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NOTES ON MONO- AND BI-PHASE INCLUSIONS IN AMETHYST

By E. J. GÜBELIN, Ph.D., C.G., F.G.A.
Lucerne, Switzerland.

THE striking beauty of a throng of euhedral negative crystals in a small amethyst crystal stirred my curiosity to investigate their mono- and bi-phase fillings in order to determine their chemical composition. Apart from the conventional crystallographic shape of some of these negative crystals I was greatly intrigued by the conspicuous distortions (viz. elongations parallel to the horizontal axes of the amethyst crystal) of the majority of these inclusions. They were all neatly arranged in two parallel arrays on two planes parallel to the narrower prism m of the first order $(10\bar{1}0)$ lying below the smaller rhombohedron z $(01\bar{1}1)$ at a distance of 1 or 2 mm inside the surface of these three prisms, and they were large enough to be visible to the unaided eye. (Figs 1 and 2).

The microscope revealed that these inclusions mainly contained a mono-phase of some fluid or gas, while only a few were bi-phase inclusions embracing a liquid and a vesicle. In order to disclose the chemical composition of these fillings it was necessary to

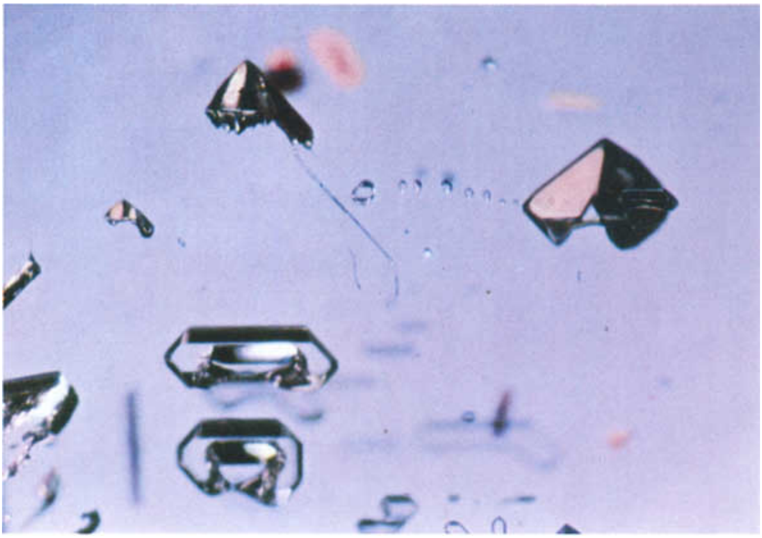

FIG. 1. The c-axis runs vertically through this picture. In the upper half the negative crystals in the shape of rhombohedral pyramids are in the right position, while the negative crystals in the lower half are extended along the horizontal axes. 10 ×

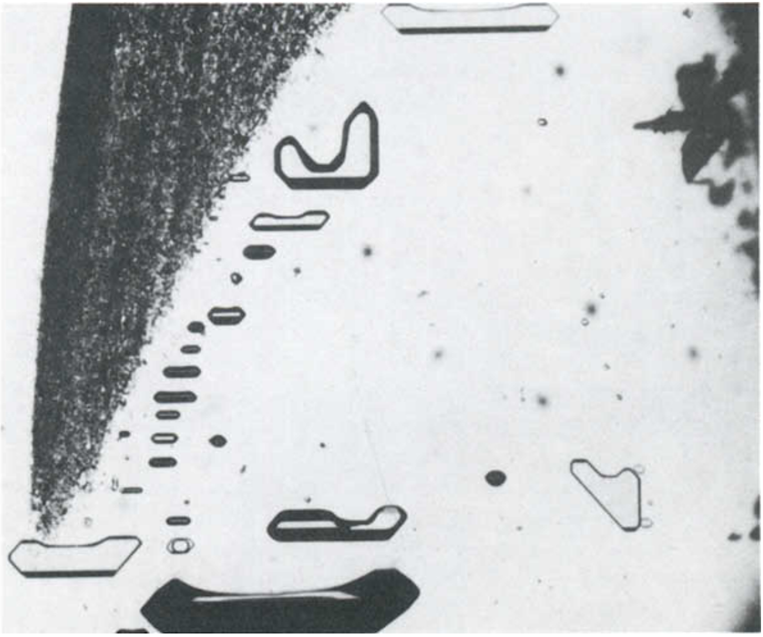

FIG. 2. Another combination of negative crystals lying parallel to one of the prisms of the first order. Almost all of them are extended along the horizontal axes of the host amethyst. 16 ×

