 6-10, f. 2, Domergue 1987: 16 f.). Their varied forms include torcs with expanded terminals of the so-called Irish type (Almagro-Gorbea

1977: 43 f.), very heavy massive torcs (Fig. 1A) with Atlantic affinities (Almagro-Gorbea 1977: 18 f., Ruíz-Gálvez 1984, 1989, Perea 1991) and bracelets decorated with "spikes" related with the so-called "Villena jewellery" (Almagro-Gorbea 1974, Perea 1991). Finally, in this group objects can be included made by hammering gold over a mould, such as the Axtroqui bowls (Almagro-Gorbea 1974) and the Rianxo helmet (Ruíz-Gálvez 1989: 54). These are associated with the goldwork of the Final Bronze Age in Central and Northern Europe (Menghin and Schauer 1977) and, from a cultural point of view, with proto-Celtic cults of deposition in water or among rocks (Almagro-Gorbea 1993).

2.2 GROUP 2: STAMPED JEWELLERY OF THE IRON AGE (7TH-4TH CENTURIES B.C.)

This ill-defined and varied collection of goldwork will require a more detailed study in the future. It consists of isolated finds of torcs and a hoard that are characterised by their stamped or punched decoration, in which the influence of Hallstatt techniques has been alleged. The collars of the Herdade do Alamo hoard (Fig. 1B), Moura, Portugal (Heleno 1935, Tesoros 1980) can be considered as late examples of the massive gold collars of group 1, but one of them displays the introduction of stamped decoration, possibly of Central European origin, and wires of filigree that can be interpreted as the first "orientalizing" acculturation in Iberian goldwork through Phoenician influence. This allows them to be dated to ca. 700 B.C. (Almagro-Gorbea 1977: 34).

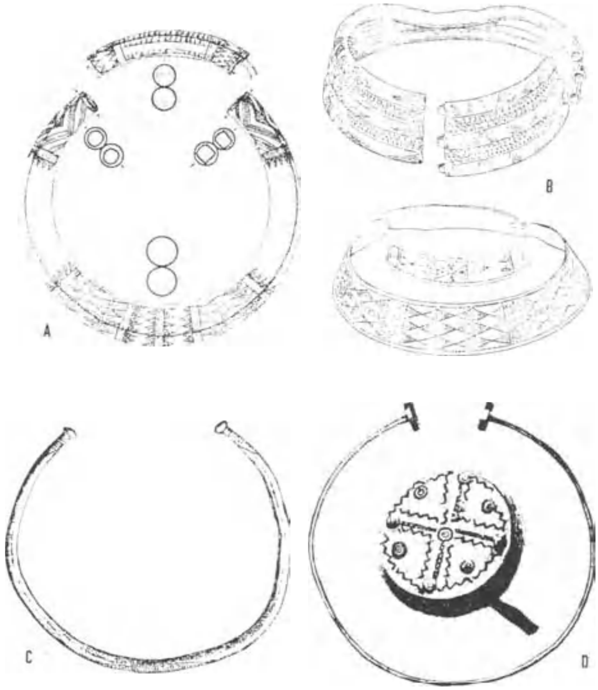

Fig. 1: A: Massive "proto-Celtic" torc of the Atlantic Late Bronze Age from Sagrajas, Badajoz. B: Gold torc from the Alamo hoard, Portugal. C: Punch decorated torc from Jaramillo Quemado, Burogs. D: La Tène torc from Tremp, Lérida. (A: after Almagro-Gorbea, B: Heleno, C and D: Delibes de Castro).

This stamped decoration was used for a long time and it is amply attested in later finds, as in some pieces of western (Heleno 1935) and "Castro Culture" goldwork (da Silva 1987). The torc from Jaramillo Quemado, Burgos (Fig. 1C) is dated to the Early Iron Age, earlier than the Celtiberian, Vaccean and Vettonian goldwork of the 3rd-1st centuries B.C. (groups 5-6), but the torc from Tremp, Lérida (Maluquer 1970, pl. 4-6) (Fig. 1D), is dated to La Tène period (Lenerz-de Wilde 1991).

2.3 GROUP 3: "ORIENTALIZING" CELTIC GOLDWORK FROM EXTREMADURA (5TH-4TH CENTURIES B.C.)

This group includes two notable hoards, that from La Martela hill-fort, Segura de León, Badajoz (Berrocal 1989) and that from Serradilla, Caceres (Fig. 2A-B) as well as other pieces such as the pendant earrings from Madrigalejo (Almagro-Gorbea 1977, Perea 1991).

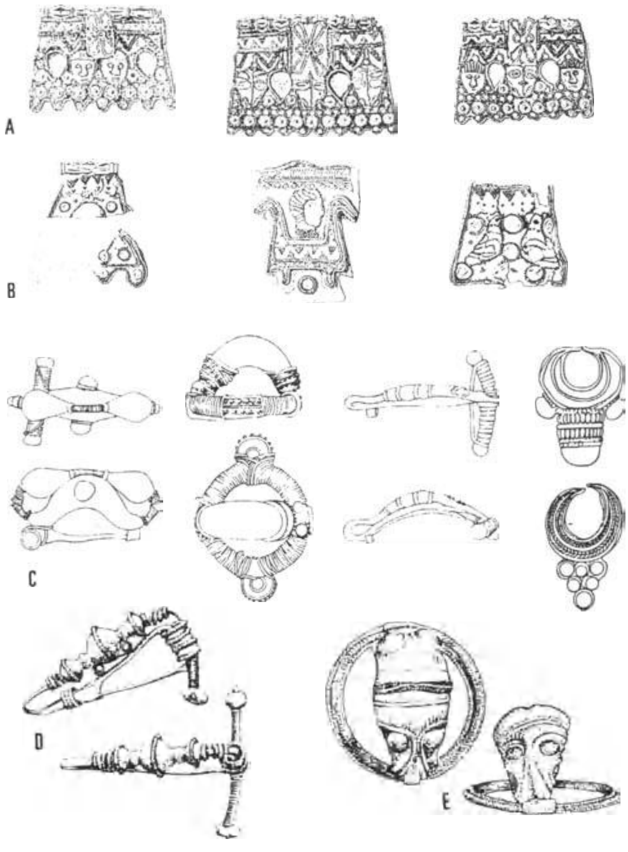

Fig. 2: A and B: "Orientalizing" Celtic gold plates from La Martela and Serradilla hoards, Extremadura. C: Vacceo-Vettonian gold fibulae and earrings from the Arrabalde hoard, Zamora. Gold fibulae from Mairena del Alcor, Sevilla (D) and from Cheste, Valencia (E). (A and B: after Berrocal, C: Delibes and Esparza, D: Fernández, E: Lenerz-de Wilde).

The main feature of this group is the total assimilation of forms and techniques such as filigree and granulation of orientalizing origin, through the acculturation of technological and formal elements due to the influence of Phoenician jewellery on Tartessians. This in turn influenced that of the Celtic peoples. But its major peculiarity from a cultural point of view is its adaptation to a Celtic iconography, attested by the preference for selecting orientalizing themes read in a Celtic way, such as the human and wolf heads in the La Martela hoard or the heraldic bird protomes associated with the human head at Serradilla. This would allow the group to be associated with the **Celtici** of the southwestern Peninsula named by historical sources (Berrocal 1992).

2.4 GROUP 4: LUSITANO-GALICIAN GOLDWORK (4TH-1ST CENTURIES B.C.)

This group corresponds with the "Castro Culture" which extends over the northwest part of the Iberian Peninsula (da Silva 1987, Calo 1993). It can be identified with the Lusitanians and especially with the Galicians, both peoples of Celtic affiliation (Almagro-Gorbea and Ruiz Zapatero 1993).

This group is the largest and most varied collection of Hispano-Celtic goldwork. It can be considered one of the most characteristic in the Iberian Peninsula and one of the largest groups of goldwork in the entire Celtic world. This fact can be explained by lying the Castro Culture in an area very rich in gold (Domergue 1987, Sánchez Palencia 1983).

The group (López Cuevillas 1951, Pérez Outeriño 1989) basically consists of over 120 torcs of various kinds with decorated bars and terminals (Fig. 3A) and about 40 pendant earrings of different types (Fig. 3B) (Pérez Outeriño 1982), whose typological variety reflects ethnical entities (Pérez Outeriño 1989). They are also rarer objects, such as hinged collars, "diadems" or belt-plates, sometimes with stamped decoration that includes figured scenes (Fig. 3D); bracelets (Fig. 3C) and some lesser pieces, such as pendants in the orientalizing shape of "Keftiu" or the so called "ox ingot" shape (Kukahn and Blanco 1959).

From the typological point of view, it combines very varied techniques and forms, from the stamped "Hallstatt" type related to group 2, to filigree and granulation of orientalizing origin, which probably arrived via group 3. Goldworking tools are known, for example in the Viladonga hill-fort (F. Arias, personal comunication) and there are ingots based on a unit of weight of about 360 g (Ruíz Gálvez, in this volume). The decorative motifs are simple geometric shapes based on SSS and 888, and figures only very occasionally appear in the later part of this period, probably in the 2nd-1st centuries B.C., as in the "Diadema de Ribadeo", Asturias (Fig. 3D) (López Monteagudo 1977, Eluère 1987).

The seriation and chronology of this group is still very poorly defined. It seems unlikely that there would be a clear and definite break after the Late Bronze Age products of group 1, which, at the beginning of the Iron Age, ca. 6th-5th centuries, must have been replaced by the stamped or punched decoration that we have included in group 2, even though this decorative technique continued to be used subsequently. Then again, the introduction of orientalizing influences, possibly through contacts with group 3, cannot have been later than the 4th century B.C. However, most of these products and, in particular, the torcs, appear to relate to the 2nd-1st centuries B.C. since their archaeological context coincides with the Galician-Roman period, the time when the "Castro Culture" was at its height.

Finally, the gold decoration of the silver cap from Châo de Lamas, Coimbra, (Raddatz 1969) should be included in the context of "Celtic" elements found in Atlantic regions. This hoard displays the obvious intermingling of Oretani (silver drinking vessels), Celtiberian (human heads and repoussé figures, etc.) and western influences (lunulae and decorative spirals), so it should be regarded as characteristic of the central Lusitanian area.

Fig. 3: Lusitano-Galician goldwork from the "Casto Culture". A: Torc from Vilas Boas. B: Earring from Fife and Vilar de Santos. C: Bracelet from Levuçâo. D: Gold plate from San Martín de Oscos. (A and B after da Silva, C: Pérez Ourteriño, D: Blázquez).

2.5 GROUP 5: VACCEO AND VETTON GOLDWORK (2ND-1ST CENTURIES B.C.)

Gold jewellery with distinctive characteristics appears in a dozen hoards (Delibes de Castro and Esparza 1989) currently known in the area occupied by Vettons and Vacceans in the

Northern Meseta (Esparza 1987), notably the hoard from the Castro de Arrabalde 1 (Zamora), containing 1080 g of gold and 5181 g of silver jewellery (Martín Valls and Delibes de Castro 1982) (Fig. 2C).

There is less gold than silver in this group. Their hoards frequently contain Celtiberian and Roman denarii as the "Celtiberian" silver hoards found in the East of the Meseta (Raddatz 1969). The Celtiberians formed a strong influence due to their expansionist tendency before the Roman Conquest in the last centuries B.C. But the wealth of gold of the Vacceo-Vettonian area suggests connections with group 4 Lusitano-Galician goldwork, at least with regard to the origin of the raw material and some of the types, such as pendant earrings and belt plates.

The most distinctive pieces of gold jewellery in this Vacceo-Vettonian group are local, symmetrical La Tène-type fibulae (Lenerz-de Wilde 1991) and also Meseta circular fibulae, indirectly of Iberian origin. Pendant earrings of distant Mediterranean inspiration are found which are related to those in group 3. Exceptionally, low alloy gold torcs, and, occasionally rings and minor items of jewellery are found as at Arrabalde, where there is also a belt plate with a zoomorphic clasp.

The Vacceo-Vettonian goldwork appears to be of a late date, corresponding to the Celtic "oppida" culture, since the known hoards are dated to the end of the 2nd century or beginning of the 1st century B.C. (Delibes de Castro - Esparza 1989). Thus this goldwork seems to be strongly influenced by Celtiberian jewellery, despite the fact that the latter was made of silver, as in the hoards from the East of the Meseta and the Oretani area (Raddatz 1969: map 2). This was the main silver-producing centre between the Meseta and Andalusia and it displays clear Celtic influences, like group 6. But the abundance of gold, the taste for over-elaborate filigree and certain pieces such as pendant earrings and belt plates attest Lusitano-Galician influences, which is understandable in view of that culture's rich gold tradition.

2.6 GROUP 6: CELTIC GOLDWORK FROM THE SPANISH LEVANT AND ANDALUSIA INFLUENCED BY LA TENE

This group contains very few pieces but has very distinctive characteristics. They come from the rare silver hoards of the Spanish Levant and the few gold hoards known in Western Andalusia.

Although the Levant areas are usually considered ethnically and culturally Iberian, the mountain regions offered constant contacts with the Celtic peoples from the interior, which could explain the presence of elements of Celtic tradition, such as the Iberian circular fibula with human heads in La Tène plastic style in the Cheste hoard (Valencia) (Fig. 2D) (Lenerz-de Wilde 1991). This suggests Celtiberian influences dated to the 3rd century B.C.

This could also be the case in Andalusia, where rich gold fibulae of La Tène type with some Iberian influences appear in the 2nd century B.C. in gold hoards such as those of Mairena del Alcor (Fig. 2D) and Puebla de los Infantes (Seville) (Fernández 1985, 1989). The assimilation of Celtic types for some prestige jewellery, as attested by these fibulae from Western Andalusia, is a phenomenon similar to that observed in the nearby Oretanian region, although there the jewellery is almost exclusively made of silver (Raddatz 1969).

3. The Celtic gold fibula attributed to the Iberian Peninsula

This piece has no known origin, but has been attributed to the Iberian Peninsula. As such it is sometimes published because of its spectacular appearance (Megaw and Megaw 1989, Lenerz-de Wilde 1991).

It does not belong to any particular Peninsula type, although it has been related to the rich silver fibulae of the Oretanian region (Lenerz-de Wilde 1991). Furthermore it displays elements from various origins, such as filigree waves of Hellenistic type and a careful, realistic execution, not usual in contemporary Hispano-Celtic goldwork, nor in Celtic art in general. Moreover, "Celtic" helmets are not known in Hispanic horseman fibulae and the shield reinforcement of the umbo presents a strange configuration.

All of these characteristics suggest that this unique piece requires a detailed palaeometallurgical study, since it does not appear to be of Iberian origin and raises certain doubts concerning its authenticity.

4. Conclusions

The Celtic goldwork of the Iberian Peninsula clearly reflects the complex cultural characteristics of the Hispano-Celtic world. Its diversity should be emphasized, since the various groups referred to correspond to ethnic groups with very different locations, material cultural traditions and chronologies (Almagro-Gorbea and Ruiz Zapatero 1993). The same diversity explains their chronology from the Late Bronze Age "proto-Celtic" jewellery, to the Romanization of the populations of the northwest, which apparently occurred very late in the 1st century B.C.

The distribution is widespread, but to a large extent coincides - not by chance - with the "Celtic" Hispania recorded on the basis of linguistic evidence, which agrees with the thesis here briefly presented in an outline.

Within this broad geographical and chronological framework, three groups can be picked out for their greater cultural distinctiveness, apart from the goldwork of the Late Bronze Age whose acceptance as "Celtic" will require a debate at a more general European level.

The first is the Hispano-Celtic orientalizing jewellery (group 3, mainly from Extremadura, with vestiges that lasted until Romanization. This is perhaps the most distinctive group in the Hispano-Celtic world, since it displays most clearly the effects of strong acculturation, mostly of Tartessian characteristics.

Secondly, there is the jewellery that we often call "Celtiberian" in a generic sense, especially that of the Vacceans and Vettons (group 5) and other more isolated pieces found in parts of the Peninsula (group 6) where the presence of the Celtiberians has been confirmed, although to date these pieces have not appeared in Celtiberia in the strictest sense, with its tradition of silver jewellery. La Tène influences are more evident in these groups, but they have been greatly reworked in keeping with local traditions, largely of Iberian origin.

Finally, the richest group of Celtic goldwork in the Iberian Peninsula is that of the "Castro Culture" of the Lusitanians and Galicians in the northwest areas (group 4). Its Celtic tradition is indisputable, but its techniques, particular forms and cultural context confirm once again the varied characteristics of the Hispano-Celtic world.

As conclusion, hopefully this new interpretation of the varied and rich Hispano-Celtic goldwork can help to enlarge the current view of Celtic jewellery in Europe and to show how it represents one of the most characteristic elements of the material culture of the Hispano-Celtic peoples.

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Chapter 5

GOLD IN EARLY BRONZE AGE GRAVES FROM DENMARK AND SCHLESWIG-HOLSTEIN

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ABSTRACT. In the Early Bronze Age graves gold occurs in several forms. First there are spirals of different sizes, furthermore bracelets, armrings and bronze objects gilded with gold foil. These last are concentrated in the Danish Islands and northern Jutland whereas armrings and spirals are mainly found in the south. This observation can be explained by regional differences in the extent of grave furnishing. In women's graves gold is very rare and only occurs in form of small spirals. These spirals are concentrated in the south, while the richly furnished women's graves of Zealand hardly ever contain gold. The long-running supply of metals to South Scandinavia and North Germany was probably based on a combination of amber as trade goods and the fact that the area did not depend on salt import.

1. Introduction

The subject of this paper is Period II of the Early Bronze Age in Denmark and Schleswig-Holstein. The traditional data for archaeological research on this period include hundreds of graves and a smaller number of hoards, containing metal objects of high quality. Since there are no natural deposits of tin and gold in this region, long distance trade must have existed. This trade probably included copper in spite of the copper deposits of Heligoland.

The high standard of metalworking and the large amount of bronze weapons, tools and ornament taken from daily use by extravagant burial customs and religious rites show that the import of metals was secure in the long term.

Especially on the Danish Islands and in northern Jutland weapons, bronze tools and, more rarely, women's and men's ornaments were deposited in bogs, lakes or rivers. These finds are sometimes described as hoards of merchants or craftsmen but woollen cloth on some beltplates and inside small bronze rolls and tubes proves that originally clothing with its bronze accessories was deposited. Therefore the majority of these deposits should be regarded as the relics of religious customs. Besides these finds, there are deposits of tools, mainly axes and sickles, which could have belonged to a fertility cult (Willroth 1985, 235; 237). In contrast to hoards of weapons and ornaments, tools can also be found in South Denmark and Schleswig-Holstein.

Although two of the most famous Bronze Age hoards, Trundholm and Bregninge, consist of broken ritual objects made of bronze and gold, gold objects are not common in hoards. This may be due to the fact that it is not possible to date the frequent finds of single gold spirals precisely, some of them may belong to Period II, although they are also common in later times. Nevertheless it should be mentioned that even the clearly dated Period II-offerings of metal goods regularly required kilograms of imported metal.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 503–514.

As briefly mentioned, most of the gold objects are grave goods. The following observations are based only on closed finds, that is about 400 men's graves and 140 female.

In grave inventories gold occurs in several forms. First of all there are spirals of different sizes (Fig. 1.4-5). Since these coiled wires are widespread in Bronze Age Europe, they are usually regarded as a kind of ingot, the so-called Ringguld (Brøndsted 1958, 52). Next are bronze objects decorated by gold sheets, especially hilts and pommels of swords and daggers but also accessories like double studs, fibulae and belthooks. The third and last group includes several forms of bracelets (Fig. 1.2,6-8) and gold rings for arms and fingers (Fig. 1.1,3). Gilded objects, gold rings, armspirals and bracelets are restricted on men's graves, whereas small spirals also occur in women's graves.

The distribution map (Fig. 2, Table 1) of these objects shows a striking difference between plated bronze and gold rings. The first is clearly concentrated on the Danish Islands and northern Jutland, whereas the latter are mainly found in southern Denmark and Schleswig-Holstein. In general, gold finds are less frequent in the north and since more gold is needed for gold rings than for plating rather small parts of bronze objects, differences in the supply of raw material for the two regions seem evident. But a large number of graves with bronze objects and most of all the extensive hoards prove, that Zealand and the north of the Danish mainland did not have any problems with the supply of tin and copper at this time. Therefore there is no reason to assume that there was shortage of gold.

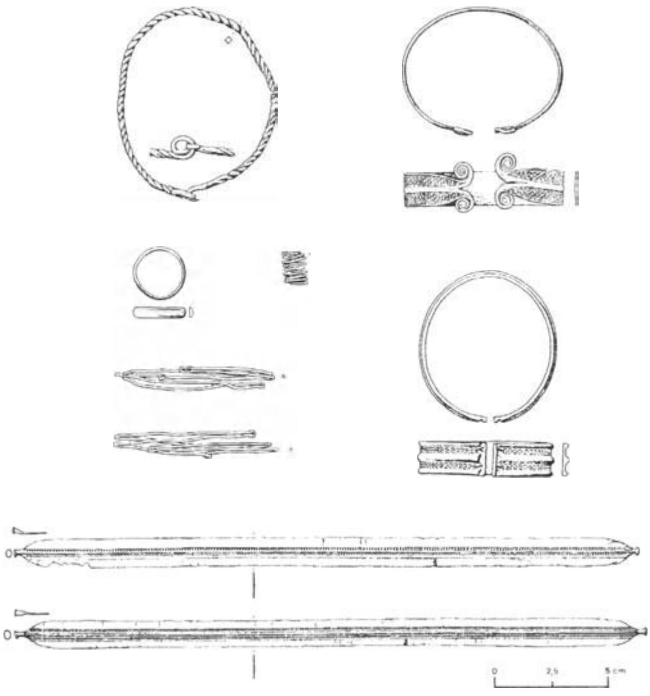

Fig. 1: 1 Hövede. 2; 4 Hollingstedt. 3 Hövede. 5 Schafstedt. 6 Hemmingstedt. 7; 8 Hövede. Drawings Fig. 1: 1.1 A/Ke 1991 Taf. 35; 1.2,4 A/Ke 1991, Taf. 37; 1.3 A/Ke 1991, Taf. 35; 1.5 A/Ke 1991, Taf. 48; 1.6 A/Ke 1991, Taf. 32; 1.7,8 A/Ke Taf. 34.

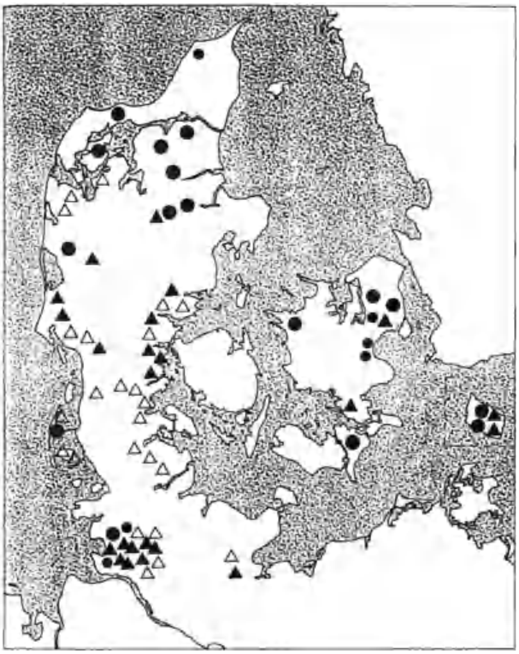

Fig. 2: Gold in men's graves. Open triangles: spirals; filled triangles: rings; big filled circles: gilt bronze objects; small filled circles: pieces of wire or sheet.

Table 1. Men's graves with gold objects.

Amlund, Vejle amt.	Bracelet (A/Ke 1990, No 4549).
Arnitlund, Haderslev amt.	Armspiral (A/Ke 1984, No 3558).
Barde, Ringkøbing amt.	Bracelet (DB I, No 928).
Brunde, Åbenrå amt.	2 armspirals (A/Ke 1981, No 3048).
Bunsoh, Kr. Dithmarschen.	Pieces of gold wire (A/Ke 1991, No 9072).
Danstrup, Viborg amt.	Belt-hook with gold sheet, fingerring (DB I, No 682).
Drage, Kr. Steinburg.	2 armspirals (Kersten 1939, 222; Abb. 75).
Drostrup, Ribe amt.	Armring (A/Ke 1986, No. 3955).
Dyssegård, København amt.	Gold sheet (diadem?) (A/Ke 1973, No. 451 I).
Eggstedt, Kr. Dithmarschen.	Fingerspiral (A/Ke 1991, No 9080).
Eggstedt, Kr. Dithmarschen.	Armring (A/Ke 1991, No 9084).
Eggstedt, Kr. Dithmarschen.	Bracelet (A/Ke 1991, No 9083).
Fahrenkrug, Kr. Segeberg.	Bracelet (Kersten 1936, Taf. XVI).
Frøstrup, Ribe amt.	Fingerring (A/Ke 1986, No 4163).
Gadeland, Kr. Rendsburg-Eckernförde.	Armring of 4 pieces of gold wire (Hingst 1952, 5).
Glüsing, Kr. Dithmarschen.	Sun-disc" (A/Ke 1991, No 9123).
Grønninghoved, Vejle amt.	Bracelet (A/Ke 1990, No 4403).
Gug, Ålborg amt.	"Sun-disc" (DB I, No 607).
Harreby, Haderslev amt.	Bracelet (A/Ke 1984, No 3394).
Harresø, Vejle amt.	Armspiral (A/Ke 1990, No 4436).
Harrislee, Kr. Schleswig-Flensburg.	Hair(?)spiral (A/Ke 1978, No 2243).
Hemdingen, Kr. Pinneberg.	2 armspirals (Ahrens 1966, 365).
Hemmingstedt, Kr. Dithmarschen.	Bracelet (A/Ke 1991, No 9153).
Hjerpsted, Tønder amt.	2 armspirals (A/Ke 1981, No 2916).
Hollingstedt, Kr. Dithmarschen.	Bracelet, fingerspiral (A/Ke 1991, No 9161).

Table 1. continued:

Hövede, Kr. Dithmarschen.	2 bracelets (A/Ke 1991, No 9157).
Hövede, Kr. Dithmarschen.	Bracelet (A/Ke 1991, No 9159).
Hövede, Kr. Dithmarschen.	Fingerring (A/Ke 1991, No 9158).
Hövede, Kr. Dithmarschen.	Armring (A/Ke 1991, No 9158).
Hvirring sogn, Skanderborg amt.	Bracelet. (DB I, No 835).
Jægersborn Hegn, København amt.	"Sun-disc" (A/Ke 1973, No 417).
Jægerspris, København amt.	Gold wire ((A/Ke 1973, No 112).
Kampen, Kr. Nordfriesland.	Armspiral, hair(?)-spiral (A/Ke 1979, No 2667).
Kampen, Kr. Nordfriesland.	2 fibulae with gold sheets (A/Ke 1979, No 2681).
Karlstrup, København amt.	Gold sheet (A/Ke 1973, No 518Qb).
Karlstrup, København amt.	Gold wire (A/Ke 1973, No 518 N).
Knudshoved Odde, Præstø amt.	Bracelet (A/Ke 1976, No 1271).
Krejbjerg, Viborg amt.	Fingerspiral (DB I, No 736).
Langvad, Thisted amt.	Fibula with gold sheet (DB I, No 526).
Lille-Sjørup, Ålborg amt.	Sun disc? (DB I, No 600).
Løsning, Vejle amt.	2 armspirals (A/Ke 1990, No 4337).
Maglebrænde, Maribo amt.	Sword with gold sheet (A/Ke 1977, No 1582).
Muldbjerg, Ringkøbing amt.	Sword with gold sheet (DB I, No 949).
Ørskov, Ringkøbing amt.	gold sheet (diadem?) (Nationalmuseet København 22079.45).
Rold, Ålborg amt.	Fibula with gold sheet (Nationalmuseet København 14448).
rom, Ringkøbing amt.	2 fingerspirals (DB I, No 2289).
Sandvig, Bornholms amt.	Double stud with gold sheet, armring, sword with gold sheet (A/Ke 1977, No 1457).
Schafstedt, Kr. Dithmarschen.	2 armspirals (A/Ke 1991, No 9226).
Sigerlevøster, Frederiksborg amt.	Sword with gold sheet (A/Ke 1973, No 246).
Skydstrup, Haderslev amt.	Armring ((A/Ke 1984, No 3527).
Smørumovre, København amt.	Fingerring (A/Ke 1973, No 353).
Store Anslet, Haderslev amt.	Fingerring (A/Ke 1984, No 3728).
Store-Fuglede, Holbæk amt.	Sword with gold sheet (A/Ke 1976, No 625).
Süderschmedeby, Kr. Schleswig-Flensburg.	2 spirals (A/Ke 1978, No 2292).
Søviggårde, Ribe amt.	Bracelet (A/Ke 1986, No 4169).
Tellingstedt, Kr. Dithmarschen.	Gold wire (A/Ke 1991, No 9252).
Tobøl, Ribe amt.	2 armspirals (A/Ke 1986, No 3922).
Tobøl, Ribe amt.	Armspiral (A/Ke 1986, No 4069).
Torsballig, Kr. Schleswig-Holstein.	2 hair(?)-spirals (A/Ke 1978, No 2360).
Tødsø, Thisted amt.	"Sun-disc" (DB I, No 578).
Utersum, Kr. Nordfriesland.	2 armspirals (A/Ke 1979, No 2856).
Utersum, Kr. Nordfriesland.	Armspiral (A/Ke 1979, No 2658).
Vasby, København amt.	2 hair(?)-spirals (A/Ke 1973, No 338).
Vester-Fiskebæk, Ringkøbing amt	(DB I, No 976).
Vinstrup, Hjørring amt.	Gold wire (DB I, No 517).
Vojensgård, Haderslev amt.	2 spirals (A/Ke 1984, No 3601).
Øster-Thorsted, Vejle amt.	Armspiral (A/Ke 1990, No 4381).
Øster-Velling, Viborg amt.	Belt-hook with gold sheet (DB I, No 711).
Åbygård, Bornholms amt.	Sword with gold sheet, armring (A/Ke 1977, No 1503).

Searching for an explanation, it becomes obvious that it is necessary to deal with the grave finds in a more detailed way. Nearly all graves are found in burial mounds. Usually the bodies lie in hollowed oak trunks surrounded or covered by stones. Inhumation is predominant but skeletons are rarely preserved and the sex of the deceased has to be identified by their personal equipment. Men are determined by weapons, mainly swords and battle axes, and little personal accessories such as belt hooks and bronze double studs, which belong either to the belt or to a mantle. The equipment can be completed by razors, tweezers, strike-a lights and, very occasionally, by tools. Women's graves contain ornaments like armrings, necklets of different forms, beltplates and ear- or hairrings. Common to both sexes are daggers, fibulae, glass and amber-beads, small knives and bronze tutuli belonging to the belt.

The large number of graves could give the impression that all members of the society were buried this way. But this is very unlikely, if one takes into account the cost of building barrows and providing grave furniture. Furthermore a more detailed examination of the archaeological data shows clearly that there are three times more men's than women's graves and children are almost totally absent. Therefore these graves cannot represent the natural population.

In spite of the great amount of finds it is still impossible to describe the status of the deceased exactly, but there are some facts which can be recorded. First of all this group of people had access to imported metals; they probably controlled the trade and/or the production of the goods needed for it. When they died, a group of persons was obliged to build a burial mound of turf, which sometimes meant the destruction of up to 3 hectares of productive land for decades, and implies the political power of the deceased. But the most important point for archaeological investigation is the way they created their image for the after life, even though one can see just a small part of the original grave goods.

2. Gold as an element of men's graves' furnishing

All men appear as warriors, often with numerous weapons, but it goes without saying that archaeological remains of graves do not have to reflect real life, and not all men buried with weapons had to be warriors. At Valleberga, South Sweden, a 40 to 55-year-old man was buried with a sword, a battle axe, 2 fibulae, little bronze tutuli, and other smaller objects (Strömberg 1974, 92f.). The preserved bones however show that the man had a delicate figure and if he actually used his weapons he surely did not do so regularly. Strömberg (1974) argues that he was a member of an upper class and owed his wealth to trade or the control of land. Weapons in Early Bronze Age graves therefore do not need to imply a belligerent society, but rather the existence of a rich upper class, whose male members carried, sometimes very precious, arms as status symbols. Unfortunately, preserved skeletons are very rare in Period II graves and strictly speaking one cannot generalize the results of Valleberga, but the investigation on Early Bronze Age swords from the Danish Islands also led to the conclusion that there were frequently scarcely used weapons in the graves (Kristiansen 1984, 198f., Fig. 6).