take recourse either to the freezing or to the heating stage. Since the application of this method of analysing fluid and gaseous inclusions has not yet been explained in English gemmological literature this occasion might be a welcome opportunity. The classical method, which was already used by H. C. Sorby more than 100 years ago, makes use of the heating-stage microscope. By means of slowly heating up the gemstone, that is to say its inclusions, the temperature of homogenization, i.e. the temperature at which the bubble disappears, is determined. This method actually reverses the course of events which took place in nature, when an inclusion slowly cooled in its host mineral. In the laboratory the specimen is heated until the content of an inclusion has reverted to its homogeneous fluid phase, i.e. until the vesicle has vanished and until the salt crystals, which might be present, have completely dissolved again. The temperature at which total homogenization is reached corresponds with the possibly minimal temperature of formation of the host crystal. In fact it does not lie much below the actual temperature of formation, particularly if the pressure of a hydrothermal mineral formation was relatively small. Matters are different if the pressure was great—then greater corrections for the temperature become necessary. Quartz is excellently suited as experimental material. It is an ubiquitous mineral which exceeds most other minerals in that it can preserve inclusions unaltered for long geological eons and in addition does not leak easily during experimentation.

As long as the inclusions essentially contain aqueous solutions there are no particular problems of investigation. However, conditions change whenever considerable carbon dioxide CO_2 (or methane CH_4) occurs simultaneously. Liquid carbon dioxide has already a pressure of 60 atm at room temperature. This pressure increases very rapidly with slight warming and consequently most specimens with CO_2-inclusions burst upon heating long before the homogenization temperature is reached, unless a strong external pressure in the experimental cell counters the internal pressure of the inclusions. This method of research has for the last few years provided a vast amount of valuable data on liquid and gaseous inclusions in minerals.

When applying the freezing-stage microscope the host mineral is very rapidly cooled down to say −100°C and then slowly warmed up again. This procedure permits observation of quite different physical and chemical alterations—e.g. the melting point of a watery solution and hence the reducing of the melting point which enables a conclusion to be reached with regard to the salt content of the solution. Or the homogenization temperature of gaseous and liquid carbon dioxide may be determined, which again allows one to draw a conclusion concerning the density of the CO_2, and furthermore the temperature of decomposition of hydrates or the melting point of carbon dioxide etc. may be found.

The freezing and heating methods offer the eminent advantage that each inclusion may be investigated individually. Other methods, such as the mass-spectrometer or gas chromatography, can only scan the total number of inclusions in a mineral. The trapped liquids are in most cases aqueous solutions with relatively large portions of mineral matter like sodium, potassium, calcium, magnesium and others on one side (cations) and chloride, carbonate, sulphate etc. on the other side (anions). It has become possible to determine these different cations and anions, though merely in relative amounts of each other and not in percentages of the filling of the inclusion. However, just these relative amounts—for instance the ratio of K/Na—are very important for the petrologist, because under certain circumstances they may serve as geological thermometers, in that they permit a conclusion as to the conditions of temperature prevailing at the time of formation. This is possible, because for instance the ratio potassium/sodium is being regulated during the growth of a host mineral by the two types of feldspar which occur simultaneously and because the ratio differs with changing temperatures. Yet, apart from this somewhat hypothetical application of a geological thermometer, the identification of the cations and anions supplies valuable information on the geochemistry of a mineral—or ore deposit—as well as about the pressure/temperature conditions predominant during the formation of a mineral.

These were the questions of interest which were aroused by the mono- and bi-phase inclusions of the amethyst.

The cooling down to −155°C on the refrigeration stage produced the following observations:

(*a*) the sublimation of a solid body took place at the temperature of −99°C (Fig. 3) in one case, and in another case at −90°C (Fig. 4):

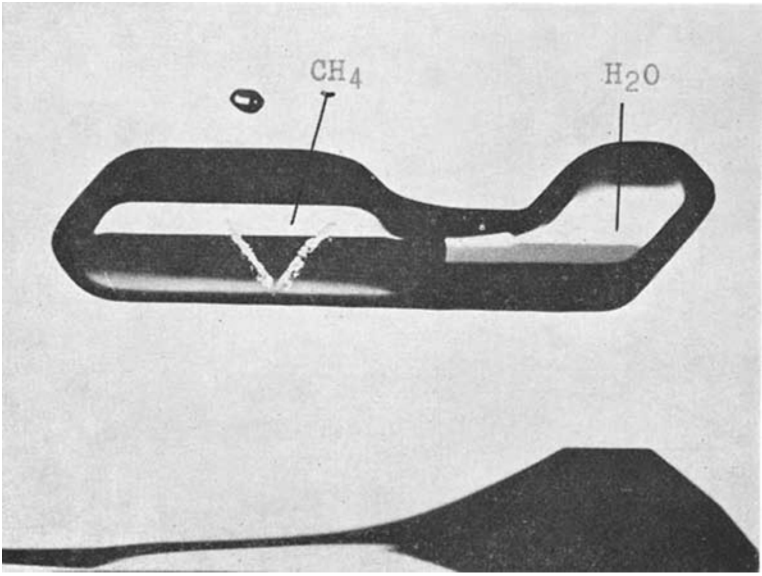

Fig. 3. In one of the negative crystals depicted in Fig. 2 a solid V-shaped body developed first in the gaseous CH_4 phase upon cooling and disappeared at −99°C. The melting point of the aqueous phase was −0·6°C. 100 ×

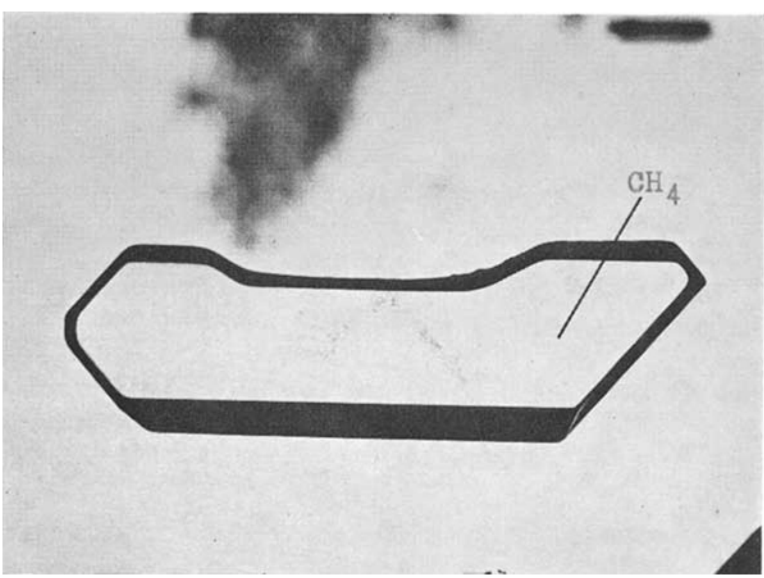

Fig. 4. In another negative crystal filled with gaseous CH_4 a similar V-shaped solid substance formed and vanished at −90°C. 100 ×

(*b*) melting of the ice at the temperature of −0·4°C (another inclusion at −0·6°C). This behaviour corresponds with a saline content of 0·7 wt% of NaCl (1·0 wt% for the second inclusion) (Fig. 5).