There is also the fact that in many cases the combinations of weapons do not seem to be logical. This is obvious if one looks at the inventories of men's graves in southern Jutland and Schleswig-Holstein, especially in the western part of Holstein, where all combinations of weapons - swords, daggers, spearheads and axes - can be found. Taking into account that the coffins were made or at least finished in the burial place, as shavings beside them show (Thrane 1978, 15), and that the corpse, and of course the grave goods, had to be brought there, it becomes evident that not only the erection of the barrow but also the burial itself was surely a public event and one has the impression that depositing weapons also served the purpose of demonstrating wealth. Probably this does not only go for the deceased but also for the persons who were responsible for the burial. Weapons are the heaviest objects found in graves, and laying them into the coffin was surely an opportunity to demonstrate to what extent one could afford to take them out of circulation. Therefore among other things grave finds seem to be the result of an ongoing competition between the members of a community with the intention to be as handsome and wealthy as possible even or maybe especially for after life. In consequence, attempts to verify social stratification by grave finds are vague about the subdivision of graves by their inventories (e.g. Kristiansen 1984, 199f.; critically regarded by Ille 1991, 148f.). Clearly distinguishable groups of grave inventories, which could indicate differences in social status of the dead, cannot be defined by their composition, but only by the weight of the objects (Randsborg 1974, 51f.).

As briefly mentioned above, the extent of grave furnishing varies regionally. Men's graves with three and more weapons are concentrated in the south, where their proportion of all men's graves (7,6%) is clearly higher than in the north (4,7%), where the amount of grave goods in men's graves decreases slightly from West to East in proportion to the increase of hoard finds (Randsborg 1974, 58). Against this background, gold ornaments might have been the most precious means to emphasize personal status. This assumption is confirmed by the striking overlap between concentration of these richly furnished graves (Fig. 3, Table 2) and the distribution of the gold rings and spirals for arms and fingers. As these objects were of unique form and material and could be worn visibly, they surely played an important role in self-image. Strangely enough gold is not restricted to rich graves, but some finds with only one weapon give the impression that armrings and bracelets had been imitated by rather primitive means, as the armring in the Skydstrup grave, which is made of small pieces of wire.

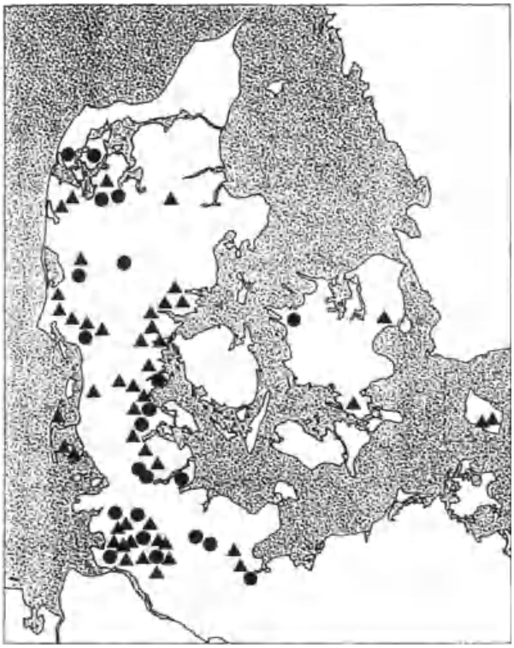

Fig. 3: Filled triangles: Men's graves with gold rings or spirals. Filled circles: Men's graves with 3 or 4 weapons.

Table 2. Men's graves with 3 and 4 weapons.

Sword, dagger, battle-axe

Höbek, Kr. Rendsburg-Eckernförde (unpubl., Landesmuseum Schleswig K.M. Archiv 278/1881).
Vaale, Kr. Steinburg (Werner 1987, 167).
Reinfeld-Dröhnhorst, Kr. Stormarn (Hingst 1959, 380).
Soed, Haderslev amt (A/Ke 1984, No 3615).
Kalundborg, Holbæk amt (A/Ke 1976, No 602).
Heager, Ribe amt (A/Ke 1986, No 4112).
Fuglsang, Skanderborg amt (DB I, No 850).
Nørre-Vium, Ringkøbing amt (DB I No 925).
Dover, Thisted amt (DB I, No 564a).
Bustrup, Viborg amt (DB I, No 742).
Grove, Viborg amt (DB I, No 677).
Bolderslev, Åbenrå amt (A/Ke 1981, No 3006).
Mjøls, Åbenrå amt (A/Ke 1981, No 3061).
Fahrenkrug, Kr. Segeberg (Kersten 1936, Taf. XVI).

Sword, dagger, spearhead

Vaale, Kr. Steinburg (Jacob-Friesen 1967, 332; Taf. 63,1-3).
Limensgård, Bornholms amt (A/Ke 1977, No 1465).

Sword, battle-axe, spearhead

Hövede, Kr. Dithmarschen (A/Ke 1991, No 9157).
Norby, Kr. Rendsburg-Eckernförde (A/Ke 1978, No 2538).

Sword, dagger, battle-axe, spearhead

Keelbek, Kr. Schleswig-Flensburg (A/Ke 1978, No 2317).
Süderschmedeby, Kr. Schleswig-Flensburg (A/Ke 1978, No 2292).
Tarbek, Kr. Segeberg (Jacob-Friesen 1967, 333; Taf. 44,9-10; Kersten 1936, Taf. XIV).
Vester-Jølby, Thisted amt (unpubl. manuscript K. Kersten. Mus. Nykøbing 25-30).
Glüsing, Kr. Dithmarschen (A/Ke 1991, No 9123).

In contrast to this type of grave furnishing, combinations of three or more weapons are very rare on the Danish Islands and the northern part of the mainland. Normally, men's equipment consists of one or two weapons, a razor and a pair of tweezers and seems to be more standardized, with the exception of four graves which contained a so-called sun-disc. These gilded bronze discs of approximately 25 to 35cm in diameter were found in the middle of the grave; this means that they obviously belonged to the clothing, although they are badly preserved and it is impossible to find out how they were fastened. They are regarded as the equipment of priests as with the disc of the Trundholm chariot, which served a ritual purpose. In general the graves give the impression that here the characterization of real or desired status by gravegoods was less important than in the south. This may be the reason why it was not necessary to furnish the graves with gold rings.

The higher degree of standardization and the lower level of grave furnishing fits the observation that in northern Jutland and Zealand gold was mainly used to clad bronze objects. In this context it must be mentioned, that there is hardly a visible difference between a polished bronze surface and gold. Gilded objects are thus not suitable for showing wealth.

This leads to the conclusion that gold had another meaning besides that of demonstrating high personal status. In contrast to bronze gold does not change colour, a characteristic, which surely contributes to the high regard for this metal. Of course, clading could have been used just for optical effect, but it seems as if the value of a gilded object did not depend only on the gold itself but mostly on its immaterial meaning.

This theory is supported by a few graves, where gold occurs in a form not yet mentioned. It involves small pieces of gold wire or sheets, which can be found singly or combined with fragments of bronze implements, little pieces of amber and other small objects of low value. Some well recorded graves show that these objects originally were kept in a little leather bag. They are sometimes regarded as the equipment of magicians, but probably they belonged to a collection of amulets. It is evident that here gold could not have served the purpose of visibly demonstrating personal wealth or social rank.

The strong immaterial meaning of gold is also evidenced by two robbed graves, which also prove its close connection with its owner. The grave of Barde, Ringkøbing amt, was obviously robbed soon after the erection of the tumulus, since the robbers knew the exact position of the coffin. They holed the top and took the sword and perhaps other weapons, but they left the scabbard, less precious things like two wooden bowls, a wooden box, a belthook, a pair of tweezers and, strangely enough, a golden bracelet. At Harrislee, Kr. Schleswig-Flensburg, the top of the coffin was broken. As at Barde they took the sword without the scabbard and only the bronze blade of the battle-axe. There was no metal left in the obviously richly furnished grave except a golden hairspiral, which lay near a woollen cap. Since grave robbery was undertaken to gain metal (Thrane 1978, 17), it is hard to believe, that the objects stayed in the grave by accident. In both cases the inside of coffin was completely rummaged and the grave robbers had enough time to put the wooden parts of the weapons back into the coffin; therefore it is also very unlikely that they failed to see the gold objects. Obviously it was more dangerous to steal gold than bronze objects. Fear of discovery could not be the main reason, although the grave robbers surely aroused suspicion with an outstanding object like the Barde bracelet, but it is very unlikely that a little gold spiral would attract attention. Therefore one should consider whether the reason for leaving gold in the grave was the immaterial value of the material or/and the object, which belonged exclusively to its rightful owner and would turn against an illegitimate one.

In summary, the region is divided into two parts on the basis of gold as an element of men's graves' furnishing. In the south gold was used in the form of rings and bracelets. Considering the strong competition between the male members of the society, as reflected in the wealth of weapons in the graves and the numerous and different combinations of grave goods, these ornaments surely demonstrated the high social position of their owners. This was achieved both by the object itself and by its material.

Vying with each other in furnishing graves was less important in the northern part of Jutland and on the Danish Islands. Gold rings are almost lacking in the archaeological material, but there are gilded objects and therefore the value of gold was probably confined to an immaterial level.

3. Gold in women's graves

The situation is quite different with gold in women's graves. In the archaeological material women are characterized by bronze beltplates, several kinds of necklets and arm ornament and, frequently, small tutuli. But these objects are found all together only in a few graves. Normally there is just one or a combination of two or three of them. Grave furnishing can be completed by a dagger, fibulae and, less frequently, by little spirals for hair or fingers, ankle rings and small bronze tubes from a skirt or a belt. But this list of grave goods can hardly describe the numerous variations in combining these objects. It seems as if grave furnishing depended more on individual decisions than on fixed rules, since there are hardly two identical combinations. As for this, women's graves are very similar to the contemporary men's graves of western Holstein, but the distribution of rich men's graves and the comparable women's graves is strikingly different.

In this context gold is very rare and occurs in form of spirals only. Their interpretation as hair or finger ornament depends mainly on the size, but is sometimes supported by the position in the grave. It must be mentioned that this kind of ornament was made mostly of bronze and therefore it cannot be compared to men's gold bracelets.

As expected, most of the gold spirals are found in the region where there is a concentration of men's armrings and spirals (Fig. 4, Table 3). But in contrast to men's graves this observation can not be explained by splendid grave furnishing, because the inventories of women's graves in Schleswig-Holstein are rather poor compared to a considerable number of fairly rich graves on the Danish Islands, which hardly ever contain gold. Since differences in supply can be excluded, this might depend on the regionally limited custom of wearing spirals, which can already be seen on the distribution map. The position is clarified by comparing these finds to the total number of women's graves. In Schleswig-Holstein and South Denmark 53% of all women's graves contain spirals, whereas in the north and on the Islands only 20%. But this observation does not explain why there are no other gold objects in the rich women's graves of the Danish Islands. Maybe the possession of gold was restricted to men.

Fig. 4: Women's graves with gold and bronze spirals. Filled triangles: gold; Open triangles: bronze.

Table 3. Women's graves with gold spirals.

Karlslunde, København amt (A/Ke 1973, No 516).
Oldenburg, Kr. Ostholstein (Jahrb. f. Heimatkunde Oldenburg/Osth. 23, 1979, 25; Abb. 1-4).
Dannewerk, Kr. Schleswig-Flensburg (A/Ke 1978, No 2338).
Klein Niendorf, Kr. Segeberg (unpubl. Landesmuseum Schleswig K.S. 10092a-b).
Tensfeld, Kr. Segeberg (unpubl. Landesmuseum Schleswig K.S. 10454g-h).
Skydstrup, Haderslev amt (A/Ke 1984, No 3527).
Kås, Viborg amt (Zimmermann 1988, 220).
Frøslev, Åbenrå amt (A/Ke 1981, No 2962).
Skydstrup, Haderslev amt (A/Ke 1984, No 3530).
Tobøl, Ribe amt (A/Ke 1986, No 3919).
Lilholt, Haderslev amt (A/Ke 1984, No 3515).

To sum up, women's gold was not only rare and on average much lighter than gold objects in men's graves but also of simple form. It is more than obvious that gold wires, which normally served as ingots, had been just cut and shaped.

4. Remarks on the import of gold to South Scandinavia

It is useful to finish this paper with some remarks on trade, and the commodities which might have supported the import of gold to South Scandinavia. Research on Bronze Age exchange normally deals with bronze, but the results apply to gold too.

It is quite clear that there was no trade in finished products, neither for bronze nor for gold objects, because in Central Europe Nordic weapons and ornament do not occur and only a few Central or Western European pieces are known from South Scandinavia. Therefore raw material had to be imported either as ingots or scrap.

Searching for the right commodities in return a number of possibilities was discussed, like cattle, rare furs from remote regions of northern Scandinavia, grain and some other agricultural products. It goes without saying, that trade in these things cannot be proved archaeologically, which of course does not mean that it did not exist. All these things might have played a role in barter, but none of them could have been the main trade good, because these proposals do not consider that the commodity traded in exchange for metal must have been available constantly every year, since in southern Scandinavia metal objects lost by burials and offerings had to be replaced regularly. But agricultural production depends on many factors, which cannot be influenced by men, for example weather or livestock disease. If one takes into account the low level of stockbreeding and crop growing, it is very unlikely, that agricultural products could have been produced in constant quantity and quality. Therefore they could have played only a secondary role in Bronze Age trade.

But of course these restrictions do not answer the present question. In a recent Swedish study sea-salt was suggested as the most important commodity for exchange between Scandinavia and Central or probably also Western Europe (Jaanusson and Jaanusson 1988, 107). Salt extraction from sea-water is a comparatively simple procedure. In cold regions it is normally based on burning, washing and drying algae, debris found on the beaches and even beach sand. On the western coast of Jutland and Schleswig-Holstein this kind of salt-production has been practiced since the Middle Ages and in some places cattle salt was gained this way up to the 18th century.

Sea-salt as a commodity in exchange for metals would be a very tempting idea, if there were no centres of salt production much closer to the mining centres than South Scandinavia, as for instance Halle a.d. Saale, where salt of much better quality has been produced since Neolithic times. Nevertheless it should not be forgotten, that South Scandinavia probably did not depend on salt import.

Finally reference should be made to amber as an exchange good, as has already been discussed in the past. The strongest argument for amber is its evidence in Central European graves. Therefore it is hard to understand why it has not been taken into account in recent studies. However, amber seems to be an ideal commodity. It occurs on the coasts of the North Sea and the Baltic, where it could be picked up and where more systematic searching could be easily managed. Furthermore it is very light and therefore it could be transported without difficulties even over long distances. Unfortunately it is not quite certain that all amber finds are from Northern Europe, but if the inhabitants of South Scandinavia really were the only suppliers of amber, they controlled its supply and therefore its price, but only to a certain extent, since they urgently needed metal. Equally the mining centres depended on export and this system could have worked as long as the latter could afford luxury goods such as amber.

The long-lasting supply of metals to South Scandinavia and North Germany was probably based on the combination of amber as trading goods and the avoidance of the need to import salt.

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Chapter 5

BRONZE AGE GOLD IN BRITAIN

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ABSTRACT. The British Isles possess a number of gold occurrences and a rich variety of gold ornaments of Bronze Age date reaching back to the earliest use of metal. However the history of gold working in the Bronze Age is curiously episodic and contradictory: for example periods when gold is at its scarcest show increased production and technical innovation in bronze metallurgy. This paper will take the Principality of Wales and its border regions as an example that illustrates this history particularly well. Gold metalwork and metallurgy exhibit three distinct stages nearly corresponding to the local Early, Middle and Late Bronze Ages. In each of these successive periods the gold objects exhibit distinct technologies, origins and functions, and these are explored in turn. The possibilities of an interest in ascribing an intrinsic value to the gold in terms of a weight standard and bullion value as opposed to its extrinsic properties of malleability, nobility and colour are considered. Metallurgical discussion is based on a re-evaluation of the data of Hartmann (1970, 1982).

1. Introduction

The mountainous Principality of Wales has abundant metal resources, particularly of copper and lead; in the late 18th century the mines at Mynydd Parys on Ynys Môn (Anglesey) were the largest copper mines in Europe if not the world. There is now clear evidence that a number of copper deposits were exploited in the Bronze Age, for example at Pen-y-Gogarth (Great Orme) and Mynydd Parys, Gwynedd and Cwmystwyth and Nant yr Eira, Dyfed (for a review see Crew and Crew 1990). Wales also has two significant occurrences of gold. (Fig. 1)

In what is sometimes referred to as the Dolgellau gold belt, to the south and east of the Harlech Dome there is still a vestigial mining activity extracting gold from quartz veins, with gold panning on an amateur basis in the surrounding area. When the world gold price was at its highest there was a proposal by an international mining company to place a large gold dredge in the adjacent Mawddach estuary. The Dolgellau gold belt contained a number of mines opened after a minor gold rush in 1843, of which only four were of any significance. Typical were Glasdir, where the ore was associated with chalcopyrite in brecciated, thinly interbedded siltstones and sandstones of the Festiniog Flags formation of the Upper Cambrian; gold tellurides also occur. Concentrates typically contained 30ppm gold with periodically larger amounts of silver. In 1913 1475 tons of copper ore yielded 7375 ounces (229kg) of silver and 737 ounces (21.9kg) of gold, while in 1914 1600 tons of ore yielded 900 ounces (28kg) of silver and 900 ounces (28kg) of gold. In the neighbouring Clogau mine

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the miners reported that the best gold ore was to be obtained where the quartz had a cloudy, greenish hue and often included brecciated country rock. Between 1861 and 1907, 145 080 tons of quartz yielded 77 501 ounces (2 410kg) of gold; an average composition was 90.16% gold and 9.26% silver (Smith and Carruthers 1925, Dunham et al. 1978, 275-6). To the south-west, at Dolaucothi, Dyfed, is a somewhat different occurrence in the Llandovery formation, to the north-west of Llandovery. The Ogofau mine had the alternative name of Roman Deep and was almost certainly worked by the Romans. The gold was obtained partly from a quartz lode containing free gold and auriferous sulphides, and partly from auriferous pyrite impregnating and replacing shales (Dunham et al. 1978, 279). The gold sources are marked on the distribution map in Fig. 1.

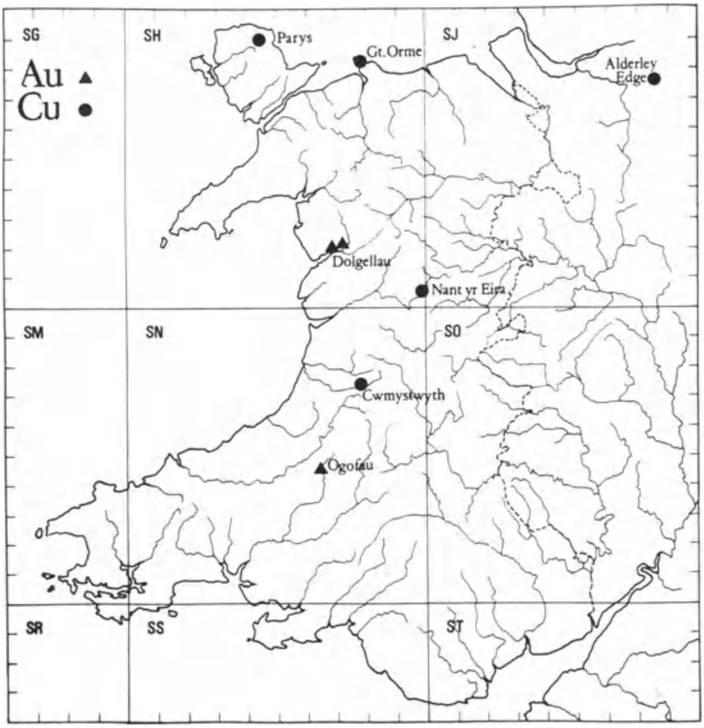

Fig. 1: Location of Welsh gold deposits, and of copper-mining sites with proven or probable Bronze Age activity. The map also indicates the 100km and 10km squares of the Ornance Survey National Grid.

Hartmann's data (published in Taylor 1980, 141) suggest that Welsh gold can have copper contents of the order of 100ppm, while some sources produce metal with 0.10-0.15%. Silver ranges from below 5% to 15%. Tin is absent but mercury, lead and zinc may accompany the gold. Although it is impossible to correlate these ore analyses with Welsh gold objects on the present level of analysis one must still consider the question of whether Welsh gold ores might have been exploited in the Bronze Age. To do this one must look at typology and distribution and also make detailed comparisons between the compositions of the Welsh goldwork and that from other areas.

Before discussing the goldwork found in Wales in each period of the Bronze Age some mention must be made of how the available analytical data is treated. This data comes from Hartmann's publications and from analyses made on behalf of the National Museum of Wales at the British Museum and in Oxford for the purpose of Treasure Trove inquests. The latter analyses were obtained with all elements as weight %, while Hartmann's give weight % silver and parts per 100 Au for copper and tin. A computer spreadsheet can be used to transform the data in either direction, and the Hartmann format was used here. The British Museum data were obtained by X-ray fluorescence and did not include values for tin. Arbitrary values were assumed for the purposes of graphing the data. The data are displayed in Fig. 2 as a weighted ternary plot based on a formula developed by Taylor (1980) where:

$$100 = Ag + 2*Cu + 10*Sn.$$

The resulting graph shows very clearly the main trend in composition, which is the stepwise increase in the proportion of copper with each successive period. From the beginning of the Middle Bronze Age there was also not so much an increase in the proportion of tin as an increasing spread of tin contents. The graph has been in two ways; its framework is based on the dating of associated finds while the framework is used in turn to date other material.

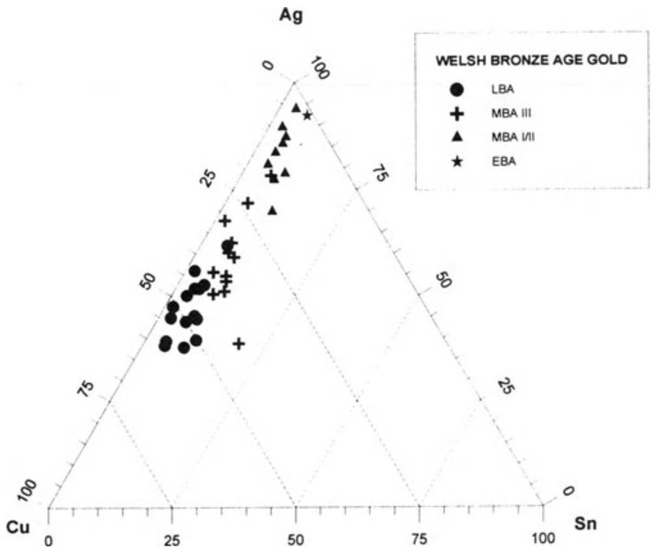

Fig. 2: Weighted ternary plot of silver, copper and tin contents in Welsh Bronze Age goldwork.

An alternative and relevant approach to Hartmann's data has recently been taken by Warner (1994). For a paper reviewing the analyses of Irish Bronze Age goldwork he used simple bivariate and trivariate plots. In order to overcome the problem of data spread over more than one order of magnitude on at least two of the axes it is normal to transform the data logarithmically. This was not entirely satisfactory for this dataset so Warner tranformed the data to the power of 1/2 or 2/3 in order to give the clearest display for the data. Using these graphs he showed very clear correlations between composition and object type and, by implication, chronology. These correlations were more detailed than could be obtained from Hartmann's assignment of the analyses to his composition groups. There is still much to do in understanding this detail, a process complicated by the fact that the metalwork chronology for the later Bronze Age in Ireland needs clearer definition. For the moment, though, Warner's conclusions very much parallel those reached here for Wales.

2. The Early Bronze Age

Gold makes its first appearance in Britain in Beaker contexts in the form of basket ear-rings and sheet gold discs at a time when copper and arsenical copper, rather than bronze, were the standard metals for tools and weapons. Although there are Beaker burials in Wales none are recorded as containing gold so that one must look to England for the evidence. Recently radiocarbon data have been obtained for two English finds. At Chilbolton, Hampshire, the primary burial in a small ring ditch was associated with, among other things, a tanged copper dagger, a gold bead or bead-cover and two pairs of basket earrings. One pair contained 9.4-9.5% silver and 1.3-1.5% copper, the other 10.8-11.0% silver and 0.2-0.3% copper, while the bead-cover contained 9.5% silver with copper undetected; tin was undetected in all these analyses obtained by X-ray fluorescence. The 1-sigma date range is 2290-2040 B.C. (cal) and at 2-sigma it is 2460-1940 B.C., so that even at this early date copper metal must have been entering the gold melts, if only accidentally (Russel 1990). Another earring, from Radley near Oxford has a similar date, and contains 6.9% silver, 0.8% copper and less than 0.05% tin (Northover, unpublished).

This first step in gold working was concerned only with sheet, and sheet remained the dominant form for the rest of the Early Bronze Age, until about 1500-1400 B.C. The next group of Early Bronze Age sheet gold ornaments may have some relevance to Wales as there are tantalising descriptions of gold objects found in the last century when Early Bronze Age burials were uncovered, but nothing has survived to be identified. The most notable feature of this group, associated with some of the richest graves of the "Wessex Culture" (Taylor 1980, 45-49) is a carefully executed geometric ornamentation of engraved lines, rectangles, lozenges and fine punched dots. The tombs containing this gold are rather few in number and concentrate in central southern England with outliers in east Anglia and the south-west. The gold used contains from 5% to 20% silver with less than 0.5 parts copper per 100 parts Au and usually less than 0.05 parts tin. Exceptions such as the Rillaton gold cup from Cornwall have up to 0.2 parts tin but these tend to have a peripheral distribution.

The third group of Early Bronze Age sheet ornaments in the British Isles does have a representative in Wales (Fig. 1) and this is the Llanllyfni gold lunula (Fig. 3). Lunulae are penannular neck ornaments expanding from square tab-terminals to a broad crescent shape often ornamented with geometric designs that echo those on Beakers (Taylor 1980, 25-44). Taylor was able to form a number of stylistic groups which showed some correlation with size and weight. Lunulae as a whole are a product of the highlands and islands of the British

Isles, with a concentration in the west and north of Ireland, continuing across Scotland to the north-east. An important association is a hoard from Harlyn Bay on the north coast of Cornwall where lunulae occur with simple bronze flat axes, which could date the find as early as 2000 B.C., although dates up to 1800 B.C. would be reasonable. The Llanllyfni lunula belongs to Taylor's "provincial" group which is distributed almost wholly outside Ireland and one could look to Cornish, Welsh or Scottish gold as much as to Irish for its metal. Compositionally this lunula stands at the head of the time series in the ternary diagram in Fig. 2. Interestingly it is not possible to separate lunulae as a whole from the Wessex gold.

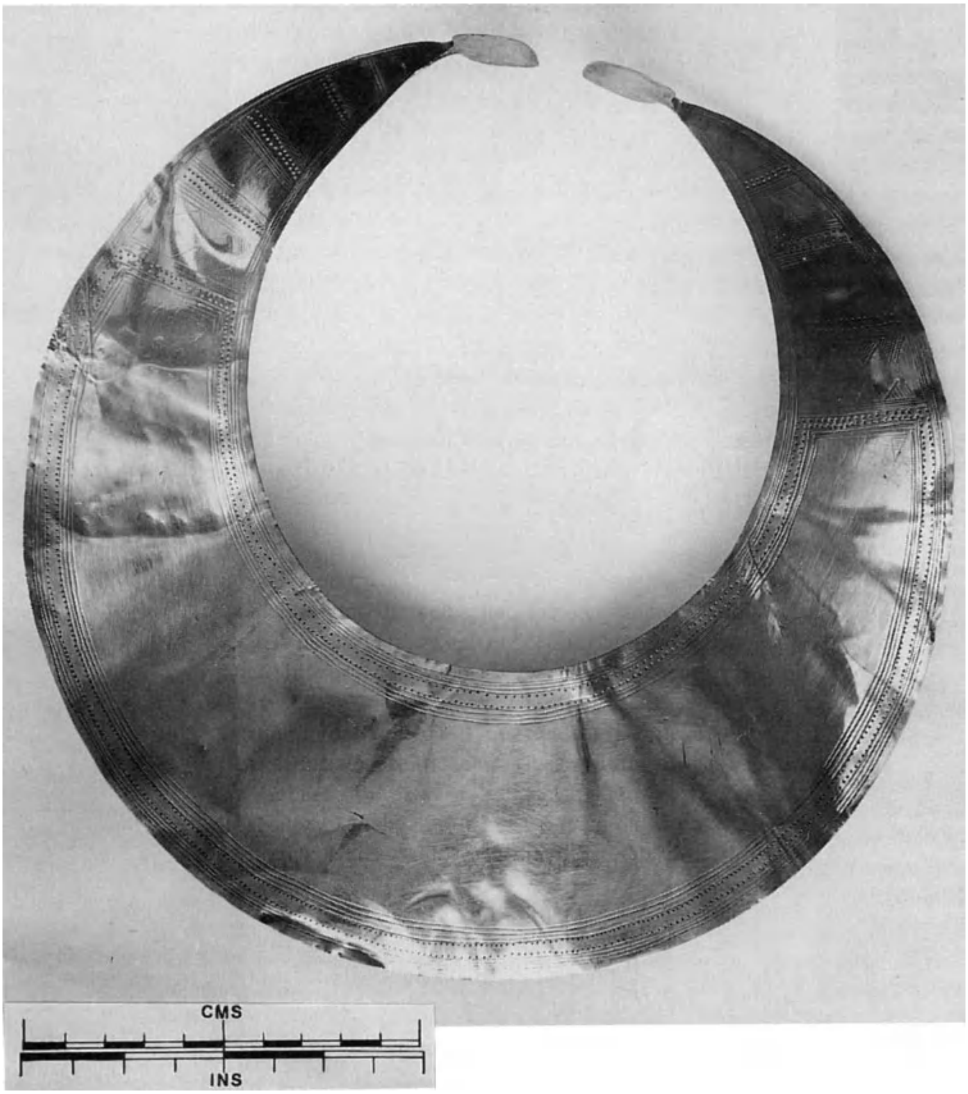

Fig. 3: The Llanllyfni lunula. National Museum of Wales.

3. The Middle Bronze Age

The culmination of the sheet gold tradition is the magnificent and unique gold cape from Mold, Clwyd (Fig. 4) (Powell 1953). This remarkable construction has all-over decoration of repoussé ribs and alternating bands of small round, rectangular and lenticular bosses. Taylor (1980, 52) has reviewed some of the parallels that might resolve the dating of the cape, but did not consider the evidence of the composition. In the ternary diagram in Fig. 2 the Middle Bronze Age (MBA) II grouping is based on a small number of hoards of which comprise only gold ornaments, and which share certain morphological and compositional features. The actual dating to MBA II depends on a number of parallels in Continental Europe, notably in Brittany (Savory 1977) but may actually extend back to MBA I. The compositional grouping defined by these hoards encompasses the Mold cape. Taylor suggested that the Mold cape might have influenced the decorative elements of a number of gold vessels, for example from Avanton, Vienne and Schifferstadt. An MBAI/MBAII date would in fact encourage this notion because in MBA I Welsh metalwork was being directly exported to Continental Europe (Northover 1980).

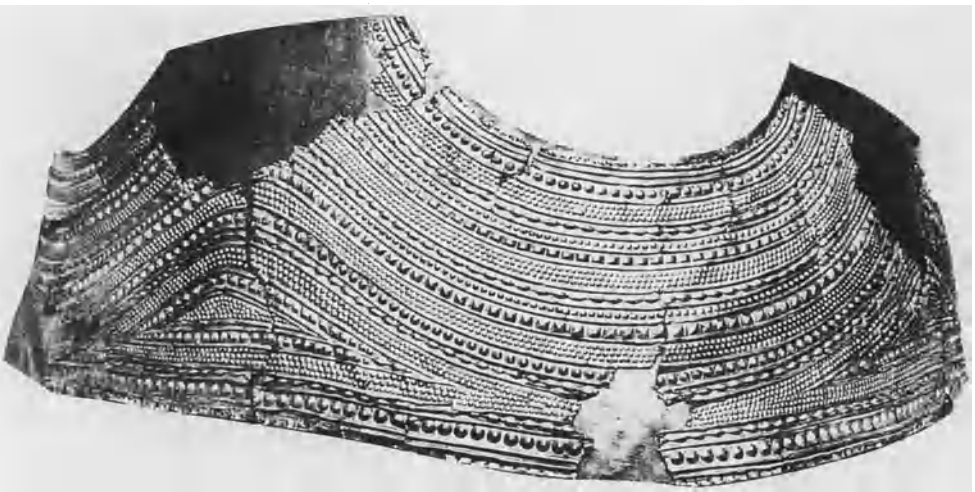

Fig. 4: The Mold cape. National Museum of Wales.