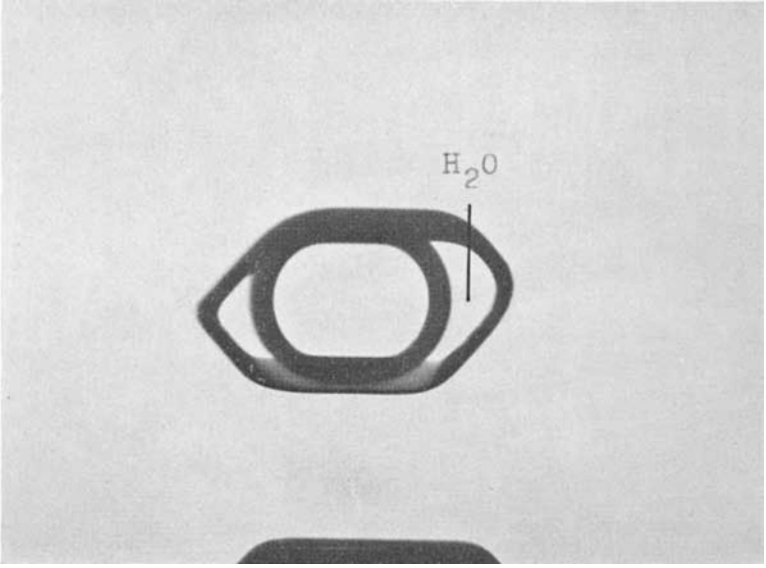

Fig. 5. Two-phase filling consisting of a saline watery solution and its vapour bubble in a negative crystal. The melting point of the ice was −0·4°C. 100 ×

No other alterations of phases could be determined. Unfortunately, the interpretation of these observations is not quite definite. The liquid phase is doubtless a watery solution with a low salt content. The problem lies in the composition of the gaseous phase. It was not possible to liquefy it even at −155°C. The solid phase, which formed directly out of the gaseous phase at approx. −110°C could not be identified. However, it is a well-known fact that when methane is cooled down a morphologically identical solid phase always emerges from the liquid methane. The solid matter, however, was not possible to analyse. If the gas is methane—and this is highly probable—then it was trapped at a very low pressure. However, if the gaseous phase is not methane then only nitrogen (i.e. air) comes into consideration because all the other possible gases would, in view of the low refrigeration, have been subjected to typical phase alteration. Hence, methane is definitely much more plausible than nitrogen.

I favour methane because of the conspicuous elongation of the negative crystals along two completely different crystallographic directions, i.e. euhedral negative crystals aligned to the crystal habit of the amethyst and distorted negative crystals which are extended along the horizontal axes. It has been observed that the presence of methane may exert a strong influence on the development of the crystal forms of growing quartzes and consequently on the shaping of their negative crystals. Stalder and Touray (1970) noticed that methane played an important role during the formation of transparent, dipyramidal quartz crystals from the western limestone rocks of the Swiss Alps. They distinguished four different types of habit, of which the differences of the first three may be explained by the dynamic co-operation of crystal growth and breaking the aperture of a fault, and they held the small amount of CH_4 responsible for the formation of the habit types 2 and 3 as well as for the absence of the x-faces on these crystals. On the other hand, they were convinced that methane was responsible for the development of the fourth habit.

Under these conditions the various shapes and the different directions of the extensions of these inclusions need not be surprising. Very similar formations and orientations of negative crystals have been observed in quartzes of the Helveticum containing methane. Negative crystals elongated along their C-axis and shapes severely distorted along the horizontal axes—all occurring on the same plane—do not even seem to be a rarity.

The different fillings in the inclusions of the amethyst dealt with in the present discussion, i.e. mono-phase and bi-phase (H_2O and CH_4), reveal that the amethyst did not grow in a pure methane environment. It would seem more feasible that at the time of the crystal growth and after a rapid reduction of the temperature and the pressure an exsolved watery solution and methane (in a supercritical state) must have been present in the birth chamber of the amethyst. As a concluding remark it may be emphasized that methane and higher hydrocarbons may in present times still exist in a free state in deposits where quartzes were formed.

Acknowledgement: I wish to extend my best thanks to Dr H. A. Stalder, Natural History Museum, Berne, for his efficient assistance and valuable advice.

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COMPARATIVE GEMMOLOGICAL STUDY OF LAPIS LAZULI AND OF ITS NEW SUBSTITUTE

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THIS is a report of a series of tests made with the first samples of a new substitute for lapis lazuli(1). A complementary paper is intended at a future date. The colour of the new substitute is of a pleasant intense ultramarine blue, of an even shade. Compared with samples of the DIN 6164 Colour Chart the closest standard is sample no. 16:4:5, with a corresponding wavelength of 469 nm. To aid gemmologists without knowledge of this colour description system, we may describe the colour tone as approximately the colour of the binding of the 1962 (two volumes) edition of "Gems" by R. Webster.

ASPECT

Under magnification, the regular and fine structure includes some tiny elongated particles with rounded ends. Tiny metallic particles with metallic lustre are incorporated, having a rather evenly elongated shape and size, quite unlike the irregularly sized, unexpected, sometimes dendritic, inclusions (occasionally with reentrant angles) seen in natural lapis. The samples under examination did not show the irregular colour distribution so peculiar to most of the natural lapis with the so-called Chile lapis as an extreme case with its random distribution of light blue or white phases.

Under the Chelsea filter, as well as under ultraviolet radiation, no specific reaction of the samples was observed.

Under the powerful beam of a fibre glass conductor lamp which was shone directly upon the flat surfaces of the samples, they revealed no light transmission, as against pieces of natural lapis that may exhibit a distinct translucency as an intensely blue light around the end of the beam of light, where some natural lapis may be opaque. Henceforth, a definite translucency of a blue colour is a clue to genuine lapis. Furthermore natural lapis exhibits often (but not always) a spotted ultraviolet fluorescent reaction made of irregularly distributed small spots of orange, yellow or whitish colours corresponding to the inhomogeneous mixture of phases of this rock.

HARDNESS

One would expect that in his effort to surpass nature the manufacturer might have succeeded in duplicating the properties of natural lapis. All the greater was the surprise to ascertain the lower hardness of about 4½ for the artificial product, which is scratched by apatite (which has 5 Mohs hardness degree), whereas trade gem-quality lapis scratches apatite, showing a hardness of about 5½. The difference in hardness expresses itself in the streak left by samples on a rough porcelain plate. Natural lapis has no streak, or leaves a very faint bluish grey mark; the state of cohesion is such that it resists abrasion and releases no odour; on the contrary, presumably because of its lower cohesion state, the substitute has a strong blue streak, leaving a powdered residue, when rubbed on the plate with similar pressure applied (see Fig. 1), because it crumbles fairly easily, while, due to this action, a definite smell of sulphur compound develops. This alternative reaction seems to be convincing, all the more as, under more strenuous conditions, viz. touched with the rotating, small carborundum abrasive disc on a

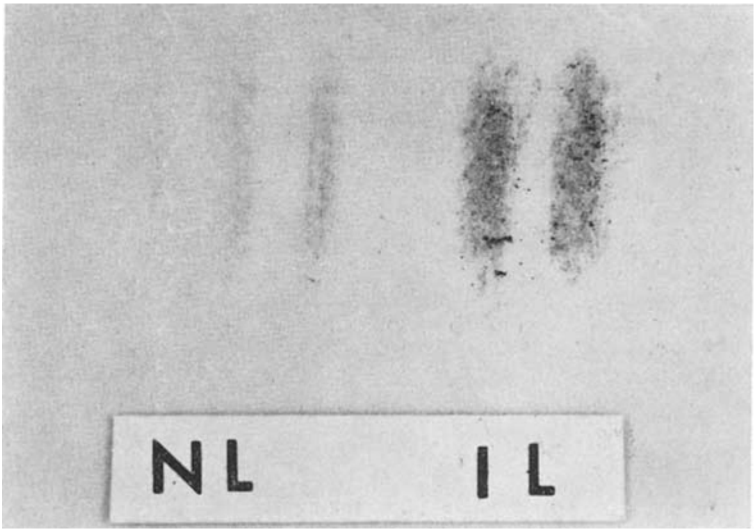

FIG. 1. Compared hardness. Streak left by natural lapis (NL) and new substitute (IL). *(Photo. C. A. Schiffmann)*

flexible motored arm used by jewellers, both natural lapis and the substitute give off the similar sulphur odour. The detection of smell is rarely practised by the average gemmologist but in this case offers a hint towards a definite identification.

In order to analyse the structure of the substitute, an x-ray powder diagram was carried out thanks to Dr W. Oberholzer, of the Zürich Institute of Crystallography, whose first results confirm that some of the phases are in a crystalline state. The aggregation state of these phases is being studied in further detail.(3)

REFRACTIVE INDEX: non-typical, vague edge at about 1·5.