Welsh mining and copper production remained important in MBA II (Bronze Moyen II/III in France, mainly Bronze C/D further east) but there appears to have been a shift in emphasis from the north, which was important in MBA I, to Mid and Central Wales. This new focus included the Dolgellau gold belt, creating thoughts of Welsh gold extraction at this time. The distribution and typology of the gold ornaments tends to support such an idea. One is really concerned here with three hoards and one single find all concentrated in south central Wales. From Capel Isaf, Manordeilo, Dyfed, and Maesmelan, Powys come two hoards of flanged bracelets. A specific feature of some of the bracelets is their hooked, slightly expanded terminals. The general form of the bracelets can be parallelled in Brittany but in detail are decidedly idiosyncratic and local. The same hook terminals are also seen on the hoard of simple ribbon torcs from Heyope, Powys (Savory 1958) (Figs. 5, 6).

Fig. 5: The gold bracelets from Capel Isaf, Manordeilo, Dyfed. National Museum of Wales.

Fig. 6: A ribbon torc from the Heyope, Powys, hoard. National Museum of Wales.

It is with these simple twisted torcs that one can approach the question of dating more directly. Twisted ornaments whether of bronze or gold appear in Britain during MBA II, often referred to as the Taunton period after a well-known and typical bronze hoard from Somerset (Smith 1959). The twisted bronze ornaments of the Taunton period comprise a variety of neck-rings and bracelets. They are usually formed form square or round-section wire or bar, manually twisted or cast with a mock twist pattern. The neck-rings or torcs have, almost without exception, simple hooked terminals while the bracelets have plain ends. The gold plain and twisted torcs that begin by imitating these bronze examples also tend to have these same simple hook terminals. Given these very exact parallels between bronze and gold for objects with hooked terminals in the Taunton period, and that all associations for objects with extended terminals, as in the flange twisted torcs to be discussed next, are later, it is reasonable to make the correlation exact (Northover 1989, 122-123). If one does so one can put the Capel Isaf and Maesmelan bracelet hoards and the Heyope torcs together in this period.

Taking these hoards as a self-consistent group one can see from Fig. 2 that they also form a coherent compositional group. Both copper and tin contents have increased since the Early Bronze Age. Copper is typically 1-2 parts per hundred gold and tin 0.1-0.2. This increase could have come in the form of bronze as both copper and tin exceed the norms for British natural gold sources (although there are some small exceptions). Why the increase occurred is hard to understand as the benefit in properties would be negligible and systematic contamination is also hard to believe. That question can be left open, but one must now ask whether the gold could be Welsh. There are two factors that point in this direction, the Welsh typology and the distribution between the two main areas of Welsh gold deposits (Fig. 7).

Fig. 7: Distribution of MBA I/II goldwork in Wales (filled triangles); M signifies the location of the Mold cape. The 100km grid squares are also marked.

There are also small differences in composition from the Irish equivalents (Northover 1989) but the difference depends on copper and tin and so says little about the actual provenance of the gold. Take away the copper and tin, and then the gold fits within the range of silver contents of Welsh sources. It should also be pointed out that small ornaments of any kind were a novelty in the Welsh Bronze Age and that in Wales there are no bronze equivalents to these gold ornaments, something largely true of the succeeding MBA III or Penard period as well.

Exactly where the development of the simple twisted ribbon torc into the elaborate flange-twisted torc (Fig. 8a) of the MBA III or Penard period (Bronze Final I or Bronze D/HA A1 in Continental Europe) took place is not certain. It may have happened in Ireland, or even in France but Wales and the Marches are one of the prime areas. Together with its lighter plain and twisted wire cousins (a form utilised when the gold wire was too slender to be split into a cruciform shape (Fig. 8b) there are now seventeen examples. In Wales all associations are of torcs with torcs except for a possible hoard of a double-looped transitional palstave and a flange-twisted torc from central Wales. Elsewhere, though, associations firmly place the flange-twisted torc in the Penard period (Needham 1990).

The flange- and wire-twisted torcs are substantial ornaments and the heaviest Welsh example weighs 754g. Most concentrate in the range 200-275g, with wire twisted torcs being lighter. Their manufacture has been reviewed elsewhere (Taylor 1980, Northover 1989) and it is probable that the correct interpretations have yet to be made. Some joining technique is implied because many of the torc terminals were formed separately and then attached but so far analysis and microscopy have failed to distingusih between welding and soldering. It is believed that the torcs were designed to be worn as a large single ring, perhaps at the waist, or coiled as an armring. The actual frequency of the two choices is unknown as several torcs have been either coiled or uncoiled or are otherwise no longer in their original shape. The elaboration of the torcs also relates to other contemporary trends: this is the period when bronze cauldrons and repoussé decorated sheet bronze shields first make their appearance. Also new are specialised metalworking tools such as bronze hammers and anvils. At Fresné-la-Mère, Calvados, France, a small hoard associates a gold torc and bracelet with, among other bronzes, an anvil and hammer (Eluère 1982).

Metallurgically there is a step change from the Taunton period with a marked increase in copper contents and, to a lesser extent, in tin contents (Fig. 2). Some incorporation of bronze is implied but it is also necessary that copper metal was added. This is of some importance because the Penard period was one of declining if not dormant mining activity in Britain and the usual metal supply was bronze scrap (Northover 1980). As in some Welsh gold mines, like Glasdir, chalcopyrite and gold are found close together the use of local copper as well as gold is a possibility. Distributional evidence is neutral as these torcs and other contemporary goldwork are spread through a wide area of Wales, but still have a concentration in the gold-mining areas (Fig. 9). Interestingly the distribution avoids the copper mining areas of the north-west, that had been important in MBA I/II.

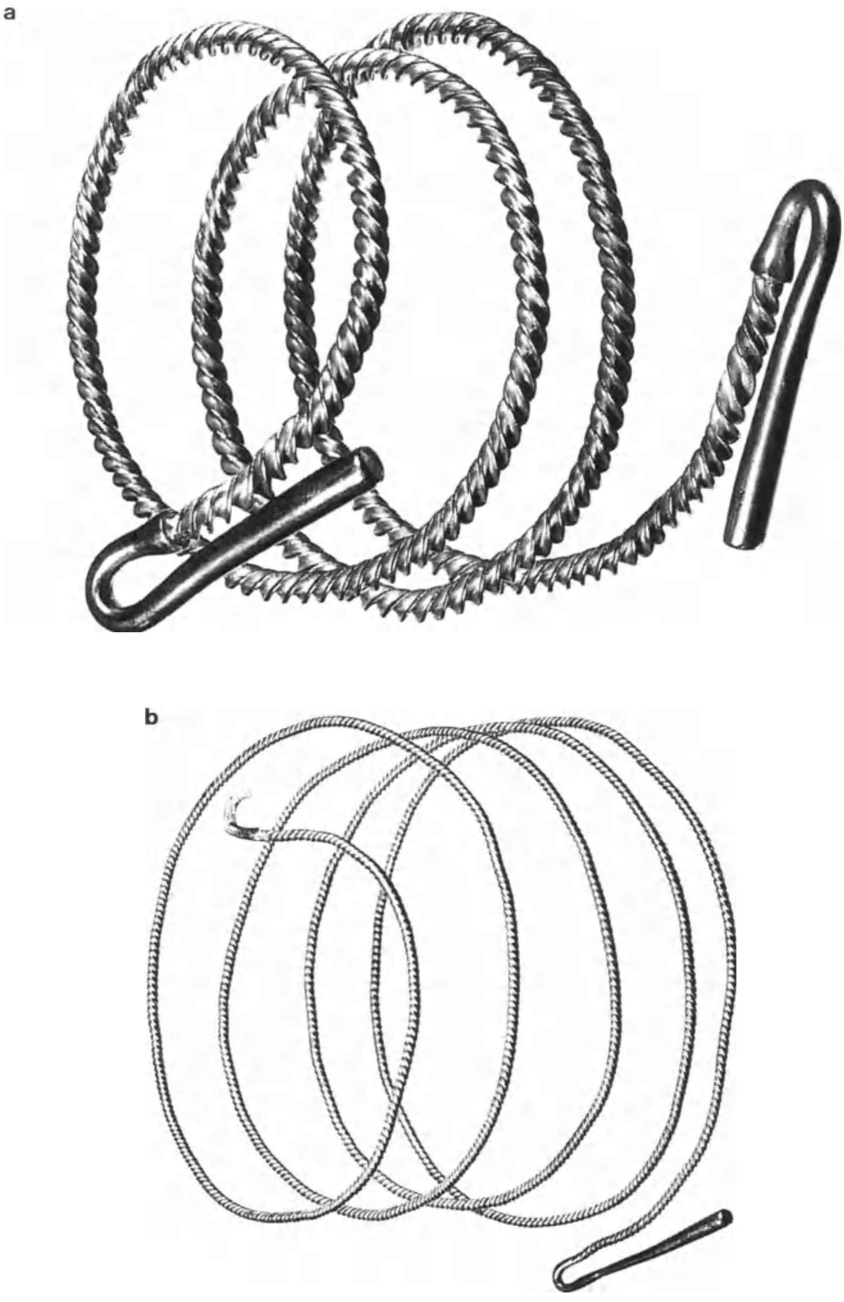

Fig. 8: Gold torcs from Llawrthwl, Powys: a) flange-twisted; b) wire-twisted.

Fig. 9: Distribution of MBA III goldwork in Wales (filled dots). The 100km grid squares are also marked.

In the same way as the Mold cape was dated to MBA I/II another unique Welsh find, the Caergwrle model boat can be dated by its composition to this Penard period. The boat is deeply carved from shale; into each carved field a piece of gold foil is inserted to simulate the bulwarks, perhaps with concentrically ribbed shields, the oars, the sea and the keel. The gold is finely decorated with ruled or compass drawn grooves, either worked direct or stamp. To provide a resilient backing for this work the gold was wrapped round metallic tin.

4. The Late Bronze Age

Events at the beginning of the British Late Bronze Age are confused. In southern and eastern Britain a new industrial tradition appeared, named after a hoard from Wilburton, Cambridgeshire (Northover 1982). This industry contemporary with Bronze Final II in France and Ha A2-B1 in Alpine and central Europe, developed a very sophisticated ceramic piece-mould casting technology and pioneered the use of leaded bronze alloys for complex castings. The industry had direct relations across the Channel with Brittany and the Paris Basin and was entirely dependent on imported scrap for its bronze supply. This metal is radically different from the preceding imports of the Middle Bronze Age, production having switched from pyritic to fahlerz type sources. This change is synchronous across a wide area of Europe from the Alps to Denmark, and in some areas the changed trade patterns, in southern Britain for example, may be related to the arrival of new and intrusive elites serviced by these industries. One of the most important features of the changes as they affected Britain was that the development of leaded bronze seems to have taken place there using a combination of the imported scrap and British lead (Northover 1982).

Given the elegance and prestige value of many of the Wilburton bronzes it might be reasonable to expect an equal creativity with gold. This, in fact, is far from the case and there is only one Wilburton association with gold, a hoard from Thirsk, Yorkshire, on the fringes of the main concentration of Wilburton material (Needham 1990). Until recently it was believed that in those parts of the British Isles outside the domination of the Wilburton industry the metallurgical traditions of the Penard period continued (Burgess 1968) using unleaded bronze, but slowly coming under the influence of Wilburton in both product types and metallurgy. If this were the case one could see the use, if not the manufacture, of gold torcs continuing until some unspecified date in this period. Needham's 1990 discussion radically alters this view and suggests that Penard traditions ended everywhere at much the same time and that for a while bronze might have been rather scarce in these peripheral regions.

In Wales, Wilburton types penetrate along the southern coastal plain and Wilburton metal is recycled into the developing local Late Bronze Age industries. Further north there is a concentration of Wilburton hoards and single finds in the Severn-Dee corridor, where it is possible that the lead the industry needed was extracted. Apart from this the map is rather blank and one must conclude that in west Wales the availability of metal really had diminished, and that Welsh mining activity could have ceased. This is even more true of gold where there is a clear break in the record.

When gold appears again, in Late Bronze Age II contexts (the Ewart Park Period, contemporary with Bronze Final III and Ha B2/B3) both distribution and typology are radically different. Apart from some small fragments of gold with a socketed axe from just outside Cardiff in the south-east, all gold objects are concentrated along or close to the north coast and all have Irish affinities. Many objects are now lost but almost all can be confidently identified as to type. Of some forty identifiable objects with a reliable provenance twenty-nine are concentrated on Ynys Môn (Anglesey) which is even now the home of one of the main ferry ports for Ireland (Lynch 1991) (Fig. 10). Of the forty gold objects all but four belong to just two types: the expanded terminal bracelet and the "lock-ring". The latter are elegant biconical, penannular hair ornaments with ruled decoration fabricated out of thin sheet joined mechanically (Eogan 1969). A hoard from Gaerwen, Ynys Môn contained eleven of each type but all but four have been lost (Lynch, *op. cit.*) (Fig. 11). The Irish connection is reinforced by Irish types among the bronze metalwork of the area and an influx of what is probably Irish metal (Northover 1980). On the other hand a hoard found near the Great Orme copper mines (Savory 1958) combines Irish "lock-rings" and local, Welsh types of bronze tools. It is worth pointing out that the Great Orme mines could have been back in production at this time.

Fig. 10: Distribution of Late Bronze Age gold objects in Wales (filled triangles). The 100km grid squares are also marked.

Very few Late Bronze Age objects from Wales were analysed by Hartmann; some other data are available but not all published analyses include tin. Reference back to Fig. 2 shows that there is a tendency for the proportion of copper to increase in both solid and sheet objects. The compositions also agree very well with their counterparts across the Irish Sea. There is every reason to believe that the Welsh examples were actually made in Ireland and that there was no local goldsmithing tradition in Wales in the Late Bronze Age. The only exception to this pattern of gold compositions is a piece of "ring-money" from Llanllyfni, Gwynedd, in the north-west of the country. Ring-money is a group of rather various small, thick, penannular rings with often, as with this example, consisting of a thick gold foil formed round a bronze or other base metal core. The gold, with 6.33% copper and 11.01% silver is typical enough of Late Bronze Age gold in Ireland and Wales, but it is inlaid with a pattern of narrow bands of electrum with 41.88% silver and 4.04% copper (Green 1988). As there is only one silver object from the entire Bronze Age in the British Isles the idea of an alloy deliberately made up with silver is rather problematic but future research may change the ideas. The exploitation of a discovery of very high silver natural gold is the alternative explanation and not beyond the bounds of possibility. The exact means by which the electrum was prepared and fused to the gold has yet to be determined.

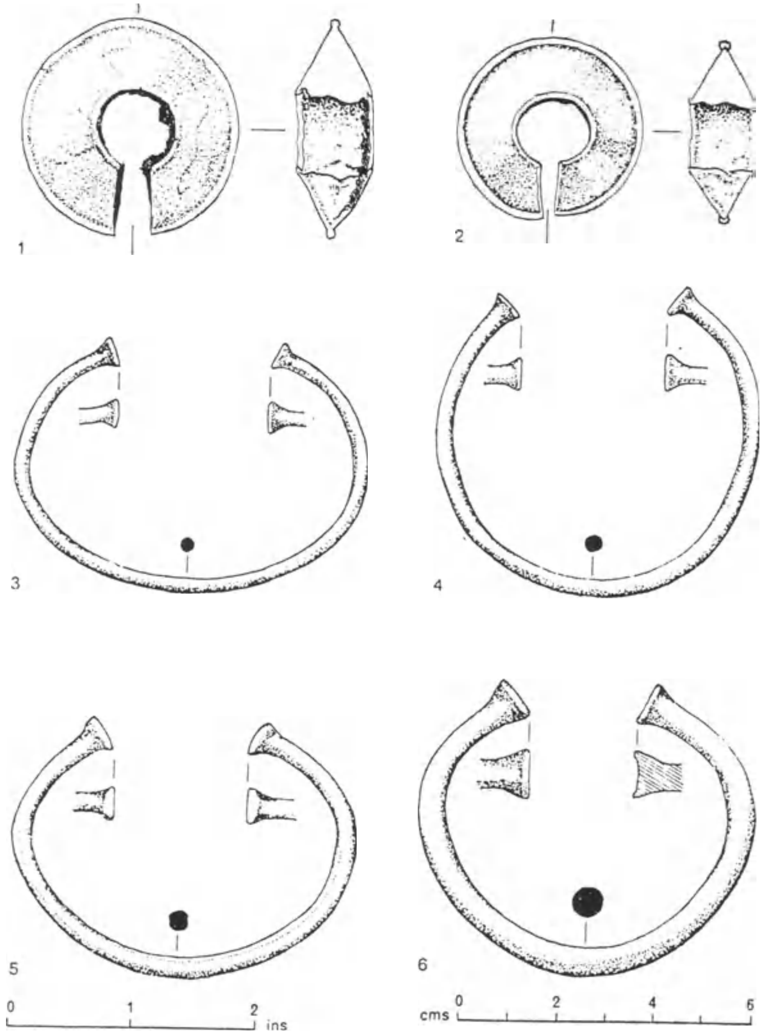

Fig. 11: Gold objects from Ynys Môn. (1-4) the surviving lock-rings and bracelets from Gaerwen. (5-6) bracelets from Beaumaris (after, Lynch 1991, Fig. 67).

5. Weight standards

A hoard with numerous copies of an individual type, such as the Gaerwen hoard and its eleven bracelets and eleven lock-rings, prompts questions about the extent to which their manufacture was standardised and whether that in turn implies a weight standard. Such a possibility was first discussed in the publication of the hoard of gold torcs, bars and bracelets from Towednack, Cornwall (Hawkes 1932). With one odd exception the weights of objects in this hoard fell into three bands: 28-30g, 60-63g, 94-96g. This is close to 1:2:3 although the lighter pieces are relatively light with respect to this scale. Nevertheless a specific way of dividing up the gold appears to have been aimed at and pairs of like objects are very close in weight. The present writer took this idea further with a review of the weights of the MBA gold torcs (Northover 1989). Taking the class as a whole, it was apparent that there was a strong regional variation in the weights, with a broad range from 300-500g in France and Ireland, 210-270g in Wales and the Marches, and 125-185g in England. At first sight this must represent the availability and, possibly, cost of the gold. Above this spread is a small number of "super"-torcs weighing 750-1200g with examples in Ireland, Wales, England and the Channel Island of Jersey. Things are more interesting when one comes to multiple finds of gold torcs; for example in the Llanwrthwl, Powys, hoard (Fig. 8a-b) the weights, allowing for missing terminals, suggest ratios of 2:1:0.75:0.5. The 2:1 ratio is repeated in pairs of torcs such as those from Tara, Co. Meath and Hampton, Cheshire, so the use of weight in apportioning and valuing gold was of importance. The weights spread too widely, however, to suggest a well-developed weight standard. The split may have been decided between the smith and his patron and depended primarily on the quantity of gold available. Now, to confuse the issue a recent find of three torcs from south-west Wales (National Museum of Wales records) has two torcs with weights that are equal within a gram.

Whether this preoccupation with weight and proportion survived is not yet clear. Examination of the published weights of Irish gold objects (Armstrong 1933) has yet to establish any clearly defined system. Where hoards contain numerous gold objects and bracelets of similar form (Eogan 1983) there is some grouping of weights. The very largest objects, too, show some pattern with simple proportions of weight between them. The problem may be that many of the objects, such as "lock-rings" "dress fasteners" and the like are too small and Bronze Age weight standards to inexact for it to be simple to extract the correct pattern.

6. The end of gold

The end of this story of gold in Bronze Age Wales is very simple. It just ends. In Wales and the rest of southern Britain gold disappears from the archaeological record at or about the end of the 8th century B.C. No 7th century (Llyn Fawr or Ha C) contexts contain gold. Indeed during this time and the beginnings of the Iron Age in Ha D, metal of all kinds becomes scarce in Britain, in stark contrast to the wealth of the Hallstatt core area. This phenomenon is as yet unexplained; attempts have been made to link the decline of bronze to the coming of iron but Ha C-D iron, too, is notoriously scarce. Gold does persist in Ireland and Scotland in the form of ribbon torcs (rather different from those of the Middle Bronze Age). In the south, though, gold does not reappear until the arrival of the first imported Celtic gold coins in the late 3rd or 2nd century B.C.

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Chapter 5

THE CEREMONIAL JEWELLERY FROM THE REGOLINI-GALASSI TOMB IN CERVETERI. SOME IDEAS CONCERNING THE WORKSHOP

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ABSTRACT. By analysis of some of the main gold finds from the cella burial of the famous Tomba Regolini-Galassi at Cerveteri it is demonstrated that these were made in the same workshop. Therefore an idea of the artistic and technological capability of an early atelier working at Cerveteri is obtained, which can be considered as the most renowned workshop in the second quarter of the 7th century B.C., not only of this important south Etruscan town, but probably even of the central Mediterranean area in general.

Since the discovery of the famous Etruscan gold jewellery in the princely graves of the Orientalizing phase in central Italy, these objects - like no others - have attracted the interest of generations of archaeologists and goldsmiths and have fascinated the wide public. Over the years the knowledge of these pieces has experienced a remarkable enrichment. This can primarily be explained by the constant progress of archaeological research but also, concerning certain aspects of ancient technology and material science, by the contributions made by restorers and scientists (Becatti 1955, 67-74, Strøm 1971, 58-106, 174-187, von Hase 1979, 15-35, Wolters 1983, 79-83, Cristofani and Martelli 1983, 35-51, Formigli 1983, 321-333, Nestler and Formigli 1993).

More clearly than before, one can now trace the development of gold-working in central Italy from the late Bronze Age (Protovillanovan culture) and the early Iron Age (Villanovan Culture) to the Orientalizing period (von Hase 1975, 99-182). For this reason one understands far better today the genesis of the outstanding gold objects of the famous Regolini-Galassi tomb at Cerveteri, which the author of this paper has had the opportunity to re-study, thanks to the generosity of Prof. Dr. Francesco Roncalli, former keeper of the Etruscan collection in the Vatican Museum, and his successor Dr. Franceso Buranelli - whom I want to take this opportunity to thank very warmly.

Before giving a brief account of the main results of the performed research one should remember the following: to judge by the archaeological evidence, it seems that gold finds from the Protovillanovan (12th to 10th century B.C.) and Villanovan (9th to 8th) periods are extremely rare. This can perhaps be explained by the fact that there are no large natural gold sources in the region which could have been exploited (Fig. 1).

Regarding the craftsmanship and artistry of the few known pieces, the Protovillanovan examples seem to a certain extent to be related to Central European traditions of the Urnfield Period, as shown by the characteristic form and decoration of the two gold bowls from the hoard of Gualdo Tadino in Umbria (von Hase 1975, 101 ff., Fig. 1-2, pl. 12, Schauer 1986, 35, 38, 48, 50 pl. 44, 4-5). From the early Villanovan period a number of objects is known -

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mainly gold fibulae - which are entirely at home in the local tradition of metalworking (cf. von Hase-1975, 112 ff. Fig. 5-6., 8-10. pl. 16-20, Cristofani and Martelli 1983, 26 ff. Fig. 2, 1-6, Fig. 3, 1-5, pl. 1-6).

The beginning of Near Eastern influence in central Italy in the second half of the 8th century is marked by the adoption of two technological advances in gold-working: filigree and granulation (von Hase 1975, 119 ff.). As pointed out in 1975 these new techniques are found adopted for the first time to embellish a small gold fibula of local type (length 2.2 cm) found in a pozzo tomb at Tarquinia dating to the middle of the 8th century B.C. (cf. von Hase 1975, 120 pl. 19 and 21, von Hase 1978, 1107 pl. 356, Fig. 12a-b, Nestler and Formigli 1993, 30, Fig. 21). There can be no doubt that the introduction of such sophisticated new techniques to southern Etruria can only be explained by the arrival of eastern goldsmiths familiar with such complicated processes (Brown 1960, 41, Strøm 1971, 212, von Hase 1975, 140 and von Hase 1978, 1107 ff., Martelli 1991, 1058).

The beginning of these Near Eastern influences in southern Etruria is also characterised by the adoption of a number of new decorative elements such as double leaves, leaf rosettes, crescents and the appearence of certain motifs of probable religious content, such as the sun, or the so called solar-lunar motif which can be found represented on various pieces of jewellery like the famous golden pectoral from the Tomba del Guerriero in Tarquinia and a number of golden pendants from Veii, Vulci, Bisenzio and Marsiliana d'Albegna (Strøm 1971, 58 f., 77 ff., Fig. 37-40, 84, von Hase 1975, 124 ff., Fig. 11-14, pl. 22-23, 25-29 and von Hase 1978, 1103 ff., pl. 353, Fig. 1, 3-4, pl. 354, Fig. 5).

The appearence of more complex motif-groups like the Potnia theron and the Potnios theron can be dated around the first quarter of the 7th century B.C. This is proven by a small gold sheet with the representation of the Mistress of the Animals, surrounded by two very oriental looking sphinxes found in the Bocchoris Tomb in Tarquinia (Strøm 1971, 70 f., no. S 42, 88, 149-150, 208-210, 212 Fig. 94, von Hase 1975, 133 ff. pl. 40, von Hase 1978, pl. 356, Fig. 10a-10b). Judging from the archaeological evidence, early Etruscan gold-work seems already in the second quarter of the 7th century to have reached its first peak.

Stylistic, iconographic and technical evidence already enables to distinguish for the Orientalizing period a north Etruscan centre of gold working at Vetulonia and a southern Etruscan centre at Cerveteri (Brown 1960, 41 ff., Strøm 1971, 89, 223 note 54a with further references, Martini 1981, 6 ff., note 25, Cristofani and Martelli 1983, 46). Unfortunately in Etruria neither remains of early workshops nor even goldsmithing tools have been found. Nevertheless by the analysis of some of the main finds from the so-called Tomba Regolini-Galassi, discovered in an undisturbed state in 1836 in the Sorbo-Necropolis of Cerveteri an idea of the artistic and technological capability of an early atelier can be obtained which, because working for a prominent member of a leading, perhaps even royal family, can be considered as probably the most renowned workshop of ancient Caere in the second quarter of the 7th century B.C. (Pareti 1947, 75 ff., 142 ff. with further references).

In this context the following should be noted: the main burial, discovered in the cella of the grave-monument and dating to the second quarter of the 7th century B.C., was evidently that of an Etruscan princess (Fig. 2) (Pareti 1947, 97 ff. and 173 ff. with references, Strom 1971, 160-168, Cristofani and Martelli 1983, 261 ff.). The breast of the dead was covered by a huge golden pectoral (height 42 cm; width 38.3 cm) made of a very thin gold sheet (0.04-0.08 mm; weight ca. 70 g) originally reinforced on the rear side by a bronze sheet, now lost (Pareti 1947, 190) (Fig. 3-5). 111 holes along the rim served to sew the pectoral on the garment (Pareti 1947, 190 ff. pl. IX with earlier literature, Strφm 1971, 64 no. S 20, 81 no. S III 9, 83 ff. Fig. 50-52, Cristofani and Martelli 1983, 41, 263 no. 35 pl. 35 with further references). Likewise at breast-level lay a large foot-disc fibula (length 32 cm; weight 173 g) made from several very thin gold sheets (foot-disc = 0.11-0.19 mm) (Fig. 6-9) (Pareti 1947, 175 ff. pl. IV with earlier literature, Strφm 1971, 64 no. S 19, 81 no. S III 8, 83 Fig. 54-55, Cristofani and Martelli 1983, 41, 262 no. 32 pl. 32 with further references). At the position of the lower arms were found two identical gold sheet arm-bands of the highest quality (length 25.7 cm, width 6.7 cm and length 25.8 cm, width 6.75 cm; weight 65.5 g and 66 g) (Fig. 10-11) (Pareti 1947, 182 ff. pl. VI, 3-4 with earlier literature; Cristofani and Martelli 1983, 38, 263 no. 36 pl. 36 with further references). The furnishings of the princess also included two pendants executed in gold sheet and richly decorated (height 3.4 cm and 3.5 cm) (Fig. 12) (Pareti 1947, 187 ff. pl. VII, 15-16 with earlier literature, Cristofani and Martelli 1983, 38, 263 no. 37 Pl. 37). In the position originally occupied by the corpse was a considerable number of small rectangular or triangular plaques with holes for attachment along their rims, which must have been sewn to clothing (Fig. 13) (Pareti 1947, 195 ff. pl. X, 49-61, 64, XI, 49-51 with earlier literature, Strom 1971, 64 ff. no. S 21., 81 no. S III 10, 86 Fig. 53). Other less important gold and silver personal ornaments from the same burial, such as fibulae, necklaces, arm-bands and pendants will not be treated further in this paper (cf. Pareti, 1947, pl. V, VII, 5-7. 47-48, VIII, X, 29-47, XI,53-62, XII-XIV, Cristofani and Martelli 1983, pl. 30-31, 33-34).

One of the main questions for the archaeologists concerned with this jewellery is the following: is there any archaeological evidence to prove that at least the most important works of this complex can be attributed to the same workshop and, if this is the case, what kind of information regarding the artistic personality of the master goldsmith who created these pieces can be obtained from the technical, stylistic and iconographic evidence? A precise comparison of the stamps used to embellish some of these pieces convinced the author that at least the golden pectoral, the large foot-disc fibula and the golden fittings, being parts of a very sumptous ensemble of status symbols, were all executed at the same time and in the same workshop. This becomes very evident from a comparison of some of the stamps used to obtain the figural decoration: the walking griffins which adorn the lower plate of the disc fibula (length 1.1 cm; height 0.83 cm) (Fig. 6, 9, 2-3) are nearly identical with those found on the pectoral (length 1.2 cm, height 1.1 cm) (Fig. 3, 5, 1-4). The motif of the backward looking lion with a lotus flower in his mouth is represented not only on the pectoral (Fig. 3, 5, 1.3,5) but also on some of the small rectangular and triangular plaques already mentioned (pl. 12,2). A comparison of the complicated filigree techniques used to adorn the disc of the great fibula (Fig. 7, 2.3) and the sides of the golden arm-bands (Fig. 10,3, 11, 1-2) makes it likely that these objects can be attributed to the same workshop. The two pendants with representations of young women and palm stalks in the background are obviously very close related to the arm-bands (Fig. 12).

Although the pectoral of the Regolini Galassi Tomb is the most outstanding piece of this genre found in Etruria, smaller golden pectorals of a somewhat different form and decoration, dating to the end of the 8th and the first half of the 7th century, are known from Tarquinia (cf. Strom, 1971 Fig. 37, 49 and 84, cfr. also the etruscan pectoral without known provenance in the Walters Art Gallery, Baltimore: Strom 1971, 75 S 58 Fig. 38). Furthermore it must be remembered that pectorals made of gold sheet and adorned with inlaid pieces of amber come from a tomb in Palestrina (Cristofani and Martelli 1983, 42, 277 no. 85 pl. 85) and Castel di Decima near Rome (Bedini 1976, 287 ff. pl. LXI,b) (Fig. 14).

Small rectangular plaques of gold sheet, very similar to the Regolini-Galassi pieces, were found in tombs dating to the Orientalizing period even in Tarquinia (cf. Strφm, 71 no. S 43 Fig. 95) and Marsiliana d'Albegna (cf. Strφm, 1971, 72 no. S 49 Fig. 40) (Fig. 14).

The best parallel for the large foot-disc fibula is the well known gold fibula from Vulci (cf. von Hase 1984, 247 ff., Fig. 1, pl. 36-42).

A pair of gold sheet arm-bands nearly identical to the pieces investigated, and therefore probably made by the same workshop, comes from a tomb in Palestrina (Fig. 15-16) (Marshall 1969, 123 no. 1356-1357, pl. XVIII, 1356-1357, De Puma 1986, 383 ff., Fig. 3-4, 7-9). A small Etruscan pendant (height 3 cm), now in the Antikenmuseum of Berlin, whose exact provenance unfortunately is unknown, can also be attributed to the Regolini-Galassi workshop in Cerveteri (Fig. 13,1) (cf. Greifenhagen 1970, 88 no. 4 pl. 67,4). This becomes very evident if one compares this piece to the pair of pendants already considered (Fig. 12, 1.3). The rendering of the main motif, the young woman with palm stalks, is nearly identical.

Even if it is possible from a typological and functional point of view to cite some *comparanda* for the Regolini-Galassi gold, there can be no doubt that these are by far the most outstanding works of the whole group. Especially the huge pectoral surpasses all other known pieces from central Italy in size, and in the artistic quality of the eight different figural-stamps used to obtain the rows of friezes which cover the whole surface in a kind of horror vacui (Fig. 3-4).

The decorative system consisting of different files of figures, forming parallel series of friezes (Fig. 5, 1-3), reminds one of a certain group of syro-phoenician bronze bowls known from Nimrud (Assyria), the Zeus Cave, Mount Ida (Crete) and Vetulonia (northern Etruria) (cf. Markoe 1985, Fig. page 356, 310-311, 236). Even from an iconographic and stylistic point of view several of the single motifs punched into the rear side of the Regolini-Galassi pectoral show very close north Syrian/Phoenician affinities. This becomes evident if one considers the rendering of the walking griffin with the closed beak (Fig. 5, 1-4) (cf. Strφm 1971, 209, 213 pl. 50-52), the Phoenician palmettes (Fig. 5, 3) (cf. Strφm 1971, 84), the grazing goat (ibex) (Fig. 5, 1-2) and the hero between the lions - the only three figural composition on the pectoral (Fig. 5, 3.5) (cf. Strφm 1971, 84, 209 pl. 50, very similar but not identical is the same motif represented several times on the silver urn of the Tomba del Duce from Vetulonia, cf. Camporeale 1965, 37 no. 3 pl. XV) (Fig. 17). At least two of the motifs are obviously of Greek origin, such as the chimaera (Fig. 5,1-2) (cfr. Strφm 1971, 210, 213 pl 50-52, Martini 1981, 8 ff. with note 30) and the winged horse (Fig. 5,1) (cf. Strom 1971, 207).

Others seem more likely to be local versions of somewhat eastern prototypes such as the standing, armless woman with double wings (Fig. 5, 1.2), or the standing woman with single, sickle-shaped wings and lotus flowers (Fig. 5, 2.3) (cf. Strom 1971, 84).

The form of the pectoral itself (Fig. 3) is of Near Eastern (cf. Maxwell-Hyslop 1971, 217) or even Egyptian inspiration (cf. Michalowski 1969, Fig. 737).

There can be no doubt that the fashion of decorating precious textiles and clothing with fine gold appliqués, attested during the first half of the 7th century B.C. in rich burials in Etruria, as already pointed out, also originated in the Near East. There it can be seen for example on royal costumes of the Assyrian kings (cf. Maxwell-Hyslop 1971, 254 ff. Fig. 162).

The mixing of local and Near Eastern features is most clear if the origin of the different elements which constitute the large foot-disc fibula is analysed: the type of the fibula (Fig. 6) has a long local history going back to the early Iron Age (Fig. 17) (v. Hase 1984, 251 ff. Fig. 3-4), whereas most of the iconographic elements again point to the north-Syrian/Phoenician area. This becomes very evident if one considers the rendering of the single lions (Fig. 7, 1.3), and their peculiar antithetic composition (Brown 1960, 30, no. 7, 31, 43 pl. XV,a).

The motif of rosettes embellished by lines of granulation, which in the present case are applied to semicircles (Fig. 7, 2.5) can be traced back to very similar forms found on Near Eastern jewellery (Hoffmann 1969, 369 ff., 370 Fig. 55 a-d, Maxwell Hyslopp 1971, 244 pl 224). The same origin can be claimed for the palmette pendants on the cross bars (Fig. 6, 8.2), the rendering of the walking griffins on the convex plaque of the fibula (Fig. 9, 2.3) and the woman's head with Hathor coiffure surrounded by a Phoenician palmette which is found at the very end of the fibula (Fig. 8,1) (cf. Strøm 1971, 84 ff., 95, 207).

The curious custom of decorating the back of the fibula with three-dimensional water-birds - in the present case seven rows of ducks alternating with six rows of striding griffins (Fig. 6, 9, 1-2) - is doubtless linked to older local traditions, but enjoys a particular popularity in the Orientalizing period on precious metal-working (von Hase 1984, 258 ff., Fig. 7-12) (Fig. 17). It must be assumed that this motif, too, had a religious meaning, even though without relevant tests a convincing interpretation is extremely difficult.

Foreign motifs such as the backward-looking lion (Fig. 13,2), the goddess with Hathor curls (Fig. 13,3) or the rosettes (Fig. 13,4) appear on the rectangular fittings, along with others of local origin like the point-boss (Fig. 13,6) or the very characteristic complex swastica (Fig. 13,5), well known for example from the geometric decoration of the locally made Villanovan pottery urns (cf. Hencken 1968, 30 ff. Fig. 18, I-I).

Finally, the pair of gold arm-bands shows the motif of the "Mistress of the Animals", familiar in Etruria on precious metal-work of the 7th century (Fig. 17) (cf. Strøm 1971, 94, von Hase 1975, 133 ff.), here combined in a very peculiar arrangement with the motif of the Hero, who attacks a lion from behind with his sword (Fig. 11, 1-2). The stylistic execution of the individual figures of this group undoubtedly bears north Syrian/Phoenician elements and even the somewhat astonishing combination of the two motifs, the "Mistress of the Animals" and the Hero fighting with the lion, is not unknown from the Near East (von Hase 1975, 136 ff., 172, note 169 pl. 38, Martini 1981, 3 ff., Fig. 3). A Near Eastern inspiration is also indicated by the execution of the young women holding hands and placed before long palm stalks, a motif found on several zones of the studied golden arm-bands (Fig. 10, 1-3) and in a somewhat different rendering on the pendants (Fig. 12, 1.3) (cf. the very similar motif, a group of female dancers, represented on a shallow bronze bowl from Idalion on Cyprus, Markoe 1985, 171 no. Cy3, 246 pl Cy3.). On the contrary the meanders in line granulation, framing the sides of the arm-bands (Fig. 10, 1-3), are surely not of Near Eastern inspiration but could be of Greek or even local origin (cf. von Hase 1974, 90 ff. Fig. 7).

Neither the form of the arm-bands (Fig. 10, 1-2) nor the type of the two pendants (Fig. 12, 1.3) enables to cite any eastern fore-runners. In both cases a local invention of the type cannot be precluded. But one must be well aware that the question is far from being resolved definitely, because jewellery of the period with which this paper is dealing is very little known from eastern, especially Phoenician sites.

For typological and iconographical reasons it seems very probable, as already pointed out, that the Regolini-Galassi work-shop also executed the two famous arm-bands from the Tomba Galeassi at Palestrina and preserved now in the British Museum in London (length 18.6 cm, width 5.7 cm and length 18.4 cm, width 5.7 cm) (Fig. 15-16) (Marshall 1969, 123 no. 1356-1357, pl. XVIII,1356-1357, De Puma 1986, 383 ff., Fig. 3-4, 7-9).

A simple visual inspection demonstrates that a good number of the individual stamps used on the pectoral are of almost the same size (Fig. 3-4, 5, 1-3) and this is confirmed by the performed mesurements (cf. Table 1).

Table 1. Measurements of individual stamps used on the pectoral.

grazing goat:	h: 0.8 cm	l: 1.0 cm
walking griffin:	h: 1.1 cm	l: 1.2 cm
chimaera:	h: 0.9 cm	l: 1.0 cm
backward looking lion with lotus flower:	h: 1.0 cm	l: 1.1 cm
grazing stag:	h: 0.9 cm	l: 1.2 cm
standing woman with lotus flowers:	h: 1.2 cm	l: 1.0 cm
winged horse:	h: 1.0 cm	l: 1.1 cm
arm-less woman with double wings:	h: 1.2 cm	l: 0.9 cm
hero with two lions:	h: 1.6 cm	l: 1.8 cm

This consideration alone makes it probable that these stamps were carved specially for decorating this object, possibly out of bone or hard wood. Their uniform style indicates, furthermore, that they were most probably made by the same artisan. The technical perfection of the rendering of the different motifs betrays a stamp-carver experienced in glyptics and the variety of motifs shows the master's wide iconographic repertoire; it is quite possible that he was the leading goldsmith of the Regolini-Galassi workshop.

The brief analysis of the main golden objects belonging to the Regolini-Galassi workshop has shown that these display a combination of elements of very different origin. The domination of motifs of Near Eastern (north Syrian/Phoenician) origin supports the hypothesis that at least the master-craftsman, who made these excellent pieces - supported by several collaborators, perhaps of local origin - could have been an immigrant from the Near East (see already Pareti 1947, 179).

The results of the present research confirm once more the idea that the rapid advances and changes in early goldsmithing, at the end of the Villanovan and the beginning of the Orientalizing period, owe much to the arrival of highly specialised craftsmen from the Near East, who established ateliers in important Etruscan cities like Cerveteri and Vetulonia and who were able to satisfy the wishes of the splendour-loving local aristocracy with the production of gold objects destined for real use or for funerary purposes (Brown 1960, 2,41, Strøm 1971, 212, von Hase 1975, 140, von Hase 1978, 1107, Martini 1981, 6, Cristofani and Martelli 1983, 35 ff., Martelli 1991, 1059). This hypothesis fits in very well with the picture of the development of goldworking and the role played by the Phoenicians in this field even in other areas of the Mediterranean in the Orientalizing period - for example in Crete, Greece and Spain (Coldstream 1982, 265 ff., pl 26, a-f, Deppert-Lippitz 1985, 54 ff., 66 ff., Fig. 24. 28. 31-37., pl. II-IV, Almagro Gorbea 1989, 68 ff., Perea 1991, 141 ff.).

The fact that the jewellery from the Regolini-Galassi tomb, whose rich decoration with the recurrent "Leitmotiv" of the potnia and the potnios theron, was made specially for funerary purposes, is indicated by the extreme fragility of the component parts - especially in the case of the foot-disc fibula which would not have survived even a single use.

Using the X-ray fluorescence method, several analyses were carried out by R. Cesareo from the University of Rome for the first time on the gold objects considered in the present article (Cesareo and von Hase 1976). The values obtained were the following:

1. Pectoral (Fig. 3): Au 66.37 % Ag 32.60 % Cu 1.3 % (= average values of 19 analysis, cf. Cesareo and von Hase 1976, 266 Tab. I no. 1, 281 Fig. 11).
2. Foot-disc fibula (Fig. 6): Au 72.05 % Ag 26.15 % Cu 1.80 % (= average values of 27 analysis, cf. Cesareo and von Hase 1976, 267 Tab. I no. 2, 281 Fig. 11).

3a. Arm-band (Fig. 10, 1)
external side: Au 77.0 % Ag 20.8 % Cu 2.2 %
internal side: Au 77.2 % Ag 20.4 % Cu 2.4 %
(cf. Cesareo and von Hase 1976, 268 no. 14, Fig. 13,14).

3b. Arm-band (Fig. 10, 2)
external side: Au 78.1 % Ag 20.0 % Cu 1.9 %
internal side: Au 78.6 % Ag 18.9 % Cu 2.5 %
(cf. Cesareo and von Hase 1976, 269 no. 15, Fig. 13, 15).

4a. Pendant (Fig. 12, 1-2)
external side: Au 78.5 % Ag 20.0 % Cu 1.5 %
internal side: Au 76.1 % Ag 21.7 % Cu 1.2 %
(cf. Cesareo and von Hase 1976, 268 no. 12, Fig. 13, 12).

4b. Pendant (Fig. 12, 3-4)
external side: Au 78.8 % Ag 20.0 % Cu 1.2 %
internal side: Au 77.5 % Ag 21.9 % Cu 0.7 %
(cf. Cesareo and von Hase 1976: 268 no. 13, Fig. 13,13).

Even if the absolute error of the measuring method ranges from 0.5 % to 2.0 % for silver and from 0.1 to 1.0 % for copper, several data have been obtained from an archaeological point of view are certainly of interest. By comparison of the analyses it became evident, that the Regolini-Galassi workshop used different kinds of gold alloys to produce some of the objects considered in this paper.

This can be shown if one compares the silver content of the different objects which ranges from about 20% to 32%. It allows to distinguish the following three groups:

I (= no. 1) the pectoral (Fig. 3).
II (= no. 2) the disc-fibula (Fig. 6).
III (= no. 3a-b; 4a-b) the two arm-bands (Fig. 10, 1-2) and the two pendants (Fig. 12, 1-4).

From the analyses it became certain that the six different sheets used to construct the foot-disc fibula (cf. Fig. 8,3) were made by using the same raw gold. It is not very surprising that the analyses showed that sheets of the same gold alloy were used to produce the two gold arm-bands (Fig. 10, 1-2). The fact that the gold of the two pendants (Fig. 12, 1-4) is so very similar to the gold of the arm-bands (Fig. 12, 1-2) confirms the hypothesis, based on the archaeological evidence, that the arm-bands and the pendants were made as part of a set by the same workshop.

In the natural state gold has a silver content ranging from about 2 % to (occasionally!) 40 % and a copper content ranging from 0.2 % to 1 %. Therefore it seems quite likely that at least some copper was added to the raw gold used to make the studied gold objects. That even silver was added cannot be proved but seems to be quite probable considering the high metallurgical knowledge and technological standard of the goldsmiths working in the Regolini-Galassi workshop at Cerveteri (cf. Cesareo and von Hase 1976, 290 ff.).

At the moment no definite conclusions can be drawn regarding the origin of the raw material of the studied gold objects. The characteristic distribution of the gold finds of the Villanovan and Orientalizing periods shows a significant concentration of find-places in the coastal area (cf. von Hase 1975, 99 ff., 101 map 1). An explanation of this fact could be that the raw gold was imported like other luxury objects by sea trade and accumulated, as always happens, in the most flourishing and powerful centres of the period (Fig. 1).

If one takes into consideration the enormous amount of work necessary to make the single objects here considered, it must be concluded that even for an experienced master goldsmith and his team it surely took several months to finish the whole set. For this reason there can be no doubt that the jewellery of the Regolini-Galassi tomb considered in this paper, although destined merely for funerary purposes, was already made when the princess for whom it was created was still alive.

Finally it should be emphasized once again that in this article many problems and research results connected with the gold jewellery from the Tomba Regolini-Galassi have only briefly been touched on, and will be presented again fully in another place.

The discussion here revolved chiefly around one point: it should be shown, using a particularly suitable example from a well-documented find assemblage, what possibilities are available today in the identification of early Etruscan goldsmiths' workshops, despite the great loss of material caused by later grave robbery and plundering of the local sancturies.

It need not be emphasized that the results achieved, naturally offer a solid basis for further studies of regional and even supra-regional relationships between different workshops.

The possibilities offered by this kind of research have recently been demonstrated once more by the author, considering specifically certain technical details such as the use of granulation and filigree on Etruscan precious metal objects from the period which is concerned in this paper (von Hase 1984, 278 ff. Fig. 18-20).

Acknowledgements
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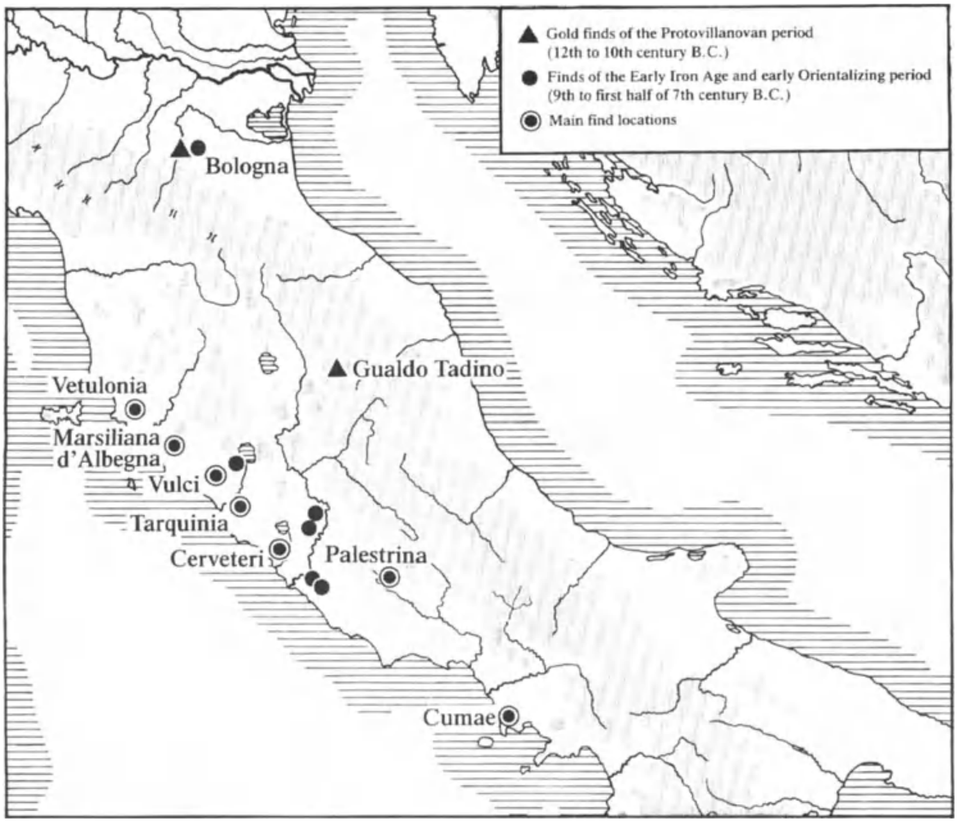


Fig. 1: Distribution of gold finds of the Protovillanovan period (12th to 10th century B.C.), early Iron Age (9th to 8th century B.C.) and early Orientalizing period (first half of 7th century).

Fig. 2: View from the Dromos into the Cella of the Tomba Regolini-Galassi, Cerveteri. The objects discussed here belonged to the main burial in the Cella (length: 7.35 m, width: 1.30 - 1.35 m).

Fig. 3: Pectoral of gold sheet from the Tomba Regolini-Galassi, Cerveteri (height: 42 cm, width: 38.3 cm; thickness of gold sheet: 0.04-0.08 mm; weight: ca. 70 g). Rome, Musei Vaticani, Museo Gregoriano Etrusco, Inv. no. 20 553.

Fig. 4: Rear side of the gold sheet pectoral from the Tomba Regolini-Galassi, Cerveteri. The base of bronze sheet is not preserved. The textile strips stuck to the pectoral are modern.

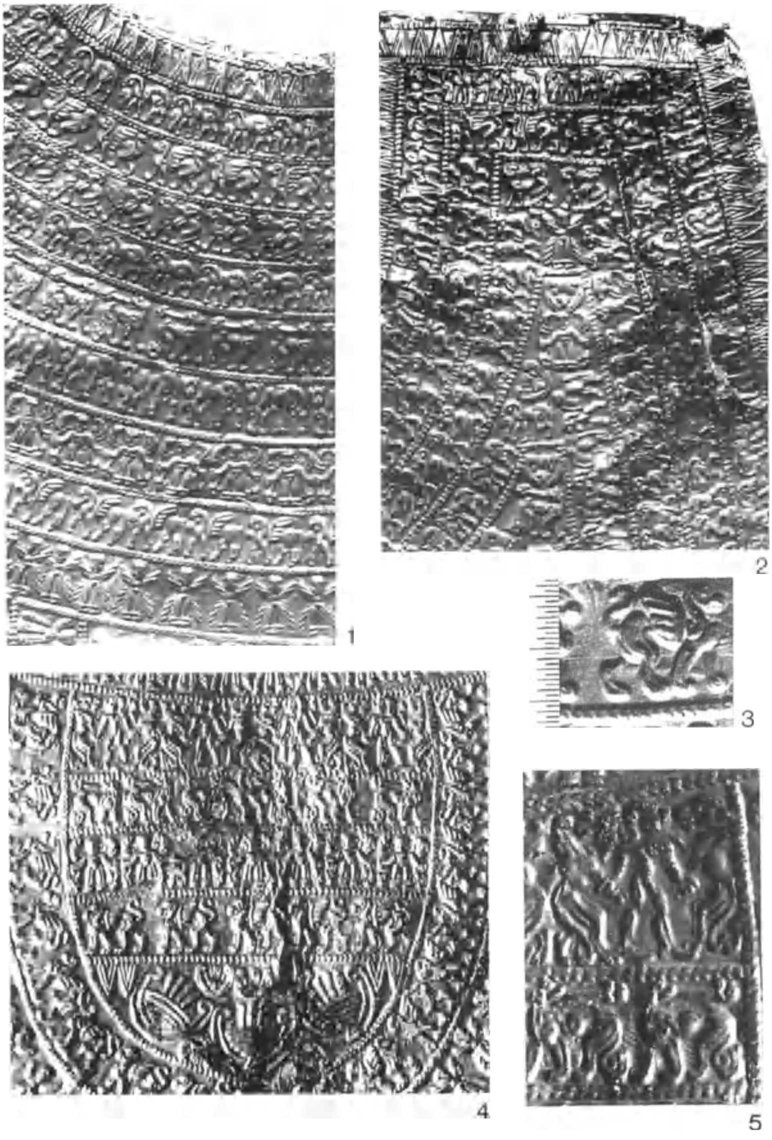
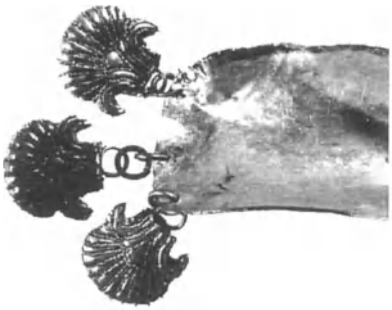


Fig. 5: 1-5. Details of the stamped decoration of the pectoral from the Tomba Regolini-Galassi, Cerveteri: the decoration has been stamped from the rear side.

Fig. 6: Gold foot-disc fibula from the Cella burial of the Tomba Regolini-Galassi, Cerveteri (height: 32 cm, width: 24.4 cm, thickness of the gold sheet of the disc: 0.11-0.19 mm, weight: 173 g. Rome, Musei Vaticani, Museo Gregoriano Etrusco, Inv. no. 20 552.

Fig. 7: Details of parts of the foot-disc (height: 16.5 cm, width: 21.7 cm) of the foot-disc fibula from the Tomba Regolini-Galassi, Cerveteri: 1. Two rows of striding lions. The single animal figures are cut from thin gold sheet, soldered to the disc and decorated with single rows of granulation. 2. Rim of the foot-disc with filigree plaited decoration. 3. Central lion figure of the lower frieze. The repairs - in the form of small soldered pieces of gold sheet - executed during the production of the fibula are visible. 4. Strongly magnified photograph of the filigree decoration of the rim of the foot-disc. 5. Details of the rear-side of the rim of the foot-disc, with stamped decorative frieze.



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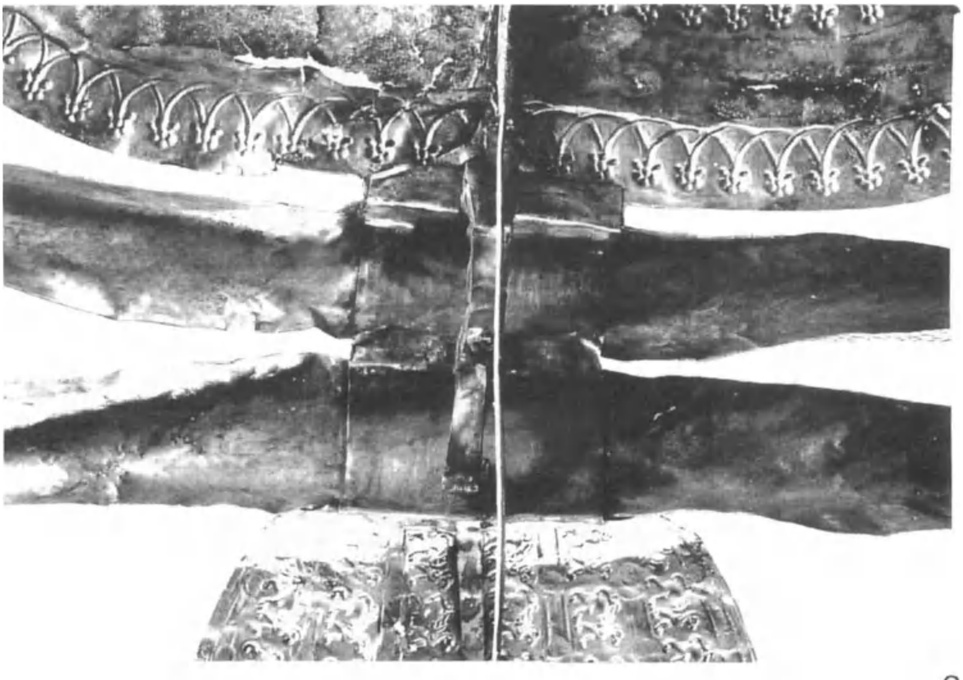

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Fig. 8: Details of parts of the foot-disc fibula from the Tomba Regolini-Galassi, Cerveteri: 1. Female head with Hathor-curls inscribed in a palmette from the lower end of the fibula. 2. Crossbars of the fibula with three pendants in the form of phoenician palmettes. Photograph taken from the rear. 3. Detail of the middle part of the rear of the fibula. The individual gold sheets of the fibula, soldered together, are clearly visible, along with the fibula pin in the foreground.

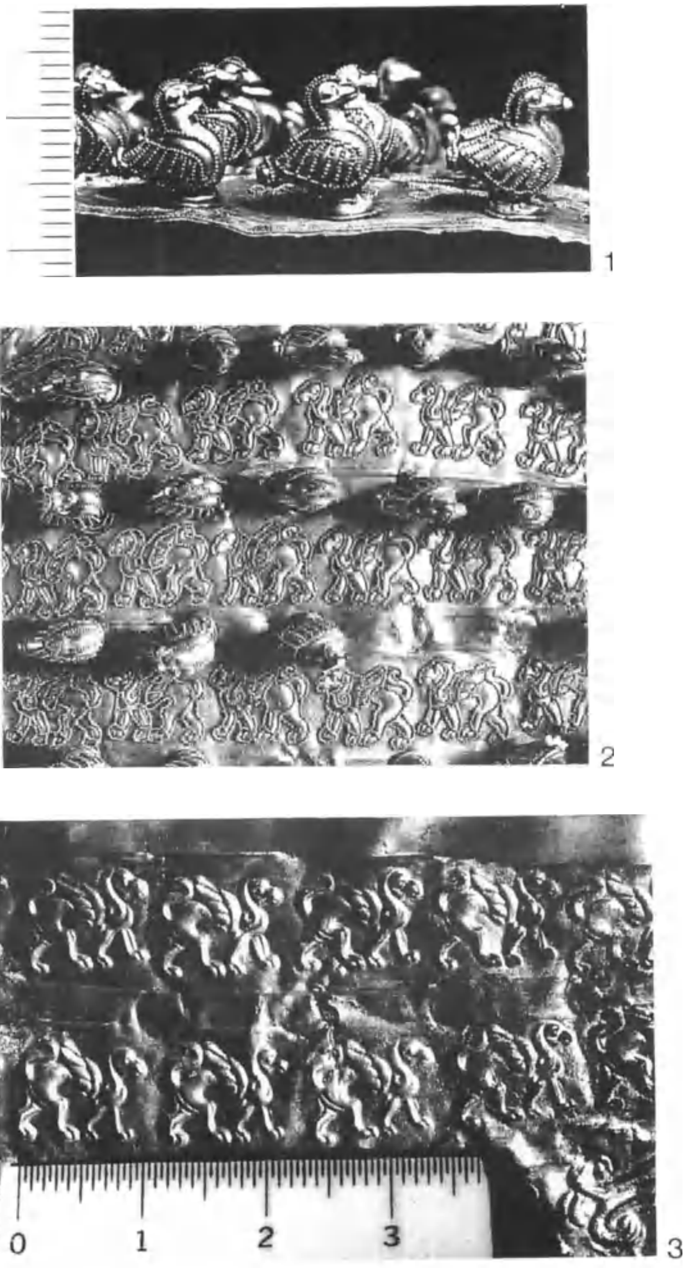

Fig. 9: Details of parts of the foot-disc fibula from the Tomba Regolini-Galassi, Cerveteri: 1. Plastic ducks from the back of the fibula, seen from the side. 2. View of the back of the fibula, from above, showing rows of griffons, stamped from the rear, positioned between the rows of ducks. 3. View of the rows of griffons on the back of the fibula, seen from the rear.

Fig. 10: Pair of gold arm-bands from the Cella burial of the Tomba Regolini-Galassi, Cerveteri. 1. Gold arm-band: length: 25.8 cm, width: 6.75 cm, weight: 66 g. Inv. no. 20 562 (Pareti 1947, Pl. VI,4). 2. Gold arm-band: length: 25.7 cm, width: 6.7 cm, weight: 65.5 g. Inv. no. 20 563 (= Pareti 1947, Pl. VI,3). 3. Detail of the gold arm-band Inv. no. 20 563. Rome, Musei Vaticani, Museo Gregoriano Etrusco, Inv. no. 20 562 and Inv. no 20 563.

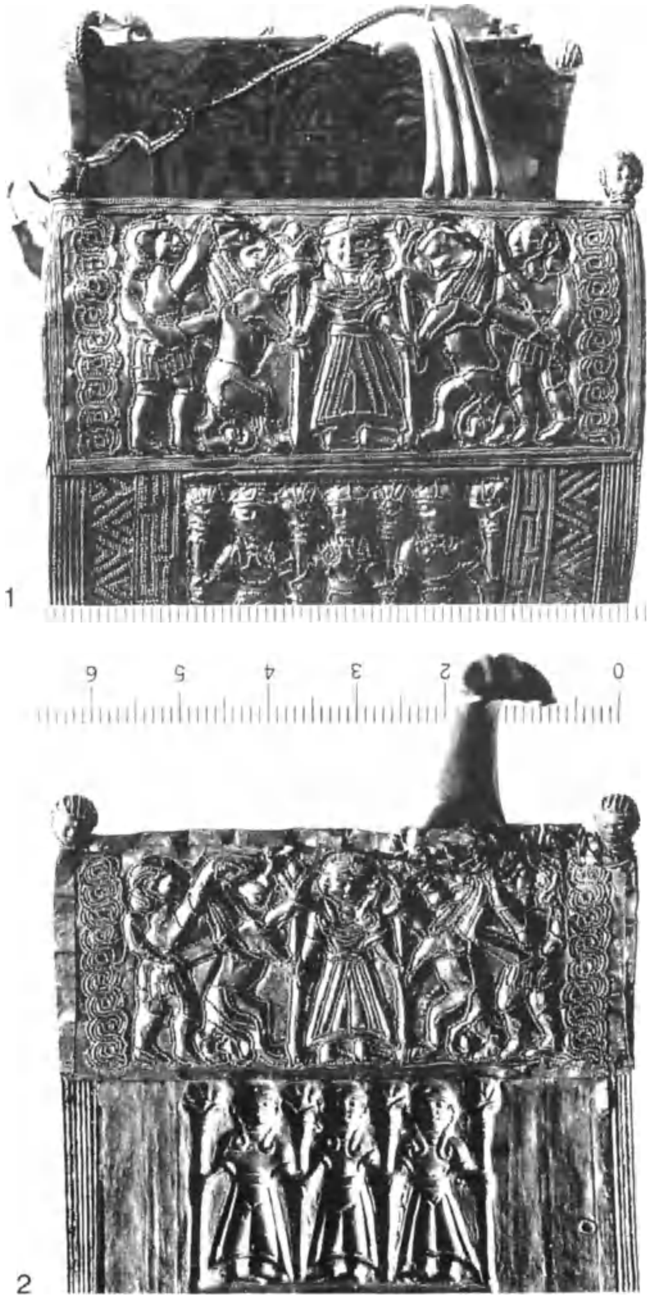

Fig. 11: Details of parts of the gold arm-band Inv. no. 20 562 from the Cella burial of the Tomba Regolini-Galassi, Cerveteri. 1. Frieze zone of the exterior. 2. Frieze zone of the interior.

Fig. 12: Gold sheet pendants belonging to a chain from the Cella burial of the Tomba Regolini-Galassi, Cerveteri. 1-2. Front and back of gold sheet pendant: length: 6.3 cm, height: 3.4 cm. Inv. no. 20 530. 3-4. Front and back of gold sheet pendant: length: 7.0 cm, height: 3.55 cm. Inv. no. 20 529. Both pieces represent probably settings of amulettes (?) which are not preserved. Rome, Musei Vaticani, Museo Gregoriano Etrusco, Inv. no. 20 529 and Inv. no. 20 530.