SPECIFIC GRAVITY

Gemmological literature gives only a range of S.G. for lapis lazuli qualities as used for jewellery. In order to obtain more precise data on different types and so to bridge this literary gap, we made a series of determinations by the hydrostatic weighing method, on samples of average jewellery types. Determinations of S.G. of more irregular or extreme types are intended to be reported at a later date. The hydrostatic method enabled us to verify a possible porosity of natural lapis by leaving all the specimens immersed for a duration of 6–15 minutes and then weighing again.

The table below is a summary of our new S.G. data (at 4°C) for natural lapis in jewellery qualities.

Lot No.	*Colour*	*Inclusions or Phases*	*S.G.*	*Porosity*
1	Blue, intense, dark, (resembling sodalite shade)	without pyrite	2·83	None
2	Blue, intense	without pyrite few white spots	2·51	None
3	Blue, less intense	without pyrite	2·73	None
4	Blue, ultramarine, homogeneous	without pyrite	2·85	None
5	Blue, ultramarine, homogeneous	without pyrite	2·77	None
6	Blue, ultramarine, homogeneous	without pyrite	2·89	None
7	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·88	None
8	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·90	None
9	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·79	None

Lot No.	*Colour*	*Inclusions or Phases*	*S.G.*	*Porosity*
10	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·86	None
11	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·77	None
12	Blue, spotted, "Chile lapis"	approx. ¼ of surface having paler blue or white phases	2·96	None

A trifling porosity resulting in a S.G. increase of 0·003 came out with no. 3 and 11, and is negligible within the precision limits of the method used, the results being rounded up to the second decimal point.

S.G. of 1 to 12, extreme values 2·51 and 2·96
S.G. of 1 to 12, average value 2·81

To enable comparison, the S.G. of samples of lapis substitute was determined using the same method:

Lot No.	*Colour*	*Approx. S.G. at immersion time*	*S.G. after 6–15 mins. immersion*	*Apparent porosity in vol%*
1	Blue, ultramarine	2·41	2·53	4·8
2	Blue, ultramarine	2·33	2·47	5·7
3	Blue, ultramarine	2·34	2·39	2·2

Extreme S.G. values 2·39 and 2·53
Average S.G. value 2·46

Just after immersion the evident porosity manifests itself by a quick shift of the balance dial which stabilized visually after 6 to 15 minutes.

With its distinct porosity the lapis substitute has an obviously different behaviour from that of natural lapis without porosity; together with the considerably lower S.G. at an average of 2·46 against 2·81, this way of separating them is very convincing.

Gemmologists working hastily with heavy liquids might be led to error, as the substitute falls within the S.G. range for sodalite, which lies in average at 2·3 with a possible variation. However, sodalite has no porosity: and, by the way, the lapis substitute would soak up quite an amount of chemicals, a reason why heavy liquids are not necessarily a recommendable method for testing porous materials. Furthermore, the colour of sodalite is on the average of a more violetish blue (colour tone 15 of DN 6164 Colour Chart), and its R.I. lies lower, towards 1·48. Under the strong direct beam of light as mentioned before, sodalite further exhibits a distinct translucency in the form of a beautiful violet blue colour.

In a search for other possible testing methods a trial was undertaken with infrared spectrophotometry, a method which gave us interesting results in a number of cases. The first results obtained in working between 2·5 and 40 mm were not conclusive, since the respective absorption curves of both the natural and the artificial lapis materials were not diverging enough to differentiate them safely.

However, the method gave a positive result in another regard, identifying sodalite mentioned above by well defined typical absorptions at 980, 740, 710, 670, 470, 440 cm^{-1} against the one broad absorption of lapis of 1420 and 1030 cm^{-1} and weaker lines between 900 and 300 cm^{-1} (Fig. 2). The advantage of this procedure being that by means of an instrument recorded results are available for future reference when written proof is required.