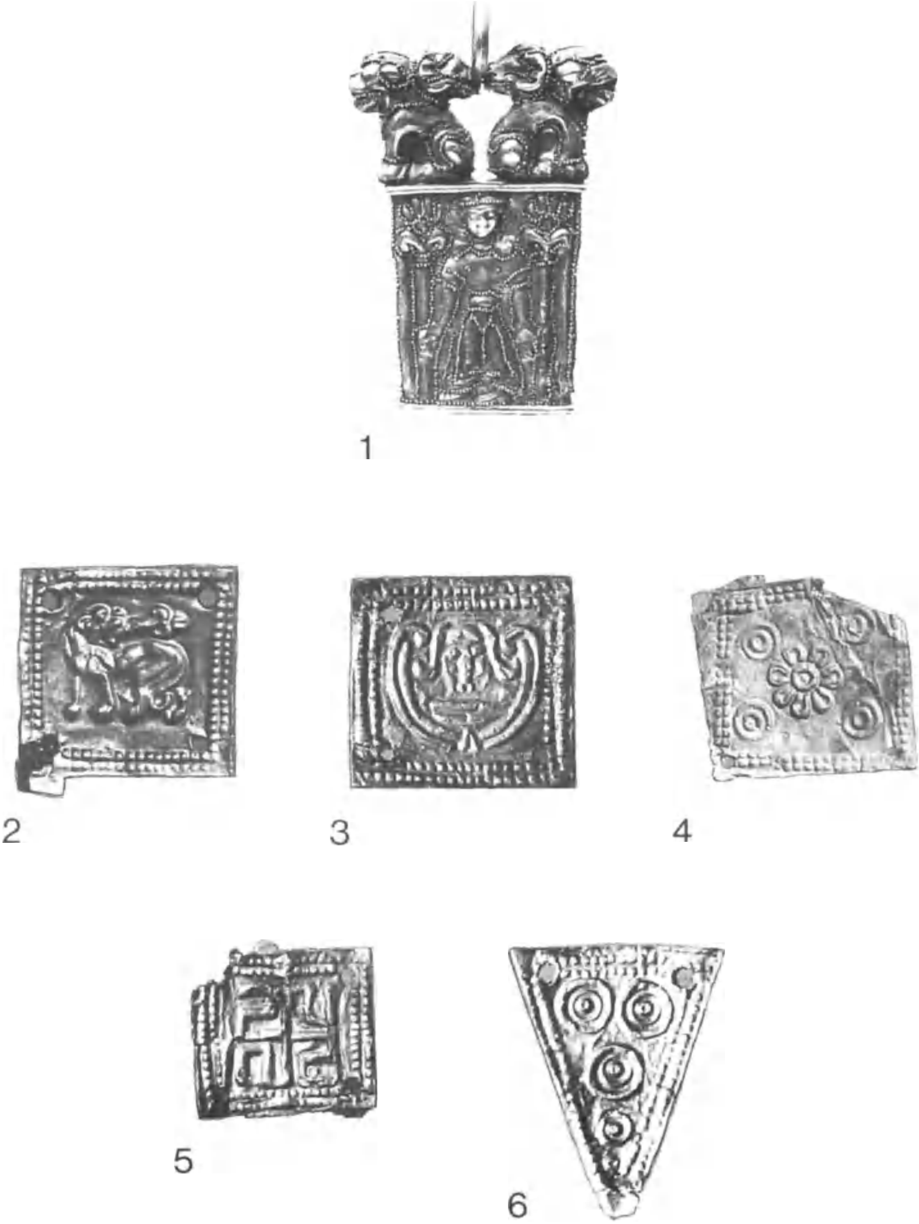

Fig. 13: 1. Small Etruscan gold sheet pendant, probably the setting of a lost amulette(?). Unknown provenance. Height: 3 cm. Antikenmuseum der Staatlichen Museen Preußischer Kulturbesitz Berlin, Inv. no. GI. 213 (Misc. 7282). 2-6. Several gold sheet plaques sewn to garments from the Tomba Regolini-Galassi, Cerveteri. Measurements: 2. length: 1.7 cm. 3. length: 1.8 cm. 4. length: 1.8 cm. 5. length: 1.8 cm. 6. length to height: 1.7 cm : 2.2 cm. Rome, Musei Vaticani, Museo Gregoriano Etrusco, no individual Inv. no.

Fig. 14: Distribution of various types of gold sheet pectorals, and small rectangular or triangular plaques of gold sheet sewn to garments (late 8th to first half of 7th century B.C.).

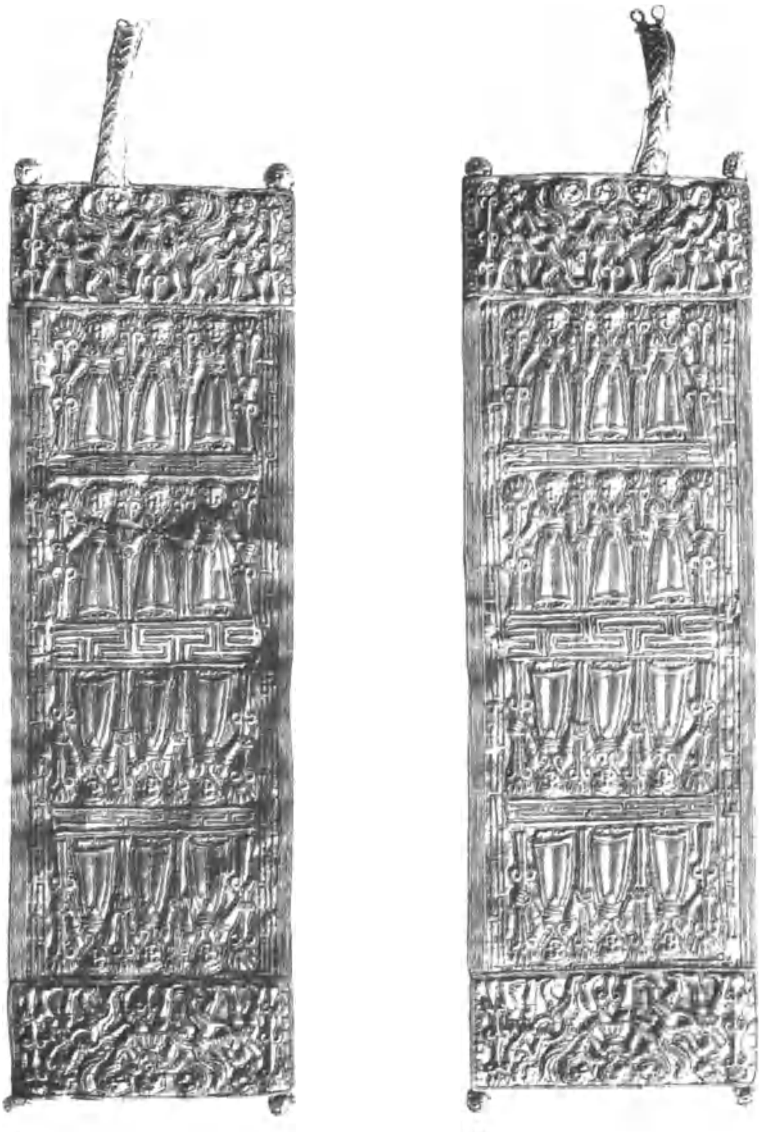

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*Fig. 15: Pair of gold arm-bands from the Tomba Galeassi, Palestrina, views from the outer side. 1. length without clasp: 19.55 cm, width: 5.7 cm (Marshall 1969, no. 1356)
2. length without clasp: 19.7 cm, width: 5.7 cm (Marshall 1969. no. 1357). London, The British Museum, Department of Greek, and Roman Antiquities, Inv. .no. GR 1872. 6-4. 699-700.*

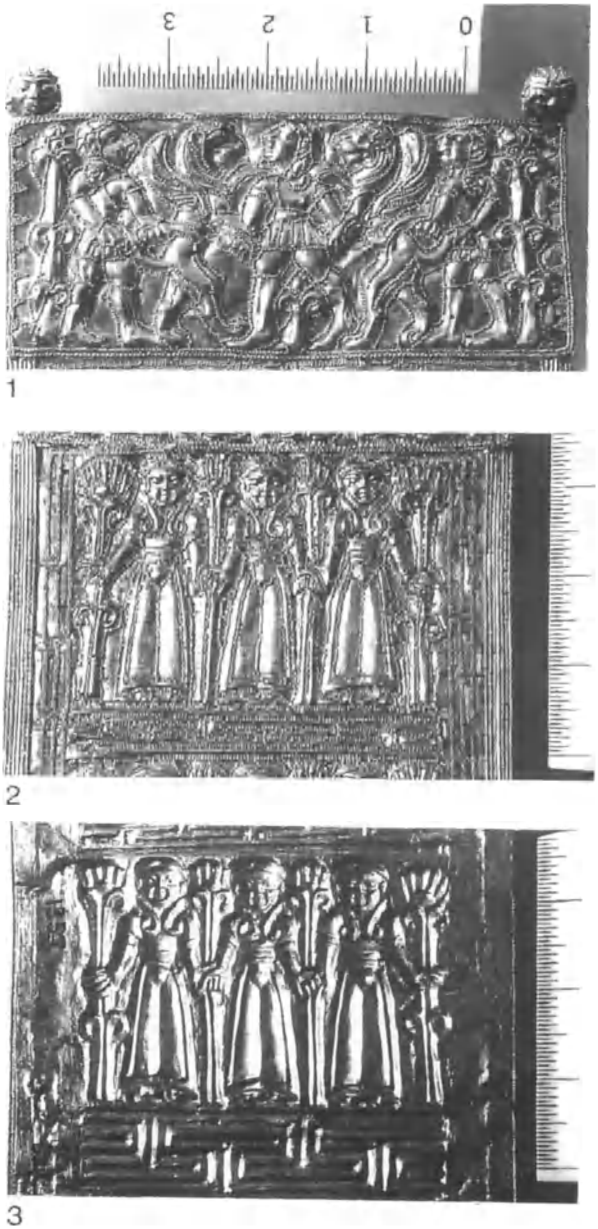

Fig. 16: Details of the gold arm-bands from the Tomba Galeassi, Palestrina:
1. Outer frieze zone of the arm-band Fig. 15,1 (Marshall 1969, no. 1356).
2. View of the first panel of the middle zone of the arm-band Fig. 15,2 (= Marshall 1969, no. 1357).
3. View from the rear of the second panel of the middle zone of the arm-band Fig. 15,2 (Marshall 1969, no. 1357).

Fig. 17: Distribution of different types of fibulae with leaf-shaped bow, foot disc and crossbar in bronze or gold and distribution of various decorative elements of the early Orientalizing period.

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Chapter 5

LA TENE GOLD AND SILVER IN ITALY:
A Review of the Archaeological Evidence

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ABSTRACT. During the earlier phase, La Tène B-C1 (approximately IV - III cent. B.C.) the majority of precious objects is found in a few "princely" tombs, according to a pattern prevalent north of the Alps during La Tène A-B1, but in Italy most gold ornaments are of Hellenistic/Etruscan type (as are most of the bronze vessels and fine pottery). From an archaeological point of view, then, most gold is likely to be of southern origin.
During the later phase La Tène C2-D (approximately II - I cent. B.C.) the picture is reversed: almost all the precious objects found in tombs are made of silver, as is the local coinage, while almost all gold objects belong to transalpine types, probably of northern origin. Gold objects as a rule are no longer found in tombs, they lay in hoards or represent "single finds", sometimes located near water sources or rivers and can be regarded as gifts to the Gods. This pattern is also closely similar to the evolution which takes place north of the Alps. The real riddle lies in the fact that these torcs and coins, which compare with or belong to transalpine types, are found in Tuscany, a region under Roman rule, and in Piedmont around Vercelli, which is close to the main gold exploitation areas.

1. Introduction

The subject of this paper is the study of gold finds from the perspective of the function which they assume in the social context, in so far as it is possible to identify this on archaeological grounds. Silver is considered too, since the distribution of gold objects is compared with that of the several silver objects that are also present. Gold objects do not occur very frequently within La Tène archaeological records from Italy. However all metals are recyclable and gold, given its precious nature, would have been remelted even more often than bronze. Thus the presence in the archaeological record of a gold object, precious and easily recyclable, is as a rule intentional rather than accidental: it is the result of a conscious decision to offer up or sacrifice the gold rather than to keep it.

2. Early phase: La Tène B-C1

The distribution of gold and silver finds during the early phase La Tène B-C1 (approximately IV- III cent. B.C.) has been summarized on the map (Fig. 1). Included here are all the gold and silver objects derived from La Tène assemblages as well as all the gold objects of a La Tène type regardless of provenance. Thus, Hellenistic and Etruscan objects have been consi-

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dered only when they come from a La Tène assemblage. During this early phase, gold is found mostly south of the Po river. Gold objects, when their provenance is known, almost always are found in tombs. The objects are primarily jewels with some gold wreaths (see Table 1). Further, gold objects are usually present in tombs of women of high rank. Some men of similar rank may also have gold finger-rings and wreaths. In rare cases, men and women can have silver tableware, the most famous example being the silver service of Montefortino tomb 33, now at the Metropolitan Museum of Art (Oliver 1977, Moscati et al. 1991, 723 n. 275).

In a few cases, the precious metal finds come from cemeteries where the tomb assemblages are preserved. Whenever possible the frequency of tombs containing precious objects was examined in relationship to the gender of the deceased, determined on an archaeological basis by analysis of the composition of the grave-goods (data concerning physical anthropology are in no case available).

A. In the cemeteries of the Marches at Filottrano (Ancona) and at Montefortino (Ancona) (Fig. 1, nr. 2 and 3) tombs with silver and gold finds are numerous (Fig. 2, A and B). Tombs with gold objects (or with gold and silver objects) are more numerous than those with only silver objects. Also the gold objects (9 at Filottrano and 24 at Montefortino) are more numerous in total than the silver objects (3 at Filottrano and 16 at Montefortino). However at Montefortino the weight of the silver is certainly greater, given the drinking set from tomb 33 weighing approx. 1.2 kg.
Most jewels, present mainly in women's tombs, belong to Hellenistic-Etruscan rather than La Tène types, (this is summarized in Table 1). If one looks at the grave-goods of the most sumptuous women's tombs illustrated by Brizio (1899), the absence of any La Tène object is striking. Brizio (1899) assigned Montefortino to the La Tène world, however, after a wide-ranging evaluation of the whole cemetery; at Montefortino there are La Tène weapons, above all the characteristic swords, as well as a few La Tène brooches, none of precious metal. This attribution has been accepted by such an authority as Josef Déchelette (1902) and has never been seriously challenged thereafter.
A comprehensive re-edition and re-evaluation of all the materials from the cemetery has not been undertaken although single objects are frequently cited and illustrated (see for instance Vitali 1991 b, 234 for colour photos of the gold earrings with triangular pendants probably from Taranto and of the gold spiral bracelets with serpent heads from tomb 23).
The only unquestionably La Tène gold object from these cemeteries is the famous torc which is decorated in the Waldalgesheim style (or "style végétal continu") from tomb 2 at Filottrano (see Landolfi 1991, 286 and Kruta 1991, 202 for colour photos, Kruta 1992 for a recent evaluation).

B. Further to the north, in Emilia, gold objects, albeit definitely fewer, are found only in two centres settled on previous Etruscan cities: Bologna and Marzabotto (Bologna) (Fig. 1, nr. 6, 7). There burials with objects of precious metal are rarer than at Filottrano and Montefortino (Fig. 2, C and E). At Bologna there are a few gold wreaths in two men's tombs and in a woman's tomb (Vitali 1992, 1991 b, 227), then there is a pair of earrings of northern Etruscan type (Vitali 1992, 295, Table 43, 1). At Marzabotto there was only a gold ring, also found in a woman's tomb (Kruta Poppi 1975, Vitali 1985). In Emilia there are also a few rings, earrings and bracelets made of silver. In Bologna the numbers of objects in gold and silver, while few, are equivalent. At Marzabotto silver is predominant while at Arcoveggio - via della Dozza and Monterenzio (Bologna) (Fig. 2, D and F) silver is the only precious metal found. The majority of these objects in precious metal is of Etruscan type, with the exception of a silver brooch from Bologna, tomb Benacci 359 (Vitali 1992, 194, Table 20, 4) and of the silver objects from tomb 4a from Arcoveggio - via della Dozza in the environs of Bologna (Ortalli 1990). These are of a La Tène type.

These data suggest the possibility, which needs to be verified by analysing other categories of archaeological evidence, that the distribution of precious metal objects might give some indication of hierarchical organisation. Such a hierarchy might be reflected not only within single sites but also between different centres such as Bologna and to a lesser extent Marzabotto, on one hand, and Arcoveggio - via della Dozza and Monterenzio on the other.

C. To the north of the Po river, especially in Lombardy, during this period there are no gold finds in the area continuosly settled by La Tène groups. Only silver objects are found: torcs, bracelets and simple wire or band finger-rings, all of a La Tène style, are concentrated in the area crossed by the Oglio river. When there are records of provenance, (essentially only in the case of Carzaghetto (Mantova) (Fig. 1, nr. 9), the tombs are always those of women (Fig. 2, G).

La Tène gold or gold-plated silver brooches are found only in the Veneto, that is, outside the area that was most continously occupied by La Tène groups. A silver brooch plated with gold foil was found at Este (Padova), in a tomb that contained otherwise local or possibly Etrusco-Italic objects. It is called "Nerca's tomb" from the name that was written on some vases in the venetian alphabet. This extraordinarily rich female tomb has been dated in a relatively precise manner on the basis of black glaze pottery, to about 280 B.C., which places it in the period La Tène B2. Among the numerous grave-goods there are both local Certosa brooches and La Tène B ones (Chieco Bianchi 1987). However, in this particular La Tène brooch the bridge (extremity of the foot) appears to be already joined to the bow. The Certosa brooches and a La Tène B one (along with another La Tène B brooch from a nearby tomb), as well as a few simple rings, are made of silver plated with gold foil. This technique, silver plated with gold foil, however, was not used by the craftsmen of the area but was an early tradition in Etruria and in Bologna (Formigli 1985 a, b). In the area immediately north of the Alps plating with gold foil is documented at least since the late Hallstatt period. It was, however, generally applied to bronze (Eluére 1987), while silver objects with gold foil plating are exceedingly rare (Eluère 1988). The similarity in the method of production employed for both the Certosa and La Tène brooches raises the possibility that they may have been produced in the same "workshop" (by the same craftsman?) even if the models of the brooches clearly derive from different handcraft traditions. Moreover, the La Tène brooch also has the spring coated in gold foil, which led Chieco Bianchi to consider that the coating may have been done for the purpose of burial. (The use of gold foil for funerary purposes in the Hochdorf tomb comes to mind, see for instance Plank 1985).

This example appears to be interesting because it shows especially clearly that the relationships between various craft traditions may be very complex. Furthermore it is not easy, at least in Italy, to separate different craft traditions, in this case a La Tène craft tradition from a local tradition, even so, the craft tradition within which the objects were made is indicated, whenever it was possible (see Table 1 and Table 2).

A lovely gold brooch of a Middle La Tène shape found at Padova (unfortunately the archaeological context is no longer preserved, Vitali 1991 b, 224) provides further evidence for the wide ranging connections within the La Tène craft traditions. (It may seem paradoxical but with a single exception from Bologna the La Tène brooches made of precious metal known in this early phase are all from the Veneto, that is from an area which during this period was not inhabited steadily by La Tène groups).

Summarizing the data relating to this early phase, one may conclude:

1) Virtually all the gold ornaments found in La Tène tombs come from the region south of the Po and are primarily of Hellenistic and Etruscan types. Evidently they were obtained through belligerent or friendly relationships with Magna Grecia and Etruria. It appears that, in the majority of cases, these objects were not remelted but, rather, were highly valued and used by the élite. The silver objects found south of the Po are also of Hellenistic type, the only exceptions being the brooch from Bologna - Benacci, together with a small bracelet and a ring of La Tène type from Arcoveggio - Via della Dozza. By contrast, to the north of the Po, in Lombardy, silver objects are exclusively of La Tène type. Moreover, some La Tène brooches in precious metal are found in the Veneto, outside the regions continuously settled by La Tène groups.
2) As far as one can gather on the basis of the funerary customs, precious metals seem to have been mainly used in these communities for jewellery worn by members of the élite and especially by the women who were a part of it. South of the Po precious metals were also used in a few cases for ceremonial objects in the Hellenistic-Etruscan tradition: objects such as the gold wreaths and silver tableware seem related to symposia or banquets. The fact that this use would be reserved to a few people of both sexes makes one think it probable that the women of high rank would have taken part in the banquets along with the men.

   Obviously there is another important use of precious metals, that is as money. Local silver coinages must have been in use in the early La Tène phase. However the early coins are never found in closed archaeological assemblages, so it is understood very little about how they were used, except for clues that can be gathered from the coins themselves.

3. Late phase: La Tène C2-D

During La Téne C2-D (approximately II - I cent. B.C.) the picture changes completely. Very few precious artifacts are found in tombs. The tombs that do contain precious metals are located on the Alpine fringes or scattered in the Veneto. In this phase, Ornavasso is the only site within the Italian border where some gold is still found in tombs, and that consists only of one finger-ring. In addition there is a finger-ring with a gold frame and two silver-gilt brooches that seem to be mercury gilded (Fig. 2).

Most gold finds are coins, usually found alone, although sometimes they were found within a hoard. These coins belong to well known types current north of the Alps, commonly called "Regenbogenschüsselchen". A few of the gold finds are located on the fringes of the Alps and there are two other areas where gold finds are more concentrated. The highest concentration is reported in Piedmont in a small area near Vercelli, on the border of thickly settled Lombardy. Two hoards are found in northern Tuscany, very far from the areas settled by La Tène groups. Finally there is the description of a hoard found in Padua in the 16th century (and of course long lost) which recently Giovanni Gorini added to the known "hoards of type Basel Saint Louis". This hoard contained one hollow torc along with gold and silver coins "made like a walnut, concave on one side and convex on the other, with lions and horses and without inscription" (Gorini 1992, 212).

The gold objects, both coins and rings, find no comparison with objects of the local milieu and this points to a transalpine origin. That is why they have been linked to the forays made by the Cymbri and Teutones at the beginning of the first century B.C. These hoards might be votive deposits, as Andres Furger-Gunti (1982) suggested, and, as such, again could be linked to those found north of the Alps (Furger-Gunti 1982, Gobel et al. 1991).

Local La Tène groups, in this time very much under the overbearing influence of Rome, appear not to have had any gold, at least not such gold as can be observed from an archaeological point of view by being found in tombs or in hoards; they appeared to have only silver at their disposal.

The widespread local silver drachmae have been left out of the general distribution map (Fig. 3). However if the distribution of the gold coins is sketchily compared with that of the local silver drachmae, the gold coins appear either to be found on the edge of the distribution of the silver coins or otherwise in areas where silver coins are rare (Fig. 4).

The distribution and nature of the gold finds in Italy in the late La Tène period has some curious features. Clearly they appear almost always to be represented by objects of transalpine character, the only obvious exception being the bezel rings from Ornavasso. Moreover it is striking that the concentration of gold coins (and torcs) near Vercelli is situated very near to one of the main gold exploitation areas (Piana Agostinetti et al. this volume, Figs. 1, 2, 3).

These observations raise the following questions:

A. If these gold objects were in effect made north of the Alps why should they have been brought to the main gold production area south of the alpine watershed?

B. If the west Alpine region was an area of gold production (as documented by the written sources at least from the 2nd cent. onwards - Piana Agostinetti et al. this volume), why are the local jewels and coins from Northern Italy, which are found in the archaeological record, always made of silver and practically never made of gold?

C. Might one, building upon Pautasso's (1975) and Egger's (1991, 117 - 118) remarks concerning the distribution of the staters with bird head on the obverse and cross with two volutes and three points on the reverse (Streber type II, 19 - 21), and which appear to be concentrated around Vercelli, dare to take into consideration the heretical hypothesis of a possible "local" minting of some types of Vindelician staters?

D. Would a possible explanation for the observations be that indirect "colonial" exploitation by the Romans drained all the gold?

These unanswered questions could be the starting point of the next stage of the research, one in which metallurgical and composition analyses might play a fundamental role.

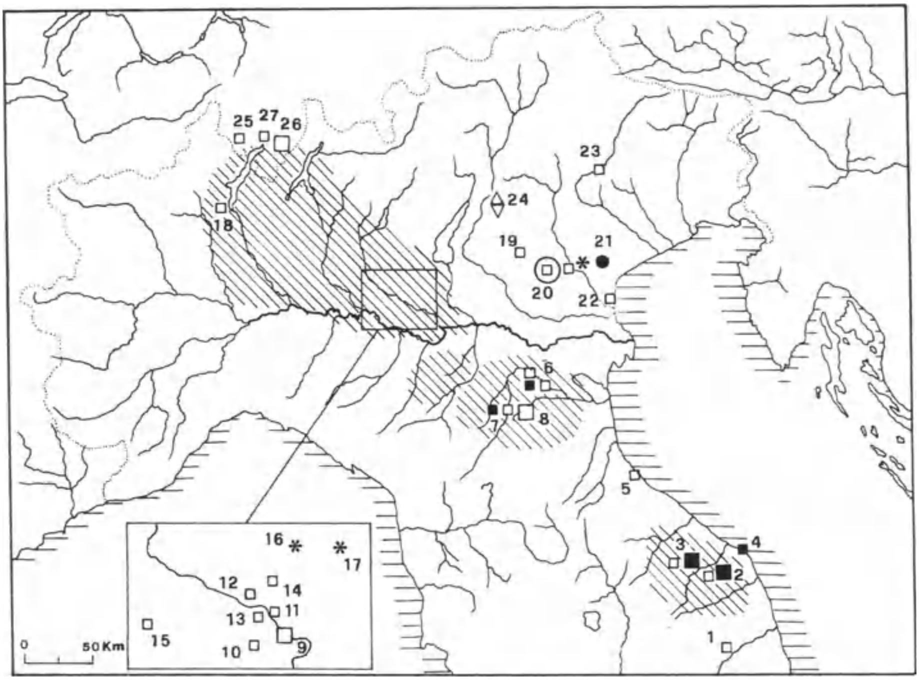

Fig. 1: La Tène B-C1 (approx. IV - III cent. B.C.) gold and silver objects found in Italy. Striped areas were continously settled by bearers of the La Tène culture.
Finds from tomb/cemetery: square, solid (gold), empty (silver). Smaller symbol: up to 4 tombs (or a small group of objects from a mixed find). Larger symbol: 5 - 10 tombs. Empty square within a circle: gold plated silver brooch from tomb. Rhomboid, empty: hoard with silver find. Single find: circle, solid (gold); asterisk (silver). (see Table 1). 1. S. Ginesio (MC); 2. Filottrano (AN); 3. Montefortino (AN); 4. Numana (AN); 5. Misano Adriatico (FO); 6. Bologna; 6A. Arcoveggio-Via della Dozza (BO); 7. Marzabotto (BO); 8. Monterenzio (BO); 9. Carzaghetto (MN); 10. Vho-Campo Campagna (CR); 11. Volongo (CR); 12. Gambara (BS); 13. Fiesse (BS); 14. Remedello (BS); 15. Sesto Cremonese (CR); 16. Carpenedolo (BS); 17. Castellaro Lagusello (MN); 18. Dormelletto (NO); 19. Montebello (VI); 20. Este (PD); 21. Padova; 22. Altino (VE); 23. Polcenigo (PN); 24. Castel Selva di Levico (TN); Switzerland: 25. Solduno (TI); 26. Giubiasco(TI), 27. Gudo (TI).

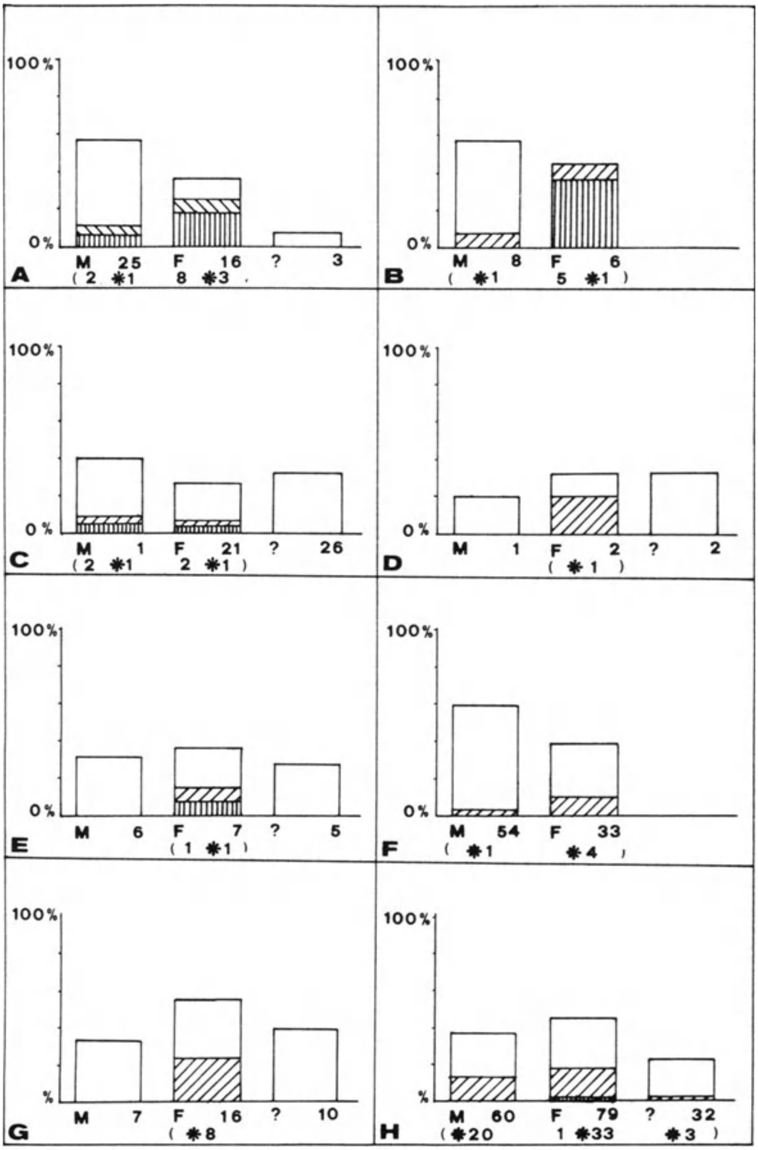

Fig. 2: La Tène cemeteries with graves containing gold and silver objects in Italy. The bars indicate the percentage of male (M), female (F) and undetermined (?) tombs in the classified sample with the actual number indicated below. The frequency of tombs with precious metals finds within each group is indicated by the striped areas, vertical for gold and oblique for silver, with the actual number indicated between parentheses, preceded by an asterisk when there are only silver objects.

A. Montefortino (AN); B. Filottrano (AN); C. Bologna; D. Arcoveggio (BO); E. Marzabotto (BO); F. Monterenzio (BO); G. Carzaghetto (MN); H. Ornavasso (NO).

(See Table 1 for sites A - G; Table 2 for site H)

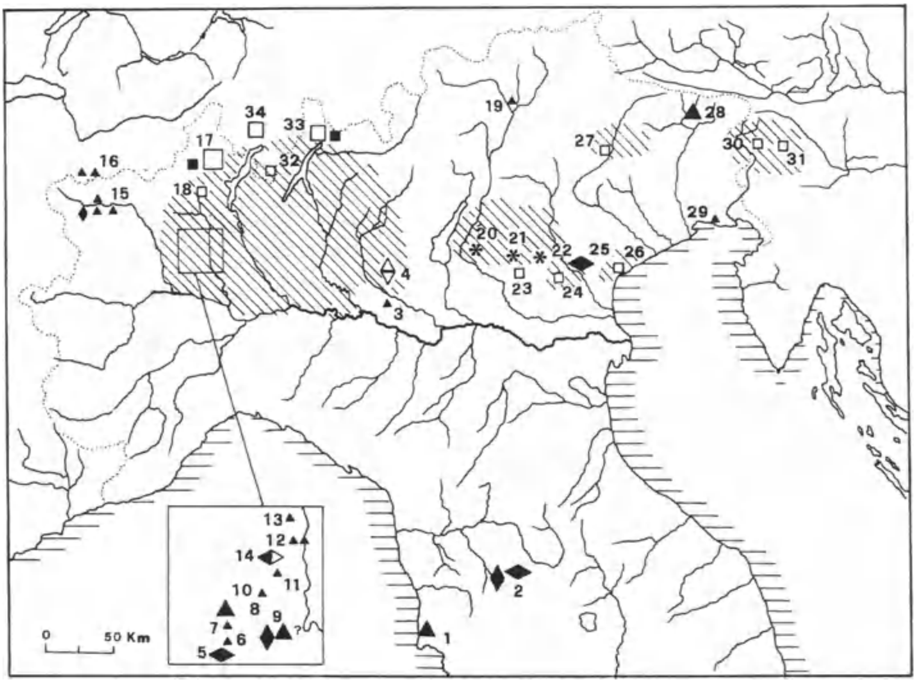

Fig. 3: La Tène gold and silver in Italy during La Tène C2-D (approx. II - I cent. B.C.). Striped areas were continuosly settled by bearers of the La Tène culture.
Find from tomb/cemetery: square, solid (gold), empty (silver). Smaller symbol: one tomb (or a small group of objects from a mixed find). Larger symbol: 9 tombs and over. Largest symbol: 56 tombs. Gold coins (different coinages are not marked and silver coins are not mapped): triangles, solid. Smaller symbol: single find (or very few coins). Larger symbol: coin hoards. Gold jewels: rhomboid, solid and vertical. Smaller symbol: gold armring/neckring single find. Larger symbol: hoard with neck-ring/armrings. Larger symbol, horizontal: hoard with rings and coins ("type Basel - Saint Louis"). Rhomboid, half solid: hoard with gold coins and bronze armrings. Rhomboid, empty: hoard with silver find. Single find: asterisk (silver) (see Table 2).
1. Campiglia Marittima (LI); 2. Siena Casacce; 3. Verola Vecchia (BS); 4. Manerbio (BS); 5. S. Germano Vercellese (VC); 6. Tronzano (VC); 7. Santhià (VC); 8. Carisio (VC); 9. Formigliana (VC); 10. Balocco (VC); 11. Arborio (VC); 12. Lenta (VC); 13. Gattinara (VC); 14. Rovasenda (VC); 15. Aosta; 16. Gran S. Bernardo (AO); 17. Ornavasso (NO); 18. Gravellona Toce (NO); 19. Sette-querce/Siebeneich (BZ); 20. S. Pietro in Cariano (VR); 21. Colognola ai Colli (VR); 22. Trissino (VI); 23. Pressana (VR); 24. Arquà Petrarca (PD); 25. Padova; 26. Altino (VE); 27. Polcenigo (PN); 28. Zuglio (UD); 29. Aquileia (UD); Slovenia: 30. Bodrež; 31. Reka; Switzerland: 32. Stabio (TI); 33. Giubiasco (TI); 34. Solduno (TI).

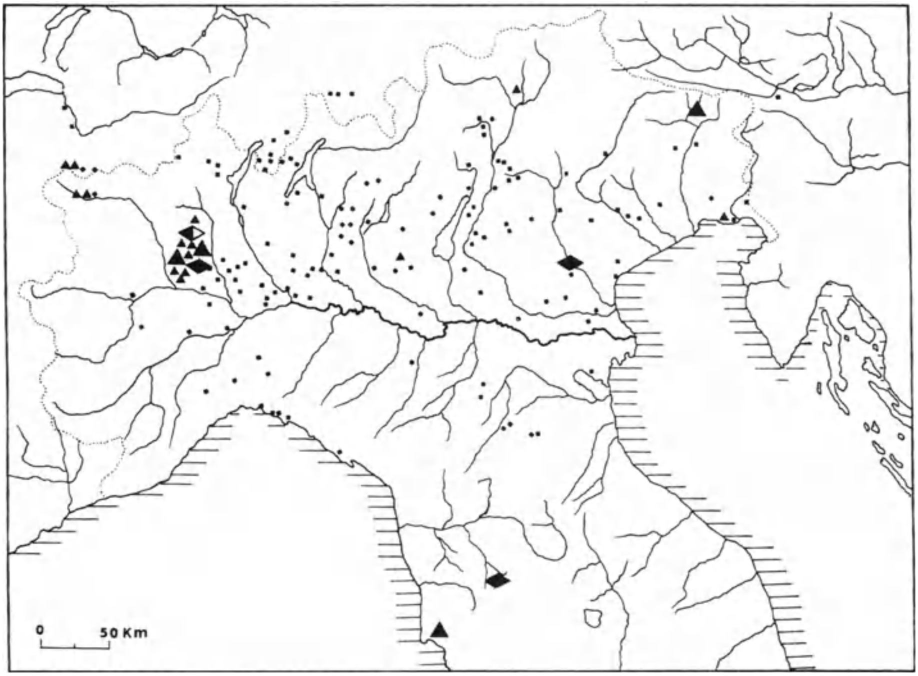

Fig. 4: La Tène gold coins and local silver coinage in Italy.
Gold coins: triangles. Small symbol: single find (or very few coins). Larger symbol: coin hoard. Rhomboid: hoard with coins and neckrings/armrings (see Fig. 3 and Table 2). Dots: distribution of local silver drachmae, type of context and quantity are not indicated (after Piana Agostinetti 1988, Fig. 3, Appendice B1).

*Table 1. Early phase, La Tène B-C1. Abbreviations and symbols used: for sex (M= male; F = female; ? = sex not determined); for craft tradition (H = Hellenistic; E = Etruscan; R = Roman; LT = La Tène); for the presence of silver (S = silver; * = containing only silver); for administrative/political units to which the sites belong (by the capital letter abbreviation into parentheses, which correspond to those used on car shields). A few sites outside the Italian political boundaries but closely linked to the Italian ones are taken into account as well. As a rule only the latest contribution/contributions are listed in the bibliography.*

	Site name	archaeological context	type of object/craft tradition
*1.	S. Ginesio (MC)	M Tomb with weapons	M : S headband
2.	Filottrano (AN)	Cemetery 28 tombs F (t. 1, 2, 9, 11, 13 * 5) and M (* t. 3)	F: finger rings in part H/E, also S ones, H necklaces, gold foil, LT torques, S phiale M: H/E S finger ring
3.	Montefortino (AN)	Cemetery 49 tombs F (t. 8, 20, 21, 21 bis, 30, 32, 39, *9, *27, *40) and M (18, 33, *13)	F: finger rings in part H/E, also S ones, H armrings, also S ones H earrings, H/E wreaths, H neckring M: finger rings in part H/E also S S drinking set
4.	Numana (AN)	Cemetery, M with LT weapons (t. 214)	M: finger ring
*5.	Misano Adriatico (FO)	F tomb	F: S armring
6.	Bologna	Cemeteries Benacci, Benacci Caprara, De Lucca, Certosa, 78 tombs (see Fig. 2) F (t. 960, 954, *963) M (t. 953, BC I, * DL 86) and ? (*t. 359, *t. C66)	F: E earrings also S ones H/E wreath, E/H S finger ring M: H/E wreath S finger ring ?:S finger ring S LT brooch
*6A.	Arcoveggio Via della Dozza (BO)	Cemetery 5 tombs (see Fig. 2) (excavation going on) F (t. 4a)	LT S finger ring LT S armring
7.	Marzabotto (BO)	Cemetery 25 tombs 18 considered in Fig. 2 F (t. M4, *t. A8)	Finger ring also S ones, S armrings
*8.	Monterenzio (BO)	Cemetery 134 tombs (up to 1990) F (t. 61, 62, 64, 101) and M (t. 14)	F : S finger rings E S earrings E S Certosa brooch M: E S Certosa brooch fragment
*9.	Carzaghetto (MN)	Cemetery 54 tombs 33 considered in Fig. 2 F (t. 17, 20, 23, 27 28, B, H, M)	F:LT S finger rings LT S armrings
*10.	Vho-Campo Campagna(CR)	From tomb/tombs with weapons	S spiral finger ring
*11.	Volongo (CR)	From tombs	LT S armring
*12.	Gambara (BS)	From tomb ?	LT S armring
*13.	Fiesse (BS)	Tomb	S armring
*14.	Remedello (BS)	From tomb/tombs	LT S armring LT S neckring MLT S brooch
*15.	Sesto Cremonese (CR)	From tomb	LT S neckring

Table 1. continued:

*16.	Carpenedolo (BS)	Single find ?	LT S neckring
*17.	Castellaro Lagusello (MN)	Single find ?	S armring
*18.	Dormelletto (NO)	Cemetery 52 tombs F (t. 11)	S spiral finger ring
*19.	Montebello (VI)	From cemetery	S brooch
20.	Este (PD)	Cemeteries F (Ricovero t. 23, 36; Benvenuti t. 123)	F: Certosa and LT S brooches a few plated with gold foil, (local) earrings, also S ones, beads, bullae
21.	Padova	Single finds ?	LT brooch also S one
*22.	Altino (VE)	Cemetery I Portoni (Ustrina, nr. 3 and 4A)	MLT S brooches
*23.	Polcenigo (PN)	From cemetery	MLT S brooches
*24.	Castel Selva di Levico (TN)	Hoard ?	MLT S brooches
Switzerland			
*25.	Solduno (TI)	Cemetery 191 tombs (t. C19x and C18)	S spiral finger rings
*26.	Giubiasco (TI)	Cemetery 540 tombs (possibly t. 117, 164, 308, 61, 235 307, 307, 353, 370, 19,54, 201)	S (spiral) fingerrings S armrings S necklace
*27.	Gudo (TI)	Cemetery 306 tombs (t. 48, 49, 57, 184) S small (spiral) rings	S spiral finger ring (or armring?)

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4. Spadea 1978, 185 - 186
5. Bermond Montanari 1987; Moscati et al. eds. 1991, 724, nr. 286
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6A. Ortalli 1990

7. Kruta Poppi 1975; Vitali 1985, 58 - 68
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9. Ferraresi 1976; Trucco 1983, 60 - 66
10. Tizzoni 1984, 34 - 35, tav. XXXVIII
11. Tizzoni 1985, 56; De Marinis 1984, 112- 113
12. Tizzoni 1985, 16, tav. 7, c; De Marinis 1984, 146
13. De Marinis 1984, 114, n. 66
14. Tizzoni1985, 53 - 54, tav. 42, e, d, f; De Marinis 1984, 114, n. 65

15., 16. De Marinis 1984, 114, 146

17. De Marinis 1984, 114
18. Spagnolo Garzoli 1992, 296, Fig.2
19. Ruta Serafini 1984, 23, Fig. 11
20. Chieco Bianchi 1987; Calzavara Capuis and Ruta Serafini 1987
21. Ruta Serafini 1984, 19 - 20, Fig. 9; Vitali 1991b, 224
22. Tombolani 1987, 173, 176, Fig. 7
23. Righi 1984, 172, tav. I, 2, 3, 4
24. Lang 1979, 83, Fig. 9, 1; Ruta Serafini 1984, 23 n. 4
25. Stöckli 1975, 121
26. Ulrich 1914; Stöckli 1975, 121; Müller 1991, 130 n. 99
27. Ulrich 1914, Beilage II, 19 - 65

*Table 2. Later phase, La Tène C2-D. Abbreviations and symbols used: for sex (M= male; F = female; ? = sex not determined); for craft tradition (H = Hellenistic; E = Etruscan; R = Roman; LT = La Tène); for the presence of silver (S = silver; * = containing only silver); for administrative/political units to which the sites belong (by the capital letter abbreviation into parentheses, which correspond to those used on car shields). A few sites outside the Italian political boundaries but closely linked to the Italian ones are taken into account as well. As a rule only the latest contribution/contributions are listed in the bibliography.*

	Site name	archaeological context	type of object/craft tradition
1.	Campiglia Marittima (LI)	Coin Hoard	About 200 thirds of staters of the Boiian Athena Alkis series
2.	Siena Casacce	1872 Hoard ?	Two LT neckrings
		1875 Hoard ?	Two LT neckrings, 10 "little discs similar to coins" (very likely smooth "Regenbogenschüsselchen")
3.	Verola Vecchia (BS)	1891 Single find	Vindelician stater
*4.	Manerbio (BS)	Hoard	LT S horse trappings
5.	S. Germano Verc. (VC)	Hoard	One torc, 10 vindelician staters
6.	Tronzano (VC)	Find	Vindelician stater/staters
7.	Santhià (VC)	Find	Vindelician stater/staters
8.	Carisio (VC)	Hoard ?	Several Vindelician staters
9.	Formigliana (VC)	1879 Hoard?	Two torcs
		Hoard?	Vindelician staters
10.	Balocco (VC)	Find	Vindelician stater/staters
11.	Arborio (VC)	Find	Vindelician stater/staters
12.	Lenta (VC)	Find	Two staters "à la croisette"
13.	Gattinara (VC)	Find	Vindelician stater/staters
14.	Rovasenda (VC)	Hoard?	Vindelician staters and two bronze armrings
15.	Aosta	1838 Find	Vindelician stater
		1858 Find	«Salassi» stater
15A.	Saint-Martin-de-Corléans	1857 Find	«Salassi» stater
15B.	Verrés	1861 Find	«Salassi» stater
15C.	Consolata	From settlement ?	Armring or torc fragment
16.	Gran S. Bernardo (AO)	Votive deposit	Two «Salassi »staters
17.	Ornavasso (NO)	S. Bernardo cemetery 181 tombs 171 considered in Fig. 2 F (3, 8, 15, 69, 14, 159, 18, 10, 13, 77, 114, 5, 25, 155, 33, 141, 136, 82, 56, 62, 87, 138, 2, 16, 28, 37-38, 106, 88, 72, 93, 95, 112, 113) M (31, 105, 137, 162, 164, 1, 17, 6/1941, 6, 7, 11, 161, 44, 49, 154, 7/1941, 96, 24, 130, 4, 165) ? (34, 74, 135)	F : H/R Finger ring (t. 3) F and M: local LT S brooches (some gilded ones) S armrings, S finger rings, R S cups
*18.	Gravellona Toce (NO)	Cemetery; (t. 17)	S chain
19.	Settequerce/ Siebeneich (BZ)	Find from settlement ?	Vindelician stater
*20.	S. Pietro in Cariano (VR)	From cemetery?	S torc fragment
*21.	Colognola ai Colli (VR)	Find	S armlet
*22.	Trissino (VI)	Settlement	S or S gilded torc fragment
*23.	Pressana (VR)	From tomb	S armring fragment
*24.	Arquà Petrarca (PD)	Cemetery 22 tombs (t. L)	S armring

Table 2. continued:

25.	Padova	Hoard ?	Torc fragment, coins also S ones
*26.	Altino (VE)	Cemetery Fornasotti (t. 1/1977)	Two S brooches
*27.	Polcenigo (PN)	From cemetery	SLT S brooch
28.	Zuglio (PN)	Hoard ?	7 Regenbogenschüsselchen
29.	Aquileia (VE)	Find	1 Regenbogenschüsselchen
Slovenia			
*30.	Bodrež (S)	From cemetery	LT S brooch
*31.	Reka (S)	Cemetery (t. 12)	LT S torc and brooch
Switzerland			
*32.	Stabio (TI)	Two tombs (t. 1)	LT S brooch
33.	Giubiasco (TI)	Cemetery 540 tombs (t. 250) (at least * t. 468, 477, possibly also *t. 98, 254, 411, 252, 90, 424, 249, 32, 87, 16, 18, 253, 251, 89, 412)	spiral finger ring also S ones S armrings S brooches S cup
*34.	Solduno (TI)	Cemetery 191 tombs (t. C35, D 21, J14, C 23, D 45, J 7, J 8, J 28)	S spiral finger rings S armring

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4. Kruta 1973
5. Pautasso 1984; Piana Agostinetti 1991, 448, n. 46

6., 7. Pautasso 1984

8. Pautasso 1984; Piana Agostinetti 1991, 457
9. Pautasso 1984; Piana Agostinetti 1991, 450, nn. 53, 54

10., 11., 12., 13. Pautasso 1984

14. Pautasso 1984; Piana Agostinetti 1991, 450, n. 52
15. Pautasso 1972, 1975, 1984, tav. II, 17

15A., 15B. Pautasso 1972

15C. Piana Agostinetti 1991, 450, n. 55

16. Pautasso 1972; Piana Agostinetti 1991, 453, n. 68.
17. Piana Agostinetti 1972; Piana Agostinetti 1985, tab. 13
18. Piana Agostinetti 1972, 185 - 186, Fig. 190,5
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21. Ruta Serafini 1984, 26, n. 56
22. Ruta Serafini 1984, 26, Fig. 13; Calzavara Capuis and Ruta Serafini 1987, 290, Fig. 9
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28., 29. Gorini 1984, 83

30. Guštin 1991, 11, tav. 40, 10
31. Guštin 1991, 26, tavv. 34, 8: 35, 3
32. Stöckli 1975, 66 -67, Fig. 62, 4
33. Ulrich 1914; Stöckli 1975, 115; Müller 1991, 130 n. 99
34. Stöckli 1975, 115

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Chapter 5

CELTIC GOLD IN BOHEMIA

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ABSTRACT. In the region of present-day Bohemia, gold objects dating from the 8th to the 1st century B.C. (Hallstatt C - La Tène D1) have been found at ca.150 localities/sites. The mining/recovery and processing of gold is discussed on the basis of these archaeological finds, and X-ray fluorescence analysis of the gold artefacts pursued by the author from the Late Aeneolithic. Fragments of a washing trough, dated after B. Dubský (1949) to the 3rd or 2nd century B.C., found near Modlešovice form the source material for a hypothetical reconstruction of the techniques of gold prospecting in antiquity. A possible goldsmith's workshop from the oppidum of Stradonice is discussed. Bohemia (ancient "Boiohaemum") played an important role in the production of gold. The significance of this valuable resource in Celtic society, and as an article for export, is demonstrated by the fact that gold production in Bohemia amounted in Celtic times to an estimated total of 17.4 tonnes.

Introduction

Because of its significant deposits (Fig. 1) of both primary ("vein") and of secondary (alluvial) gold in placers (review Morávek et al. 1992), Bohemia became one of the European centres of exploitation and treatment for this yellow king of metals. A demonstrable use of gold objects from the end of the Aeneolithic, with frequent finds from the end of the Earlier Bronze Age (Reinecke A2), leads to the conclusion that, at the latest, by the turn of the 2nd and 1st millenium B.C. the beginning of gold exploitation from the placers of Bohemia, continuing with shorter interruptions until the late Middle Ages started. It is estimated that in the course of running the gold placers in Bohemia a total of 22-56 tonnes of gold could have been obtained (Morávek et al. 1992, 15), with, during the Hallstatt and La Tène periods about 17.4 tonnes, from which at least 58kg of gold objects have been registered by the archaeologists (Waldhauser 1991, 22). The estimates are to a large extent based upon the metal content of the alluvial deposits.

1. Gold objects from the period Hallstatt C - La Tene D1 (8th-1st century B.C.) in Bohemia

Most importantly there is the coined gold; much less common are personal jewels and dress accessories. Gold is also known in the form of droplets on industrial ceramics and as residues from a "workshop" in the oppidum at Stradonice, as well as in the form of tiny particles in the so-called "goldpanner's hut" at Modlešovice.

G. Morteani and J. P. Northover (eds.), Prehistoric Gold in Europe, 577–596.

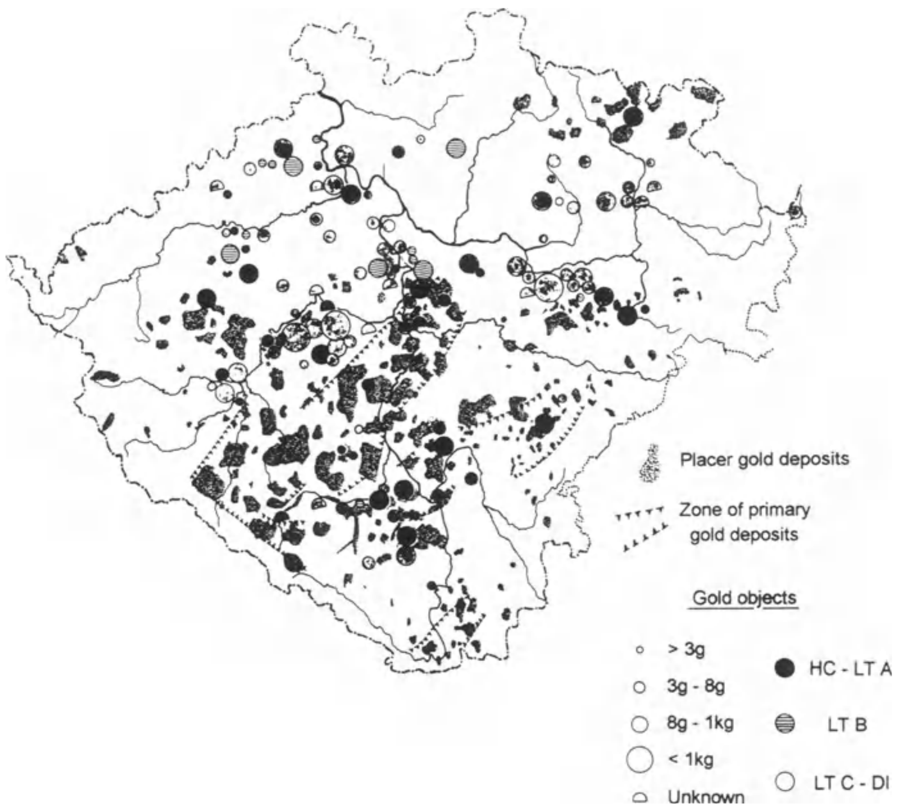

Fig. 1: Primary and secondary deposits of gold in Bohemia and gold objects from Hallstatt C until La Tène D1 (state at 1990). Secondary and Primary deposits of gold.

The form and function of gold objects from around 150 sites (Fig. 2) changes with time (Fig. 3):

Hallstatt C: torcs, spirals and belt sheets (Gürtelbleche).

Hallstatt D: small rings, so-called "head/hair/braid" ring predominate - in some cases they are ribbon like and ornamented.

La Tène A: for the first time gold-clad fibulae (Scheibenfibeln), boat-like "Kopf/Haar/Zopfringe" and finger-rings appear. The occurrence of "Gürtelbleche" ceases. In the prince's tumulus at Hradiště, unique solid rings/bangles are found.

La Tène B1-2a: fingerrings, bracelets, and beads are typical, the last mentioned also used as amulets - a torc fragment must also be mentioned.

La Tène B2b-C1a: the first imported coins and also the first made in Bohemia; also gold rivets; some earlier types (finger-rings) were still used.

La Tène C2-D1: typical is the abundance of coins, both singly and in hoards (3/6 - around 6787 pieces), with a unified weight system with units (weight ca. 8 g), thirds, eigths and twenty-fourths. From the typological viewpoint, they belong to the Athene-Alkis series, "shell-like" series and the so-called secondary series (sitting man/boar/horse and others). Of other gold objects, mainly finger-rings, less frequently pendants, a unique gold fibula and an imported gold jewel are recorded.

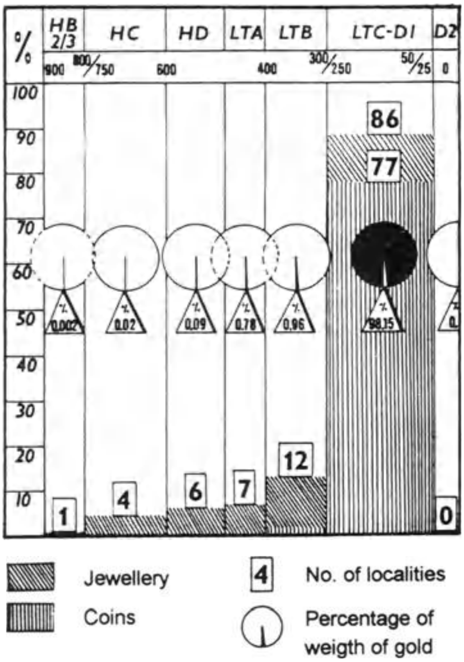

Fig. 2: Frequency distribution of gold objects in Bohemia: (1) jewels, (2) coins, (3) Number of sites, (4) Percent of total weight (state at 1990).

Of industrial refractory ceramics, clay plates (moulds) for fusing the blanks (Schrötlinge) of gold coins, crucibles and a pan-like heating tray have been registered. There are also irregularly shaped gold bars or ingots, and the gold "scrap/waste" identified at Stradonice (see below) (review see Waldhauser 1991, 14-15; for details, including the Bronze Age: Paulsen 1933, Castelin 1965, Břeň 1959, Jansová 1974, Michálek 1976, Hásek 1955, Čujanová-Jílková 1975).

2. Distribution of gold objects during Hallstatt C - La Tène D1 in Bohemia

In the course of about seven centuries, the centre of gravity of the distribution of gold objects changed its position three times (Fig. 4). In the period Hallstatt C - La Tène A the gold objects, with some exceptions, occur in the southern half of Bohemia, i.e. in the territory where the majority of gold deposits is situated. In the period La Tène B, the gold objects come almost exclusively from northern part of Bohemia, from localities without natural occurrences

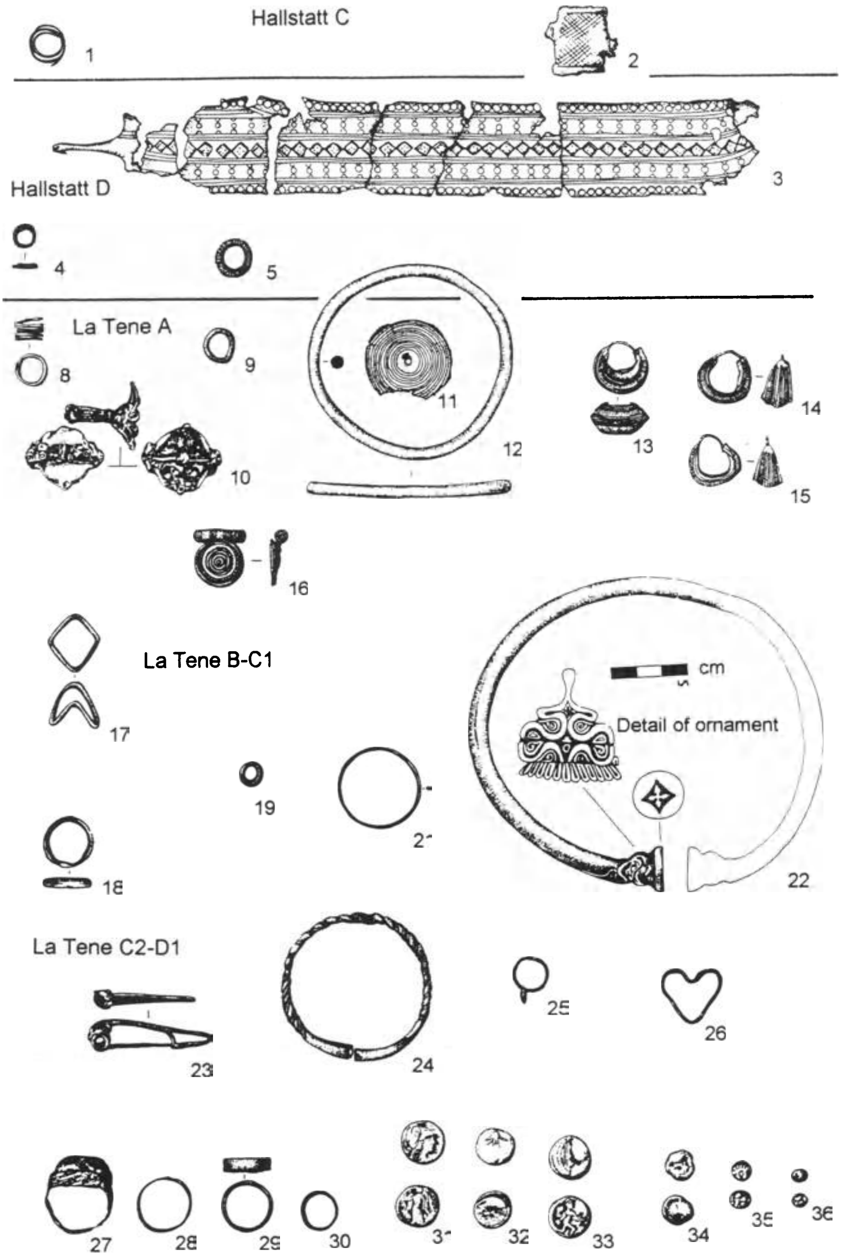

Fig. 3: Gold objects from Bohemia (Hallstatt C-La Tène D1). 1 Bylany, 2 Červené Poříčí, 3 Opařany, 4 Praha-Bubeneč, 5 Chlum near Blatná, 6-7 Opařany, 8 Hradiště near Písek, 9 Skalice, 10 Hořovice or vicinity, 11-15 Hradiště near Písek, 16 Hořovičky, 17 Hostomice, 18 Praha-Hloubeětín, 19 Jenišův Újezd, 20 Praha-Vokovice, 21 Praha-Žižkov, 22 Oploty, 23 Stradonice, 24 Podmokly, 25-30 Stradonice, 31 Nechanice, 32 Osov, 33 Nizbor, 34 Kolín (Starý Kolín), 35 Lísek, 36 Hradiště near Písek.

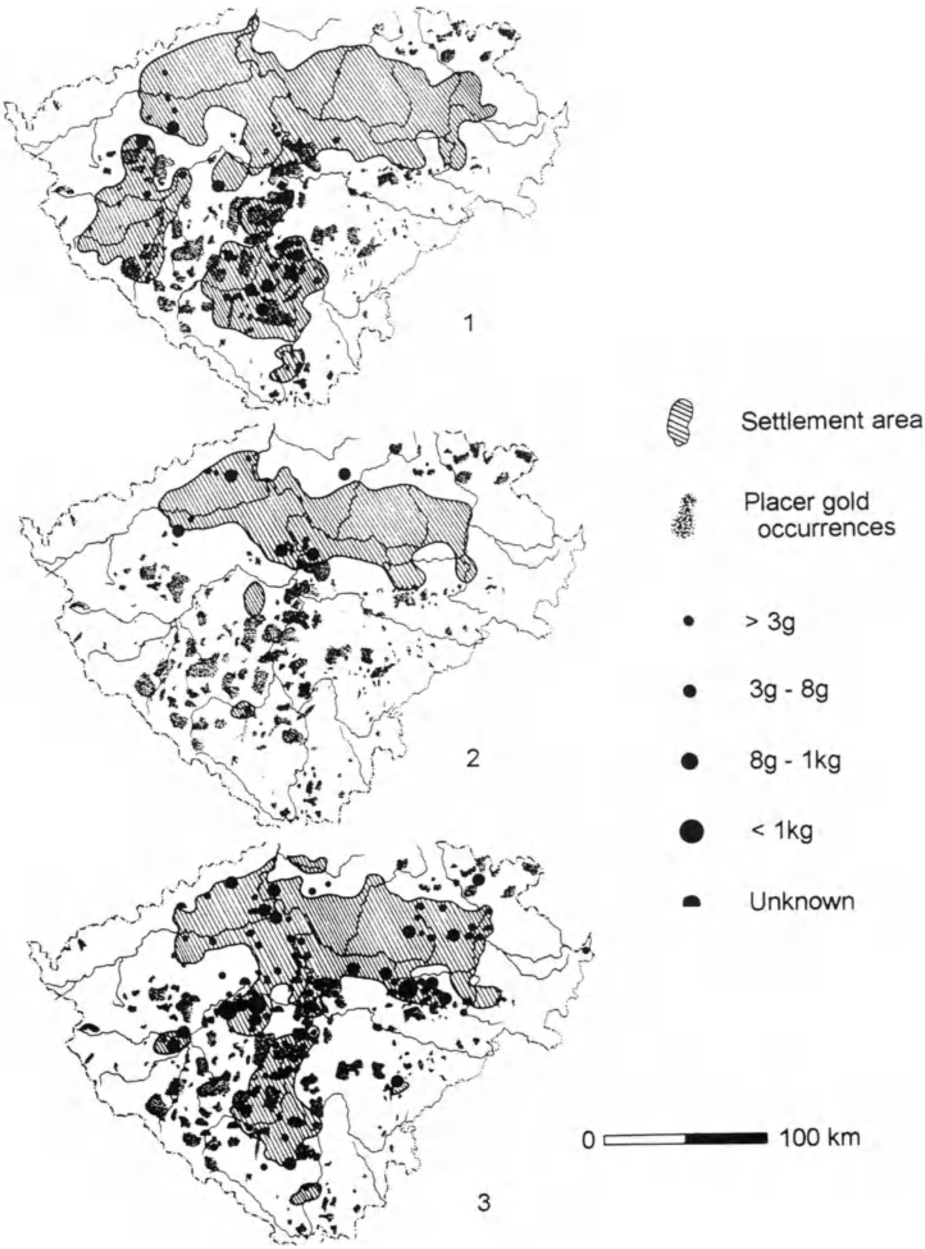

Fig. 4: Occurrence of gold objects in the different periods of "pre-Celtic" and Celtic settlement in Bohemia: 1 Hallstatt C - La Tène A; 2 La Tène B; 3 La Tène C - La Tène D1 (state at 1990).

of gold. In period La Tène C1-D1 gold objects, primarily the coins, are to be found across the whole territory of Bohemia inhabited by Celts, with two conspicuous concentrations in middle-western Bohemia and at the border between eastern and middle Bohemia, doubtlessly connected with the economic and political centres of power of that time. These concentrations represent the "urban" civilization of the oppida in period La Tène D1, which was closed by the collapse of Celtic presence in Bohemia, after which followed the immigration of Germans who, at least at the beginning, did not exploit the Bohemian gold deposits.

3. The Celts and gold exploitation in Bohemia

Indirect indications of Celtic gold exploitation are presented by archaeological traces of the presence of the Celts at the sites of medieval placers and gold mines. Evidence of Celtic material culture there includes, first of all, pottery fragments and gold coins from the sites lying beyond generally cultivated areas, that is from higher altitudes and ground configurations where settlements and burial grounds are uncommon, and other ecological indicators of settlement are absent. The following localities are involved:

- Luka p/M near Prague - finds of pottery on a rocky slope near the medieval St. Barbara gold mine (La Tène C2-D1), (Waldhauser 1988)
- Leskovice (southeastern Bohemia) - hoard of coins and habitation site at an altitude of 600m, tens of kilometres distant from Celtic territory, in neighbourhood of medieval gold placers (La Tène C-D1), (Waldhauser 1987)
- Trutnov (northernmost Bohemia) - analogous to Leskovice, but without habitation site. Only in this gold deposit has the occurrence of the trace element palladium been proved, known in the alloys of the "Boiian coinage" of the Celtic coins in Bohemia (La Tène C), (Paulsen 1933, Hartmann 1986)
- Staré Kestřany and Třebsko/Kamenná - (two sites in South Bohemia), pottery from the floodplain at the sites of medieval placers; current research work has not demonstrated the existence of Celtic settlements in temporarily flooded areas (La Tène C-D1), (Dubský 1949, Michálek 1977, Waldhauser et al. 1989)
- Všenory (middle Bohemia) - sporadic potsherds from a narrow valley, again beyond the area of inhabited sites, from 7th-5th centuries B.C, at medieval goldwashing sites (Hallstatt C-D), (Kudrnáč 1982)
- Kasperské Hory (southernmost Bohemia) - find of pottery and two gold coins from the altitudes of 700-850 m, from the sites of medieval gold mines and fields (La Tène C-D1), (Waldhauser 1988).

Some finds, it is true, possibly represent archaeological traces of other activities of the Celts (e.g. transhumance, use of long-distance roads, incidental movements of Celts beyond their settled areas etc.); in general, however, there seems to be only a small probability for this. Other indications helping to determine the sites where gold was exploited by the Celts might represent the concentrations in mass and abundance of gold objects. However, other factors have some prominence, for example the secondary distribution of gold in period La Tène C-D1 (Fig. 5). In contrast, for the period Hallstatt C - La Tène A the increased quantities of gold placed as grave goods in the tumuli and cemeteries in the south and west Bohemia (e.g. Hradiště by Písek, Manětín-Hrádek by Pilsen) may indicate the placer mining of gold in the lower courses of the rivers Otava and Lužnice, and their tributaries in southern Bohemia; possibly also on Manětínský creek and on its tributaries near Manětín in western Bohemia. At this last-mentioned cemetery gold objects were found in 6% of all graves, a percentage which appears to be extraordinarily high (Beneš 1978, 60).

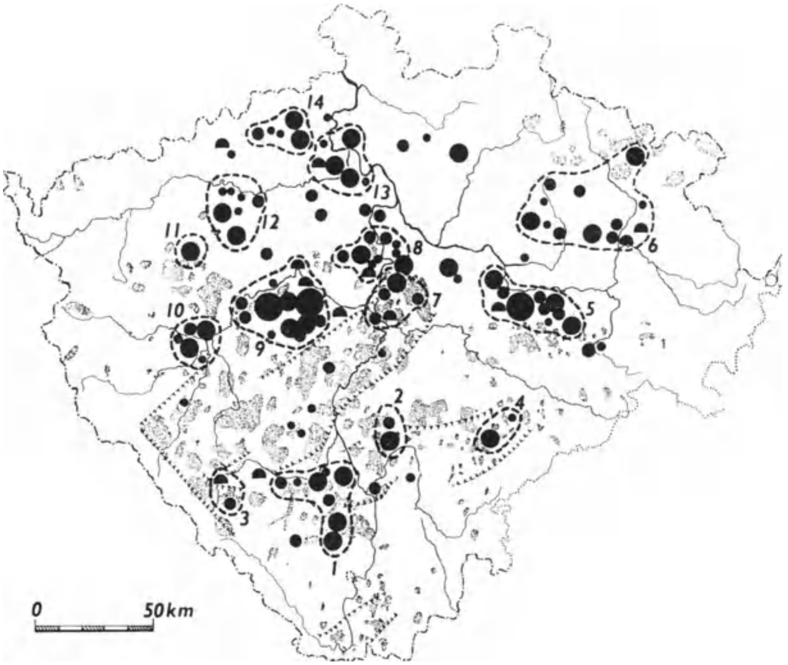

Fig. 5: Concentrations of occurrence of gold objects from Hallstatt C - La Tène D1 in Bohemia. Added are primary and secondary gold deposits (see Fig. 1) and the extent of contemporary settlement in the different periods.

4. Goldwashing trough from Modlešovice and the nearby Celtic settlement

There are about three pages in the report on the rescue excavations made in 1940 on the edge of the floodplain of the Otava river, including interpretations and specialist reports available today (Dubský 1949, 368-372). Also a part of material recovered has been saved: the wood fragments, pottery, bronze bracelets; unfortunately, the palaeobotanical finds are missing: hemp stalks, the weed goosefoot (chenopodium albium). Also, the sheep's fleece, pig's tooth and "gold containing dust", which was said to have been obtained by washing of the hemp stalks and subsequent amalgamation, are also absent. According to the archaeological investigations, two discoveries were made, the functions of which were different: 1) a "pit", length 7 m, width unknown, thickness of the "layer" 0.6 m; depth from surface 1.7 m, orientation of the longitudinal axis E-W; "partial revetment" of pit walls with double layer of granite stones, and 2) a "seat, former residence", thickness of the cultural layer/level 0.4 m. The above mentioned finds of pottery sherds and bronze bracelets were found in context 2) "seat", while the others come from context 1)"pit". All finds were illustrated.

The reconstruction of the goldwashing trough from Modlešovice, assumed, following Dubský (1949), to be of Celtic origin, is based upon the wood fragments recovered, and upon Václav Mayer's opinion (personal communication) that one wood fragment served as a sidewall, an assumption which can be confirmed by iconographic sources from the 16th century. The joining of the sidewalls by three cross bars may be regarded as proved, because one pair of holes has been preserved. A line through these holes gives a slope of 10-20° to the horizontal. On the basis of the alignment of these cross members, a two-part floor was laid consisting of a number of split boards arranged by a tongue and groove joint. By adjusting these boards it was possible to select various angles for the optimum sedimentation of the gold suspension. The sheep wool found here possibly was used in the form of fleece for trapping the suspended gold particles. More difficult to explain is the use of hemp stalks; probably they were used for caulking the two-part, movable trough floor.

In 1987 the author, together with Jirí Fröhlich, made some experiments with a model of a goldwashing trough reconstructed on the basis of the fragments found near Modlešovice (Fig. 6). The two-part floor proved in the tests to be technically very sophisticated, because it was possible regulate means of the movable board the velocity of flow on the trough, and hence the optimum sedimentation of the gold. When the trough is used, no waste heaps on the banks (Seifenhügel) will be formed because all waste material is floated downstream. Using a trough of Modlešovice type two men were able to achieve an output of almost one gram a day, demonstrating the efficacy of the device (Waldhauser and Fröhlich 1990).

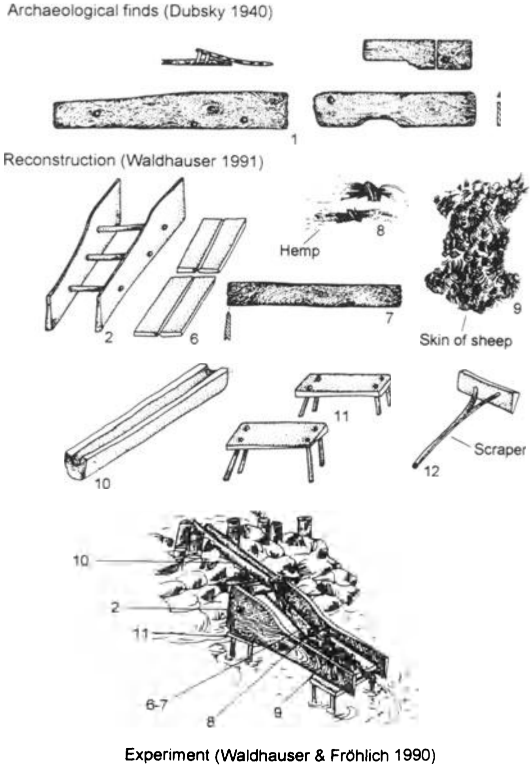

Fig. 6: Trough from Modlešovice, distr. Strakonice.

It is not easy to date the Modlešovice trough. The bronze bracelets found at this site belong to the phase La Tène B2b-C1a (3rd-2nd century B.C.); the pottery falls within the developed stage La Tène B and the beginnning of La Tène C. Pottery made partly from graphitic clay with combed decoration, typical for the Celtic settlements of southern Bohemia during periods La Tène C and D1, is missing here. The ^{14}C dating of a small wood piece, found at the site but without any information about a provenance, whether in contexts 1) or 2) or even in an upper layer with the pottery from 12th-13th century A.D., gave the date 860±121 B.C. (Prague, Charles University, laboratory sample No. 191; see Waldhauser 1991, 18). According to Dubský (1949), the wood fragments of the trough belong with the La Tène finds. However, this information cannot be checked.

The dating of the trough to 3rd-2nd century B.C., following Dubský (1949), raises other questions. The bronze bracelets of Modlešovice show certain analogies with the finds in the territory of flat cemeteries in the northern half of Bohemia. Observations of the penetration of the Celts from the north to the south of the country since La Tène B2/C has already been pointed out. The diameter of bracelets found at Modlešovice (65x70 mm) corresponds with that of the bracelets from La Tène B-C1 graves in the northern half of Bohemia, i.e. to bracelets worn exclusively by adult women; might this be held to show that at the trough on the Otava River in southern Bohemia Celtic women were also at work? After all, it appears in the report of the ancient Greek Athenaios who, referring to his informant living around 100 B.C., writes: *"There are certain small rivers bearing gold grains. These are washed out from the sand by women and invalid men "* (Diodorus, Bk V, 17). The gold won at Modlešovice may also have been used for making gold coins, because it is just in the 3rd century B.C. that the first coined gold appeared in Bohemia (Polenz 1982).

New archaeological research of the areas around Modlešovice, made in 1991 and 1993 by Jan Michálek (personal communication), has given greater precision to our knowledge of some aspects of Celtic activities there. He succeeded in discovering part of a settlement, apparently a farmstead of La Tène C, at a distance of about 0.5 km from the ancient goldwashing site. Finds of more than 10 glass and shale bracelet fragments, without significant parallels in the settlements and oppida of southern Bohemia, indicate the wealth of the inhabitants of the farmstead, which probably resulted from the exploitation of gold. Within about 100 m of where the trough was found, a cremation grave with an iron sword was discovered (La Tène B2b-C1a). There is the question whether the bronze bracelets were connected with the goldwashing activity and/or represent another part of the grave goods not distinguished as such by Dubský (1949) (many thanks for data kindly provided by J. Michálek).

5. Interpretation of the chemical composition of La Tène gold in Bohemia

This preliminary report is based on a framework of the production of gold objects from the end of the Aeneolithic to the La Tène period.

The problems must be considered chronologically; i.e. the compositions of gold objects must be compared not only within individual periods and between the different socio-economic formations of those periods, but also through the following phases of the Celtic settlement of Bohemia:

La Tène A - prosperity, princely sites, tumuli with luxurious burial gravegoods

La Tène B1 - immigration, economic depression and disintegration
La Tène B2-D1 - growth, then prosperity, including the exploitation and processing of natural raw materials and their distribution; oppida as centres of some materials processing activities.

The whole period of almost two thousand years before Celtic period is important to our arguments, that is the Bronze Age and the first, Hallstatt Iron Age during which gold objects were used in Bohemia. The scientific approach to these questions was realised only recently when, thanks to a project funded by the Volkswagen-Stiftung, it was possible to make X-ray fluorescence analyses of ca. 150 gold objects, distributed throughout the period from approximately 2500 B.C. to 50 B.C. They are supplemented by several tens of analyses from other sources, partly of Celtic coins (Paulsen 1933, Hartmann 1986, Nemeškalová-Jiroudková 1984), partly of objects from Middle Bronze Age (Čujanová-Jílková 1975), and of objects from Bohemia which come from museums and other collections outside Bohemia (Hartmann 1970). Also an analysis of Slavic gold has been published (Smetánka and Stverák 1992).

Several of the problems encountered are reviewed:

Problem 1: The homogeneity of the material, and the sensitivity of the X-ray fluorescence analysis method: Two or three replicate measurements were made on 25 of the objects. The measured variation of 0.01 to 1.0 % between them is small compared to the overall variation of gold contents between objects of 20 to 99.54 % Au, so analytical variability will not influence the conclusions. The same considerations apply to silver and copper. Much more of a problem is the evaluation of Sn and Pt contents which could not be detected reliably using an XRF apparatus with energy dispersive spectrometry. Nevertheless it is possible to draw useful conclusions about the character of the gold alloys used in the last millenium B.C. in Bohemia.

Problem 2: Composition of the alloys of which the gold objects were made: In almost all cases major percentages of gold and silver, minor percentages of copper, and traces of tin, zinc, palladium, platinum, mercury and lead were found. In the objects examined, the following gold contents were found (Tab. 1):

Table 1. Gold, silver and copper contents of objects investigated (in %).

Most frequently	85 - 94% Au
Less frequently	71 - 85, 94 - 97% Au
Exceptionally	20 - 71, 97 - 99,5% Au
The balance is as follows	
Mainly	1 - 28 % Ag
Mainly	<1% Cu
Exceptionally	up to 72% Cu

High-purity gold material (over 93% Au) appears relatively late, in La Tène A (5th century B.C.), and the extremely low-purity material (less than 50% Au) as late as La Tène B1, from the 4th century B.C., but only sporadically. Alloying with copper occurs in single examples as early as the end of the Aeneolithic (Radovesice, Bell Beaker culture, 5.36% Cu, 42.56% Ag, 52.09% Au) with a few cases in the Late La Tène period; however, in Bohemia it becomes common as late as the early Middle Ages (9th-10th century A.D., Smetánka and Štverák 1992, 426, Pl. 2). Compostions are known from the Bohemian gold deposits with up to 60% Ag and 10% Cu (Morávek et al. 1992, Fig. 19). Generally, since the Bronze Age, gradually (!) more and purer gold appears, which can be regarded as a trend because only a few exceptions exist.

The differences in the composition of gold objects were determined by the variation of the silver percentage. Exceptionally, for objects (2.5% in total) in which extremely low contents of gold were found, this was replaced by copper and other metals (see below).

Problem 3: Purity parameters of gold objects from the end of the Aeneolithic until the end of the Celtic presence in Bohemia: Current results can be summarized in the following way:

- The Aeneolithic gold from Bohemia (small sample, only 3 specimens) shows similar compositions to those common in a wider European context; the electrum found in a plate from Radovesice appears to be a specific exception.
- Two groups of gold compositions from the Earlier Bronze Age (mean content in the first group about 73%, in the second group about 83% Au) might indicate two different sources of gold being exploited in southern and/or western Bohemia, but the gold earrings in northwestern and middle Bohemia used both. An exception is a gold spiral earring from Bílina in NW-Bohemia, the material of which was purposely or accidentally alloyed or contaminated with copper (8.14%).
- Other gold deposits with gold purity about 88%, and with an admixture of tin (?), were being exploited no later than in the Middle Bronze Age in western Bohemia, wheres in subsequent periods, a slight decrease of mean purity can be observed. In the course of these periods the two purity groups of the Earlier Bronze Age (mean value 86 % Au) vanish. The Hallstatt period gold objects, with a total of only a few specimens analysed, cannot be evaluated for the moment. In La Tène A there appear for the first time higher purity gold objects (93.5-99.46% Au), e.g. from an enclosure near Droužkovice in northwestern Bohemia. Pressing, but at present unsolved problems are:

  a) Their identification with the gold from other similar high purity finds (e.g. Podmoky, Bytíz, Morávek et al. 1992) and/or
  b) Evaluation of the extent to which they might be products of mechanical or thermal refining of gold. It will be necessary to consider the question of continuity with the gold technologies of the Mediterranean area, whose finished products (Schnabelkannen, Attic figure decorated pottery), as well as stylistic patterns for luxury products, increasingly came into the territories north of the Alps, and into Bohemia as well.

A fundamental change in the purity parameters of gold objects not only in Bohemia, but also in northeastern Switzerland and in southern Germany occurred during the phase La Tène B, when low carat alloys occur in finger-rings. The Bohemian material (finger-rings and beads) is without any doubt purposely alloyed with copper (40.35-46.85% Au, 15.80-17.69% Cu). The explanation of this phenomenon is perhaps to be sought in a lack of raw gold during a period of Celtic migrations and economic recession. The low purity objects in Bohemia were very probably directly imported, see the finger-ring from Grave 6 at Hostomice from phase La Tène B1a, the beginning of the newly established flat cemeteries, although they could represent an implantation into the Bohemian environment of an idea deriving from the starting points of Celtic migrations (Waldhauser 1991, 27). At least in Bohemia, the use of low purity alloys was short-lived - it lasted only about one century - because from phase La Tène B2b the high purity gold objects, whose metal may have come from the renewed or intensified exploitation of the old and/or new gold deposits in Bohemia, occur again.

From about the period La Tène B2b, the indigenous "Boiian coinage" is to be found in the territory of earlier Czech tribes. They are characterized by a conspicuously high purity, often 90 - 98% Au, in coinage period A, 94.5 - 97.1% Au or even more in Period B, finally decreasing during Period C (mostly 89.6 - 93.8%, in single cases 77.6 - 87.7% Au, (Paulsen 1933, Castelin 1965). The purest gold coin has 99.47% Au (Nemeškalová-Jiroudková 1984, 274). The purity values of Period C of the Celtic coinage closely correspond to about one half of gold objects from the oppidum at Stradonice. Thus, at least for a time, the same metal was used for minting and for making gold jewellery.

Thus the most important set of gold objects, that from the oppidum near Stradonice is approached, in which, as regards the composition (purity) of the alloy, three groups are discernible:

- High purity objects: 90-97% Au with admixture of Ag and Cu (22 specimens - 73% of objects - rings, fibulae, finger-rings, "workshop" waste).
- Medium purity objects: 60-85% Au with (6 specimens - 20% - imported goods, counterfeits ?).
- Low purity objects: 25-41% Au with admixture of Ag, Cu, Pb and Zn (2 specimens - 7% - occasional small rings).

From the typological viewpoint the high purity objects are markedly different from the medium purity ones. While in the first group there are the finger-rings, a fibula and numerous pendants, all simply shaped and belonging to the local La Tène culture of the oppida, the following objects are represented in the medium purity group: a filigree ornament (Bren 1959, 208, Fig. 7, 8), a fingerring in snake form with finely hammered scales, an ornamented hollow object with engraved ornamentation, all without any stylistic parallels in the Celtic jewels from Bohemia, but in several cases, of course, with parallels in classical gold objects. Most probably they were imported from the Classical Mediteranean world; they are hardly going to be forgeries. The purity is identical with that of several analysed Etruscan products 61.5-96 % Au (von Haase and Cesareo 1973).

The composition of low purity "gold" objects from period La Tène C-D1 from the oppidum Stradonice (27.28-40.55% Au, 0.70-3.08% Ag, 56.12-71.89% Cu, 5.15-6.78% Zn and 3.71-4.46% Sn) differs on the one hand from the low purity objects from period La Tène B1 by the presence of zinc and tin, on the other hand from the alloy found attached to the refractory ceramic from Brníčko (see below) by the absence of lead and tin. It may be classified as an intentional alloy of gold and with a copper-base alloy containing zinc and tin. The possible importation of the small rings should be considered, as zinc is seen as increasingly typical of classical copper alloy objects from late Republican times onwards. The possibility the low purity objects could represent a raw, unrefined gold alloy can be excluded completely.

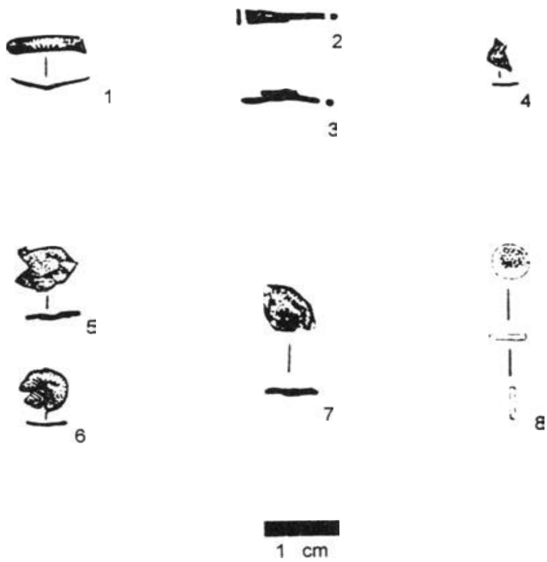

Fig. 7: Stradonice, oppidum. Gold "waste" from the collections of the National Museum.

Of great importance for the present understanding of the use of gold in Bohemia are the fragments of a rod, a drop and semi-finished blank (Schrötling) from the Stradonice oppidum (Fig. 7). They are unique documents recording a probable goldsmith workshop, perhaps even a mint. The rod bears traces of cutting at both ends and might be interpreted as raw material for the final phase of the production of gold jewellery.

Until now, workshops in Bohemia for producing the blanks for the coinage have been identified only from the occurrence of ceramic "coin moulds"(heating-trays), at the oppida. The possible workshop (or workshops) can be theoretically dated on the basis of the purity of gold residues from those workshops (90,5- 97.5% Au), which roughly corresponds with the purity of great majority of coins made during coinage Period C and a short while before, approximately in La Tène C-D1b. A critical point that must be mentioned is that the provenance of all Celtic gold objects from Stradonice oppidum, from discoveries made after the year 1877, is given only in the inventory book of National Museum in Prague.

6. The mobility of gold objects: export and import of "Boiohaemum's" gold during the La Tène period

The movement of gold objects among individual communities and persons was directly dependent on the locations of gold mining and, more importantly, washing. During Hallstatt C-

D no intensive movement took place because only a little gold circulated and because, in general, the gold objects were almost exclusively confined to southern and western Bohemia, within a radius of only 30 to 50 km (Fig. 4). An analogous situation is assumed to exist in La Tène A, in which, however, a greater accumulation of gold is demonstrable. In this respect the example of Hradiště near Písek, with its "prince's" tumulus with 0,37 kg of golden grave-goods should be mentioned. Theoretically, gold could also have been an export commodity at that time. In La Tène B, a remarkable and extensive movement of gold and/or gold objects is to be supposed, as these almost exclusively occur beyond the area of the gold deposits. After the regular introduction of coinage, especially in La Tène C-D1, it must be concluded that the mobility of gold reached a maximum. The distances between the gold sources and the artefact find-spots in Bohemia (up to 70 km) as well as an intensive export and import of minted gold confirm this assumption. Gold was used by many communities and individuals, so that it could be said that the metal was in general use. The export of minted gold from Bohemia has been demonstrated by numerous hoards as well as single finds. The coins were exported into former Serbia, into the territory north of the Alps, into part of Gallia, considering only the territories inhabited by Celtic tribes. There was also interest in the "Boiian coinage" in the regions with non-Celtic population, e.g. in the territories subjected to Roman rule (Campiglia Marittima) or among the German tribes along the middle reaches of the Elbe, and on the shores of the Baltic Sea. This wide distribution suggests that the significance of "Boiohaemum's gold" was as much as anything that of an export commodity and also suggests a high intensity of exploitation of the gold deposits in present-day Bohemia.

In discussing the causes of the export of gold coins from "Boiohaemum", a number of possibilites is to be considered: 1) trade, 2) gift exchange, 3) migration, 4) cult. In 89 examples of third-unit coins found in Campiglia Marittima in central Italy it was found that most of them showed no traces of a lengthy circulation. Numismatic research has revealed that the hoard found at Campiglia Marittima (0.217 kg) was compact and consisted of relatively new coins. It may be infered that this was not personal or group wealth accumulated over many years, but rather a merchant's property. The coins were possibly used for long-distance trade, or more directly representing gold as a commodity. In the area around the find-spot, e.g. at Vetulonia, gold was processed in great quantities, and the "Boiian" coins may well have been used as raw material (Nemeškalová-Jiroudková 1975, 410-412). Of course, unminted gold may also have been exported from Bohemia, unfortunately, the "gold bar", mentioned in the literature, which was found in a grave under a tumulus of La Tène A date at Hradiště, has been lost. The export of gold dust, of course, is scarcely demonstrable by archaeological methods.

Though Bohemia, thanks to the richness of its gold coinage based on its gold deposits, belonged among the most important sources of the yellow metal in Europe, there are also, surprisingly, some cases known where gold was imported into the territory of today's Czech Lands, e.g. the "Tectosagian" coin from southern France, which was found near Hostýn, or the "Haeduan" coin of Weiding, just at the German-Czech border, possibly linked to a trade route. "Vindelician" gold coins from southern Germany have been found repeatedly in Bohemia, both in the country side and at the oppida (for bibliography on this question, see Waldhauser 1991, 23-26).

The people living in "Boiohaemum" were in no sense an exclusive supplier of gold, neither in the form of finished products, nor as raw material. On the contrary, gold was also imported into Bohemia from outside. The probable exhange of goods accompanied by payments in gold coin may have been of the greatest importance for the Celtic civilisation in Central Europe.

7. Gold refining in the La Tène period: the find at Brníčko

In 1940, during earthworks for highway construction, a La Tène settlement from period C was partially investigated near Brníčko, district Šumperk, Moravia, Czech Republic, in the foothills of Jeseníky Mountains. From the sunken house I-3 (4.3 x 3.5 m), whose bottom was crossed by a groove from an internal structure of unknown shape, comes a fragment of the base and body of a vessel made of graphitic material (Fig. 8, 32). On the basis of other pottery found at the same time, it can be dated to the phase La Tène C1, at the turn of the 3rd and 2nd century B.C. The diameter of the vessel was 21 cm at the base, above which were at least 4 cm high walls. On the inside of the wall, and of the base, over an area of about 22 square centimetres, are situated 5-8 droplets of yellow metal of about 1 mm diameter, ca. 10-30 droplets with diameters of about 0.3-0.6 mm, and ca. 50 (possibly up to 80) droplets with diameters around 0.1 mm. Just on the base, flat, lobe-like branched formations of yellow metal are discernable, partly situated in the lowest spots of the uneven surface. Two other droplets of diameter 0.5-1 mm are, exceptionally, to be found on the profile of the sherd fracture at the upper edge, together with another flat tiny foil-like particles (diameter round 1 mm), which might be of natural origin. The distances from inside surface of the sherd for these droplets are 3 and 13 mm, in the case of the foil 13 mm. The total weight of droplets has been estimated at 1g. The inside surface bears traces of high heat in the form of a violet black to greyish green coloration with slaggy structure, for a greater part, however, the coloration is brownish black. The vessel was made of a fabric tempered with graphite (charcoal?) lumps (diam. up to 5 mm) and light grog (diam. up to 3 mm). The outside surface was roughly smoothed, and pits up to 3 mm in diameter left after oxidation of the grog or carbon in the course of firing, are visible in it.

This pottery fragment is preserved in the Regional Museum at Olomouc under inventory number 11633. It was published by Schirmeisen (1943, 143) and Meduna (1980, 156, 1980a, 28), who took the yellow globules to be washed gold which got into the ceramic mass together with the grog.

On 29 June, 1993, thanks to the Volkswagen grant, three of the droplets of yellow metal were analysed by the X-ray fluorescence method, in the Institute of Nuclear Research at Řež near Prague (RNDr. Frána) (Tab. 2).

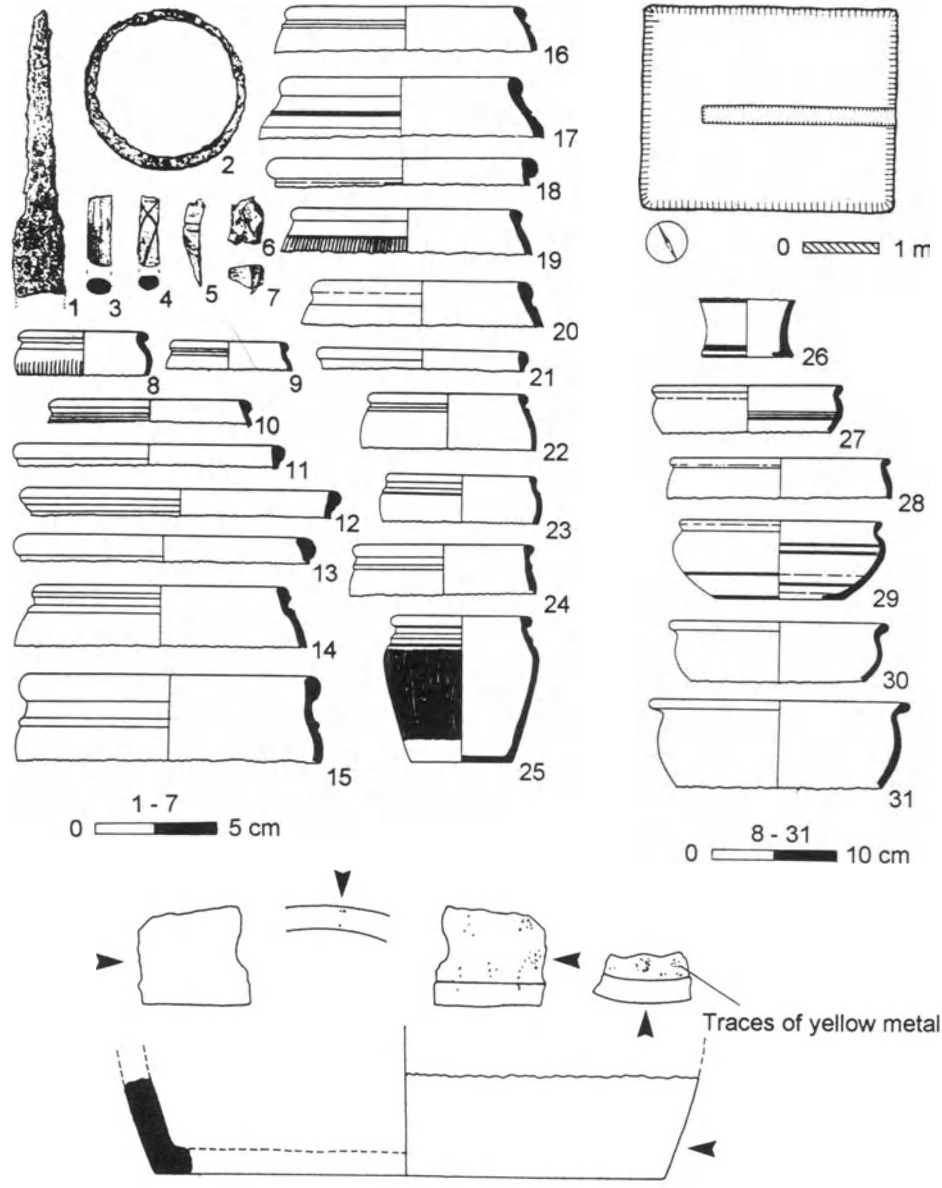

Fig. 8: Brníčko, distr. Šumperk. 1-32: The metal, shale and glass objects from sunken house No. I-3, together with the ceramics; No. 32 with the droplets of yellow metal. (No. 1-31 after Meduna 1980).

Table 2. XRF analysis of three yellow droplets.

Measurement no.	Droplet 1 6523	Droplet 2 6524	Droplet 3 6525	Exterior surface 6526
Au	51.33	62.12	49.17	0.00
Ag	19.36	16.52	17.86	0.00
Pb	14.01	11.62	13.51	0.00
Cu	15.30	9.72	13.65	0.00
Zn	0.00	0.00	5.81	0.00

From the results of the X-ray fluorescence analyses some preliminary conclusions may be drawn:

1) From the absence of metals on the outside surface one can accept that intentional thermal processing of an alloy is recorded here, demonstrated by the gold occurring as fused globules, a form which does not arise in nature. The published hypothesis (Meduna 1980, 156) that on the outside surfaces of this industrial ceramic gold in "natural form" is present, can be unambiguously refuted (thanks to RNDr. P. Morávek for kindly advice).
2) The main component of the alloy is gold: minor parts are represented by silver, copper, lead, and, in one case, by zinc.
3) The alloys identified here have no parallel among hundreds of analyses of gold objects from the La Tène period. They must therefore represent gold in the course of processing, either more or less directly from the washer, or as a semi-finished product at a later stage in the processing.
4) The presence of significant (e.g. 11.62 %) Pb indicates i) either a stage in a fire-refining process based on cupellation after the addition of lead metal (see Morávek et al. 1992, 197), and/or ii) the use of polymetallic ores containing Au, Pb, Cu and Zn, which commonly occur in the Jeseníky Mountains (Morávek et al. 1992), a possibility which which has been proved in Celtic settlements in southern France (Cauuet 1988).

The refining of gold-bearing ores in the late Middle Ages has been convincingly documented through the investigation of hearths or furnaces at Žampach near Prague: the slag there contained up to 19.3% Pb, but only up to 1.15% Ag and 0.25% Au (archaeological research made by the Author, National Technical Museum, Prague, 1991, unpublished).

The fragment of industrial ceramic with residues of gold-containing alloys from Brníčko is still being studied; nevertheless it is already possible at this stage in the research to highlight some important facts:

a) In the Brníčko locality, a lowland, so-called agrarian settlement, not an oppidum is involved, from which coin moulds for the melting of blanks for gold coins are documented.
b) The pottery from Brníčko forms a yet unknown type of technical ceramic and relates to new styles of prehistoric/Celtic gold processing. The use of graphitic material is also exceptional.
c) Into the phase La Tène C1, to which the find of Brníčko belongs, fall the oldest finds of Celtic coins characterized by their high purity; because of this the numismatists assumed

that the gold had either been imported from the classical Mediteranean world or from the Near East/Iran or had been refined (Hartmann 1986, 672-674).

d) The settlement of Brníčko was situated in close proximity to the gold-bearing river Oskava in the southern part of Jeseníky Mountains, where medieval mining of polymetalic gold ores and goldwashing have been well documented (Novák 1985).

8. Gold and Society in 7th-1st century B.C. Bohemia

As in other regions of Central Europe (Müller 1991), so in Bohemia at the end of the Hallstatt period and the beginning of the La Tène period, gold was a symbol of status, so that it was used in the grave goods of high-ranking individuals who probably occupied the rank of chiefs of territorial districts. Exceptionally in the most luxuriously outfitted graves many gold objects are present, accompanied by other imported objects. Single gold objects, e.g. the hair rings or amulets, occur in graves in the vicinity of the gold placers (Manětín-Hrádek).

During the Celtic migrations of the 4th and 3rd centuries B.C. new gold symbols came to Bohemia, by which the members of the ruling class were distinguished. Some of these gold objects found may well be imported goods. In contrast to earlier centuries, the placers in Bohemia were hardly exploited at this time.

A fundamental change in the use of gold occurs in the 2nd and 1st centuries B.C. and is probably dependent on the substantial increase in gold exploitation. For the first time gold came into possession of broad masses of the population of the whole of "Boiohaemum" and was, in coined form, used not only as a means of payment in trade and commercial transactions, but also as sacrifical offerings. Thus, gold belonged both to men and to gods. In the oppida, evidently, a new, gold-owning society developed, and when this was extinguished gold exploitation in Bohemia temporarily ceased.

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Chapter 5

NEW ASPECTS ON CELTIC COIN HOARDS IN SOUTHERN GERMANY

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ABSTRACT. The discovery of rainbow-cup ("Regenbogenschüsselchen") coin hoards in South Germany during the last 15 years has created a new situation for numismatists. New finds from Großbissendorf, Sontheim, Wallersdorf and Ammersee give us new information about the specific composition of gold coin hoards in late La Tène, new types and the die-links. Most of the coins in these hoards show no traces of circulation and were perhaps hidden soon after their production. The knowledge of the places where rainbow-cups were struck is limited, but it is already known of two mints (Manching and Kelheim) in Bavaria. Questions about the people, who posessed such great hoards, and why they were deposited and not recovered are still debated.

1. History of research

In 1771 when the day-labourer Janota found fragments of the ring handle of a cauldron and some scattered golden buttons on the bank of the river Beraun, near Podmokl in Bohemia, he was neither aware of the significance of this now legendary hoard, nor that the buttons were Celtic gold coins (Voigt 1771). The discovery of the greatest Celtic hoard in Bohemia soon became known to the ruler of the territory of Pürglitz, Karl Egon zu Fürstenberg, who then took measures to bring together all the coins that had been carried off by coin hunters. Shortly after its discovery more than a third of the complete hoard was dispersed, and only after various enquiries, with the help of a civil servant and a spy were most of the coins tracked down. Thus, the treasure was rescued for the ruler Karl Egon zu Fürstenberg, but it was lost for scientific research, because by order of the Emperor he was allowed to remelt the gold pieces, which from then on circulated as ducats with his portrait and monogram.

According to the calculation of the numismatist Rudolf Paulsen, who gives a short description in his book of the coinage of the Boii, the hoard contained at least 30 kilograms of gold, corresponding to approximately 5,000 coins and was the greatest find ever made (Paulsen 1974, 62f.; Radomĕrský 1955, 59 No. 92; Castelin 1965, 144f.). Except for two or three dozen coins, all the others went into the melting pot so there is today only a pale reflection of this extensive hoard in the collections of the museum in Prague, and in several foreign collections. A short description of this precious find can be read in a letter of the scholar Adauctus Voigt to his friend, written in the same year as the discovery of the hoard, and showing in a copperplate the fragments of the cauldron and a small section of the coins lying in it (Voigt 1771, Pl. I1-13, 15, 17f.). It is known, despite the inexact drawing, that the hoard contained coins of different denominations and designs, which can be assigned to the so-called older gold coin production of the Boii.

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This remelting and reminting as well as the sale of an ancient gold hoard to private collectors, was not an isolated case, but also occurred in Bavaria with two important hoards found in the 18th and 19th centuries. These were the well-known hoards of Gaggers (Kellner 1990, 171-175) with 1,300-1,500 rainbow-cup coins found in 1751, and the hoard of Irsching (Kellner 1990, 157-159) with more than 1,000 pieces discovered in 1858. For the Gaggers find, very little information apart from the types is available. Only a handful of pieces from the Gaggers hoard still exists in the Coin Cabinet in Munich, among them the frequently published and cited coin with the motif of a deer with large antlers.

In contrast to the vague information about the composition of the Gaggers hoard, more details about Irsching are possessed, because nearly the whole hoard was analysed by the keeper of the Royal Coin Cabinet in Munich, Franz Streber. He published his results in a discourse to the Bavarian Academy in 1860-1862, in which he came to the conclusion that the rainbow-cup staters were a Celtic coinage (Streber 1860/1862). After this publication by Franz Streber, the situation hardly changed until the end of the nineteen seventies, and his work was therefore used for a long time as a reference for Celtic gold coins from Bavaria. Now H.-J. Kellner's new publication of the Celtic coins of Southern Bavaria gives us an excellent review of the state of research up to 1989 (Kellner 1990, 9ff). Until the discovery of the great hoards was made in 1976, it was almost impossible to make any statement about the circulation of Celtic gold coins. Now there are the oppurtunities for a new form of hoard analysis on a much wider basis.

The exploration of the oppidum of Manching since the early nineteen-fifties has been a disappointment with the regard to advancing our knowledge of Celtic gold coins, as only few pieces of gold, together with some plated pieces, have been found. The coins found at Manching are mainly silver, the so-called "buschel" quinars and their quarters, and cast *bronze* coins. These medium and small denominations were certainly of a greater importance for the daily life in an oppidum than the gold coins.

However one must not forget the earliest evidence for the use of Celtic gold coins in the daily life in Southern Germany. This is a small purse made of bronze, which was discovered in 1972 at the center of the excavated area of Manching (Kellner 1990, 52f.; van Endert 1991, 1, 91-93). The deposit contained five small gold coins with an average weight of 0.3 grams and a quarter of a rainbow-cup stater of the smooth type. The small coins are of high quality, and for four coins two pairs of dies were used, which allows to conclude, that they didn't circulate for very long. This purse is one of the most important finds from the oppidum. The capacity of this box, with a diameter of only 4.3 centimetres, was modest and only suitable for small denominations. It was originally sealed with an organic material which has not survived. Except for this extraordinary find, the number of the gold coins has been of little importance.

The series of the large coin hoards discovered in the 20th century began with the discovered of more than 400 silver coins in a jug at Neuses, Upper Franconia in 1976, which brought to light not only different varieties of the "Buschel" series and its quarters, but also four rainbow-cup staters (Overbeck 1990). This find, made by chance while cultivating a bed of asparagus, was the first important silver hoard since the discovery of the Manching hoard in 1936 (Kellner 1990, 63-76). Although the percentage of these four gold coins in Neuses in comparison with the silver coins is very small, it shows, however, the mixture of different metals and denominations which were in circulation together and deposited at the same time.

2. Recent discoveries of hoards in Bavaria

2.1 GROSSBISSENDORF

Ten years later, in 1986, the first important gold hoard was discovered in Northern Bavaria on a holiday farm near a small village called Großbissendorf (Brandt and Fischer 1988, Dannheimer and Gebhard 1993). As with the day labourer Janota in 1771, the owners of this farm believed that they had found a gold button, but a dentist, and a numismatist in the Germanisches Nationalmuseum Nürnberg explained to them that this button was an ancient coin. An excavation in 1987 by the Prähistorische Staatssammlung München of the area where the first coin was discovered uncovered 207 staters and other denominations. The complete hoard today consists of 386 rainbow-cups and Bohemian gold coins. It is not only one of the largest finds, but also one of the most important because of the mixture of coins of different provenances. Nine to ten percent are rainbow-cup staters and quarters, the rest are Bohemian mussel-staters and thirds. The most frequent types are those with the following motifs: star (Fig. 1, 1), leaves with torque and pellets (Fig. 1, 2), lily (Fig. 1, 3) and styled head (Fig. 1, 4). The Bohemian staters (Fig. 1, 5) and thirds (Fig. 1, 6) do not possess any motifs, but only a hump, or a swelling which resembles a mussel, or some simple strokes. The importance of this hoard lies not only in the quantity of the coins, but also in the existence of new types, such as the so-called point-type and whirl-type, and a type which resembles a chinese lantern (Fig. 1, 7). The average weight of the rainbow-cups and the Bohemian staters, which is independent of type, is 7.7 grams and it is astonishing that there is only a small number which differs from this weight. It can be affirmed that all pieces conformed to a rigid standard.

2.2 WALLERSDORF

A hoard of 368 rainbow-cup staters of the smooth-type (Fig. 1, 8-9), one quarter rainbow-cup, and one Bohemian coin was discovered in 1987 in Wallersdorf, Southern Bavaria (Kellner 1989). The Bohemian piece is very rare with a marvellous design, and shows a fighter with a sword and two crossed rods (Fig. 1, 10). The hoard possesses a remarkable homogeneity because in it there is only one type. Others which are known from earlier hoards with motifs like star, leaves, bird or torque with pellets, are missing. Occasionally there are pieces with small symbols in form of short lines or strokes which resemble a roman numeral (Fig. 1, 11). The interpretation of these signs is still unresolved, but there is certainly no connection with any accidental damage to the dies; these motifs were engraved intentionally and were perhaps mint marks. It is also possible that these signs are remnants of a former motif which is still not deciphered.

2.3 "AMMERSEE"

There is only a little information about a Celtic gold hoard discovered in 1990 in the region of Ammersee, because the exact location of the find is still unknown, and it seems probable that a lot of it went into private collections (Egger 1991). Most of the coins belong to the rare bird-type with the reverse motif star, three pellets and lyre (Fig. 1, 12). There are several coins of this type, which are die-linked. Some types are extremely rare, for example the curly hairstyle-type (Fig. 1, 13), the propeller-type (Fig. 1, 14) and the flower-type (Fig. 1, 15).

2.4 SONTHEIM

The last find of this series, which was discovered in summer 1990 near Sontheim in Unterallgäu, contained the same types as the hoard of Großbissendorf, complemented by several rare types (Ziegaus 1993). There are only the large denominations of the rainbow-cup coins in it, and most of the pieces show the motifs with the star, leaves and torque with pellets. Types which were rare in the Großbissendorf hoard are now well represented, for example the point-type (Fig. 1, 16), the whirl-type (Fig. 1, 17), the type with the three loops (Fig. 1, 18) the three half-moon type (Fig. 1, 19) and the hook-type (Fig. 1, 20).

3. Analysis of types

It is not possible to analyse the remains of the hoards from the 18th and 19th century finds at Gaggers and Irsching with modern methods such as die-linking or metallurgical analysis. Today it is essential to conserve all hoards as a closed complex, because the comparison of several hoards allows a search for correlations between their contents in terms of types and variants (Table 1). Of special importance for the new hoards is the fact that well-known types are combined with very rare or new types, and one therefore knows which types were produced and circulated at the same time. If one searches both for the common ground and differences between the hoards discovered since 1986 and those of earlier times, for example Gaggers or Irsching, it appears that there are pairs of hoards which are similar in their typological composition. The first group is represented by Sontheim and Großbissendorf, the second by Gaggers and Irsching. The majority of coins from Sontheim and Großbissendorf is of the star- and leaves-types, at Gaggers and Irsching the serpent-type (Fig. 1, 21) and the bird-type (Fig. 1, 22).

Table 1. Coin hoards from Southern Germany and their typological composition.

Type	Sontheim	Großbissendorf	Ammersee	Irsching	Gaggers	Wallersdorf
star	166	115	4	4	?	-
leaves	133	104	-	≈ 470	3	-
hook	14	2	-	-	?	-
loop	11	1	-	-	?	-
fringe	6	4	1	-	?	-
half-moon	7	2	-	-	?	-
point	4	1	-	-	?	-
whirl	5	1	-	-	?	-
smooth	4	1	-	5	?	368
bird	-	-	17	≈ 180	8	-
serpent	-	-	-	≈ 200	6	-
rainbow-cups	-	113	2	-	1	1
Bohemian coins	-	42	-	-	10	1

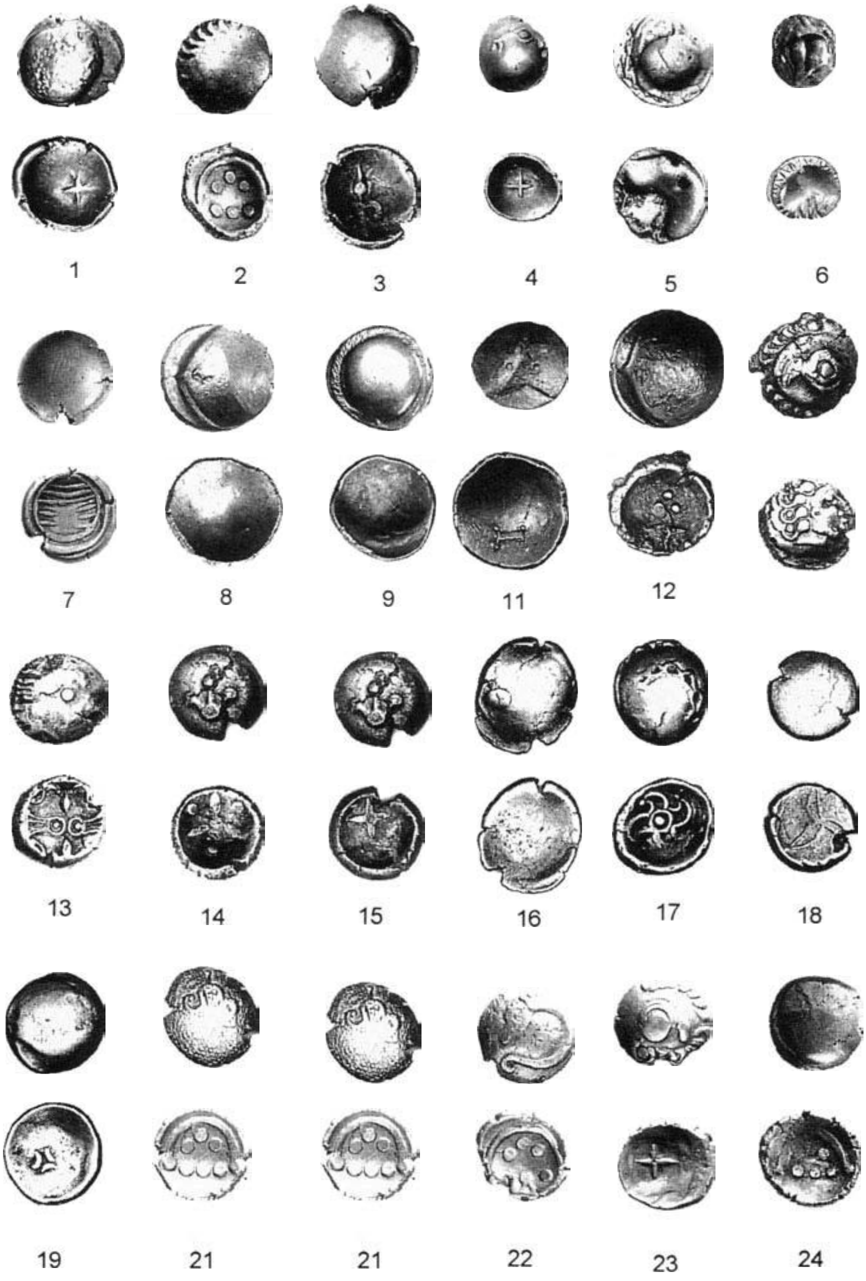

Fig. 1: 1-7 Großbissendorf; 8-11 Wallersdorf; 12-15 Ammersee; 16-20 Sontheim; 21-22 Irsching; 23-24 Großbissendorf (M. 1:1).

It is an interesting phenomenon that the star-type, represented in the hoard of Irsching by only four of more than 1,000 pieces is of far less importance in proportion to the quantity of this type in the hoards of Großbissendorf and Sontheim. One may also note the absence of the serpent-type and the bird-type in Großbissendorf and Sontheim, which in Irsching make up more than a third of all pieces. Very interesting, too, is the composition of the Wallersdorf hoard with its large number of smooth-type because there is no connection at all with the other hoards. In spite of the different typological compositions of these hoards, they have a great deal in common when the motifs of the different types are analysed using the method of die-linking. The greater part of the hoard of Sontheim comprises coins from the same pair of dies and therefore resembles the composition the hoard of Wallersdorf. It is of great importance that the smooth rainbow-cup staters in Wallersdorf were produced with a small number of dies. An analysis on the occasion of a short presentation by H.-J. Kellner soon after the discovery of the hoard showed that 92 percent of all coins derived from four or five pairs of dies (Kellner 1989, 12). And a new, still unpublished numismatic examination concludes that approximately 60 percent were produced with only one pair, while the smooth surfaces of the obverse and the nearly smooth reverses of the coins differ only on a very limited scale. The Ammersee hoard has a similar composition, where there are not only coins of the bird-type from the same dies, but also single and rare pieces, the inevitable result of regular money circulation. The evidence of coins being circulated are the visible signs of use such as worn motifs and old scratches. Analyses of the surviving coins of Irsching which are still in several museums demonstrate the same phenomenon for the dominant types of serpents, birds and leaves with torque and pellets.

Analyses of the motifs and dies used for the coins from Sontheim and Großbissendorf show that there are clear parallels in regard to the same designs and dies (Ziegaus 1993, 40 and 6 star-type, 53-64 leave-type, 65 f. hook-type, 67 loop-type, 68 fringe-type, 79 point-type, 79 whirl-type). The comparison lets assume an indirect connection between these two finds which resemble the composition of hoards of Bohemian gold coins found in Starý Kolín, Bohemia (Rybová and Motyková 1983, 167 note 14; Nemeškalová 1984; see also: Kellner and Castelin 1973) and Campiglia Marittima, Etruria (Paulsen 1974, 126 with Pl. E; Nemeškalová 1976). They also contain coins from the same dies and show die-links. The hoards from Sontheim and Großbissendorf and Starý Kolín and Campiglia Marittima demonstrate the possibility of depositing a mass of coins, produced from the same dies found at locations far away from each other, but certainly belonging to the same period. The majority of the coins from the same dies have not been withdrawn from regular circulation, money that had been collected and deposited over a period of time, but represent a proportion which was stored after their production. That similar, die-linked coins were not in general circulation among the population at large can be demonstrated by the absence of wear on the pieces found in the hoards. One possible explanation for coin assemblages of this type is that they were purposely minted for deposit. In Sontheim and Großbissendorf there are also coins which possess traces of circulation, and it is not surprising that these are single pieces without any die-links.

Knowing that the mint master has used the same dies for coins which were deposited in different hoards, now certain types and variants can be combined and the changes in the motif of a die can be reconstructed. The number of coins which can be produced with only one pair of dies was very limited. Even so, in the case of the hoards from Sontheim and Großbissendorf often a radical change between pieces in one group can be observed, so it can be said that it is not known the complete production from one pair, but only part of it. A proof for this hypothesis lies in other locations with coins produced from the same pair of dies. An instructive example is a group of 35 coins of the leaves type in the hoard of Sontheim, in which the changes in the motif of the torque are nearly invisible. The result of a comparative analysis demonstrates that six coins of the hoard of Großbissendorf possess the same traces of die use on the reverse-motif, so a minimum production of 41 coins from the same pair of dies can be assumed (Ziegaus 1993 group II 1 No. 174-208; Ziegaus 1991 group II 1 No. 190-195).

Searching for the which die was used most frequently in the Sontheim hoard, it results that for a group 57 pieces of the leaves type the mint master used the same obverse die (Ziegaus 1993 group I 1-4 No. 160-216). This obverse shows different phases of die use. In the beginning the motif is of fine quality, at the end the design is superficial and without any definition. Pieces of an intermediate quality with broader leaves or an indistinct torque with pellets do not exist. The quality of strike in different subgroups reflects a repeated change of the reverse-dies, while the obverse-die was neither changed nor retouched. As a consequence, pieces of different subgroups possess the same worn-out obverse-motifs, but different motifs on the reverse. It is also curious to see that there is, for example, a lot of pieces from the same pair of dies in the hoard from Großbissendorf, while on several occasions the same die combination is only represented by a single piece in the Sontheim hoard. This phenomenon can also be observed the other way round. The implication is that these two hoards were deposited absolutely simultaneously.

Summing up the results of this short discussion, most dies were of a soft bronze-alloy and the hard metal used for the coins quickly destroyed the die (Dies: Dannheimer and Gebhard 1993, 301 no. 293-300). It is the author's personal belief that the life-time of the motif on a die was normally limited to the production of about 1,000 coins, but this also depended on other circumstances, for example the hardness of the die material and of the blanks, and the know-how and the experience of the mint master. The life time of the die itself was certainly not limited in all cases to as small a production as 1,000 coins. It rather can be said that a die was reconditioned as often as possible as there are a lot of coins in all hoards which show the remains of older motifs, which had not been completely erased before engraving a new motif (Pl. 1, 23-24). It is known from a lot of coins which were damaged by fine cracks within the area of the motif on the die that this was no reason to change the die, but at the moment a die was too short to be held or the die broke, an exchange was unavoidable.

4. Centers of coin production

The present knowledge of the where all these rainbow-cup staters were produced is limited (Fig. 2). In Bavaria gold coin production is known in Manching and in Kelheim/the ancient Alkimoënnis (Kellner 1990, 9 f.; Hartmann, in: Kellner 1990, 230-234; Overbeck 1986). The great number of coin moulds with different diameters and different depths of depression make it clear that Manching was an important center for silver and gold coin production. Gold blanks are extremly rare and have only been found at one site (Dannheimer and Gebhard 1993, 302 No. 302). There was also coin production in other, less researched areas such as the La Tène oppida and villages of Staffelberg, Karlstein and Stöffling (Ziegaus 1989, 109; Menke 1968; Dannheimer und Gebhard 1993, 301 no. 296). The greater number of

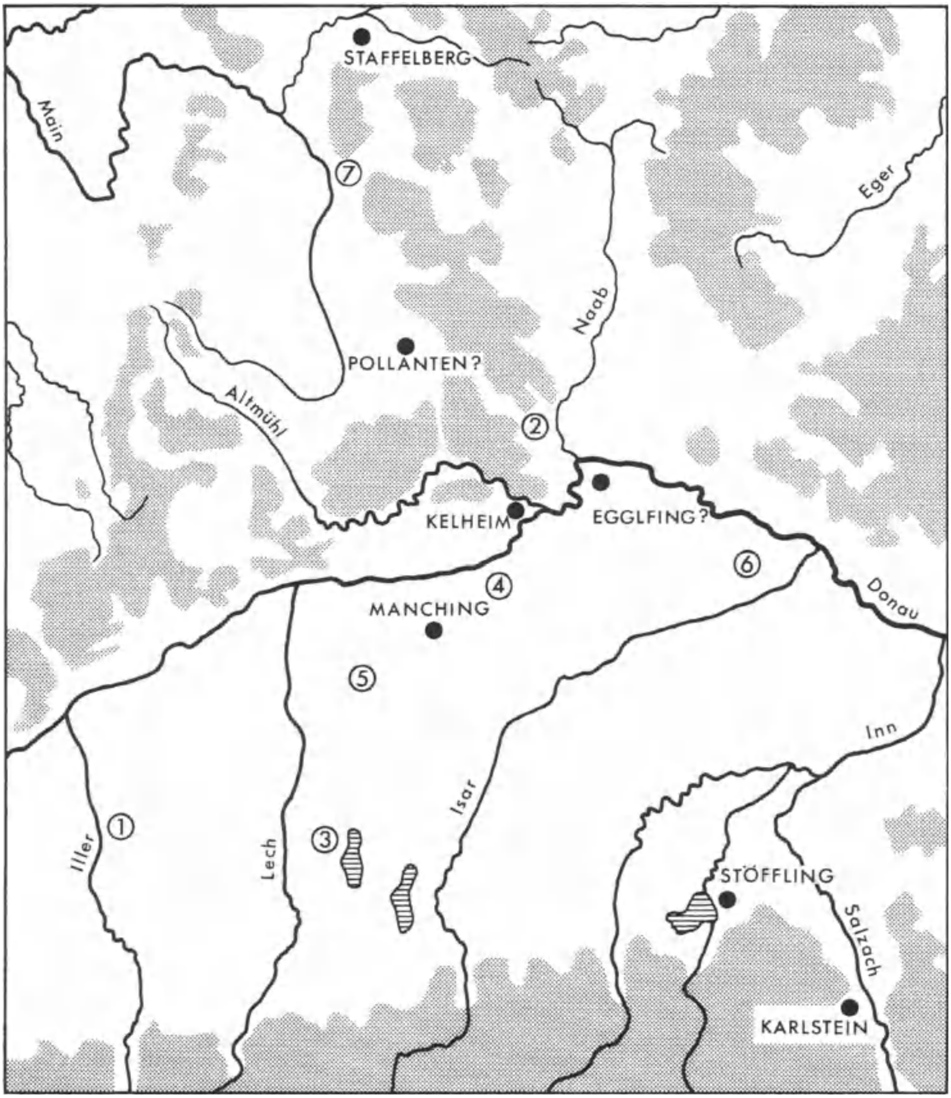

Fig. 2: Mints and coin hoards in Southern Germany. 1 Sontheim. 2 Großbissendorf. 3 Ammersee. 4 Irsching. 5 Gaggers. 6 Wallersdorf. 7 Neuses.

coins of the same type in the Sontheim and the Großbissendorf hoards gives a vague idea about the location of the mint. The similar quality of the star- and leaves types seems to make it unreasonable to supposee that a mint was located in both Sontheim and Großbissendorf with the assumption of production with the same dies at different places at the same time. This may also be excluded by the fact that there are coins which show traces from the same worn-out dies. One can consider the fact that gold coin production is attested at Manching, which is midway between the two find spots. The excavations at Manching have produced only one rainbow-cup stater of the star type, which shows no similarities to any piece in the great hoards which contained more than 270 die-linked and single pieces (Kellner 1990, 51 no. 51). No stater of the leaves-type is yet known from Manching. Perhaps it was not at Manching but the mint at Kelheim/Alkimoënnis or another, still unknown mint, where these types were produced.

5. Interpretation of coin hoards

The questions about who possessed such big hoards and the reasons why they were deposited and not recovered are still debated. Gold hoards such as those of Großbissendorf, Sontheim and Wallersdorf, which contained more than 350 coins, represent considerable wealth. But a comparison with the 18th and 19th century finds, for example, Podmokl with about 5,000 pieces, or Gaggers and Irsching with more than 1,000 coins demonstrates that there is a considerable variation in numbers. It is also characteristic that nearly all these hoards contained only large denominations; less valuable coins such as the 1/4 staters, the buschels and the cast potins were not included. It may therefore be presumed that the owner of a rainbow-cup hoard with 350 pieces was rich, not a chieftain, but perhaps a trader or an aristocrat.

In earlier research, the deposition of coins was connected with successive crises from the second half of the second century B.C. to the Gallic wars of Caesar (Forrer 1968, 334; Pink 1974, 24). The migration of different tribes is known, of which the Cimbri and Teutones are the most famous. There are some indications that they crossed Southern Bavaria in the second or first decade of the second century B.C. and the deposition of hoards can be linked with this migration. Given the similar composition in terms of types at Sontheim and Großbissendorf both could have been hidden at the same time. But there are other hoards, such as Wallersdorf, with a single quite different type. Then there are the Irsching and the Ammersee hoards where the star-types and leaves-types were of minor importance. On the other hand, there are more than 470 pieces of the leaf-type in the hoard of Irsching, nearly half of the complete hoard. The lack of information on finds in an archeological context gives no solution to the problem because dating material is rare and allows only a general fixing in the late La Tène period (Polenz 1982; Kellner 1990, 35-37; Dannheimer and Gebhard 1993, 227).

Another possibility is to interpret deposits as votive hoards for gods or goddesses. The ancient authors, for example Strabo IV 1, 113 p. 118, Diodor V 27, 4 or Caesar, De Bello Gallico VI 17, 4, tell about the rites of the Celts for depositing precious objects near river banks or marshy soil. But the possibility of objects being hidden because of the approach of enemies cannot be excluded. There is a passage in Caesar's "De Bello Gallico" telling of the Menapii, who feel safe in their country and laid all their property down in the forests and in the marshland *"illi nulla coacta manu loci praesidio freti in silvas paludesque confugiunt suaque eodem conferunt"* (Kellner 1984; König 1990). Is it therefore possible to interpret these coin-depots as a sacrifice without any additional archeological context, or what criteria might allow this special interpretation? The author only knows of some rare examples which justify this standpoint. An interesting find is the deposition of three coins found at Villenneuve in a wooden statue, in a crack in its arm (Wyss 1979).

6. Chronological aspects

The dating of rainbow-cup staters remains difficult, but there are now some new points of view. The associations of coin hoards with their different types, weights and metallurgical composition show, that not all of them could be produced at the same time. The beginning of gold coinage in Bavaria must be dated to the last decades of the third century B.C. (Polenz 1982, 56 ff., 65 ff.; Boehringer 1991; in general: Overbeck 1987), and its end will be nearly identical with the end of the great oppida (Kellner 1977; Kellner 1990, 39; Gebhard 1991, 100-104). There are coins with weights from 8 grams down to 6.9 grams averaging 85% - 60% gold. The coins with light weights, from 7.5 grams down to 6.9 grams and an alloy of about 70 % or less gold, such as the serpent-type and some bird-types, seem to be produced at the close of the La Tène period, in other words, the decades from the end of the second century B.C.to the end of the oppida civilisation. It now can be presumed that coin hoards, such as those of Großbissendorf and Sontheim, containing types with higher weights, and a composition of 70% - 75% of gold might have been produced during the first half of the second century B.C., and deposited shortly after their production. The discovery of new finds and their compositions will be a chance to test the validity of the arguments about coin hoards presented here.

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