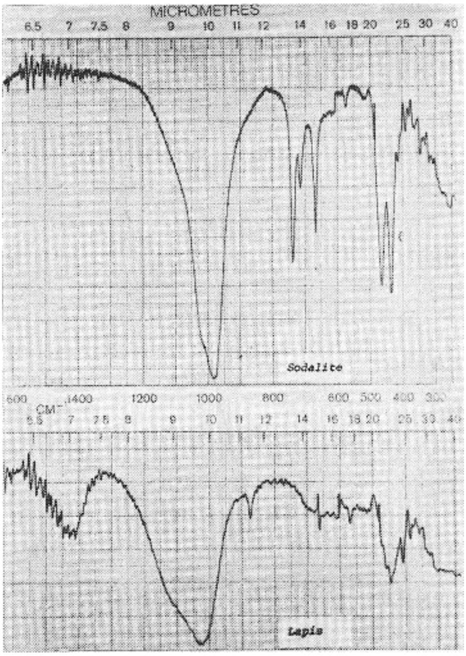

FIG. 2. Differentiation between natural lapis and sodalite by means of their infrared spectra between 9 and 40 μm.

Finally, some chemical reaction tests were included on pieces of natural and artificial lapis in order to search for their different reactions. It should be known, that due to being a rock of inhomogeneous structure and because of its components, lapis is sensitive to acid and when set in jewellery should be treated with caution. An unconsidered drop in the diluted acid bath in use with jewellers may ruin the surface of lapis. This destructive test was performed in applying a drop of 3 acids and observing the development and the result of the reaction under the microscope as in the table below.

Chemical tests and reaction at room temperature on cut pieces:

Diluted Industrial Acids	*Natural lapis*	*New lapis substitute*
Sulphuric	Reaction not very rapid. Sulphur fumes slow to develop, not very strong. Irregular white residue.	Rapid attack. Immediate effervescence. Strong, sulphurous fumes.
Nitric	Reaction slower, not very strong. After evaporation, trace of the drop hardly visible. Fumes weak.	Attack irregular. Fumes less pronounced than above, but developing rapidly.
Hydrochloric	Reaction quicker than no. 1. Gas bubbles arise much less rapidly than on the substitute surface. Formation of a colourless jelly.	Reaction and fumes immediate. Drop keeps round shape.

The photographs (Figs 3 and 4) will enable the reader to grasp a better idea of the relative intensity of the reactions. It is intended to discuss these reactions in more detail at a later date.

Altogether, the new substitute has properties sufficiently unlike the ones of natural lapis to distinguish them quite easily. For the gemmologist in this case care in testing and knowledge are the necessities. On the whole, at least some of the properties of this substitute are strikingly similar to those of a lapis imitation made

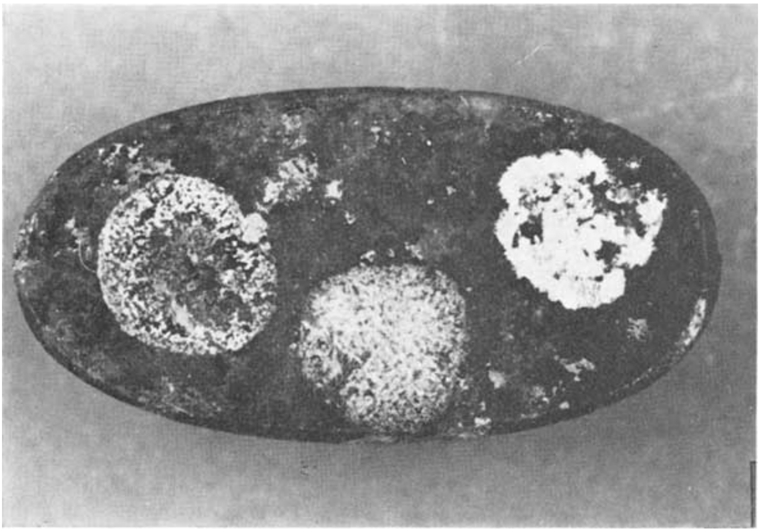

Fig. 3. Natural lapis, action of diluted acids on the surface of an oval-shaped stone.
right: drop of sulphuric acid, strongest reaction with white residue
left: drop of nitric acid, weak reaction
below: drop of hydrochloric acid, medium reaction
(*Photo. C. A. Schiffmann*)

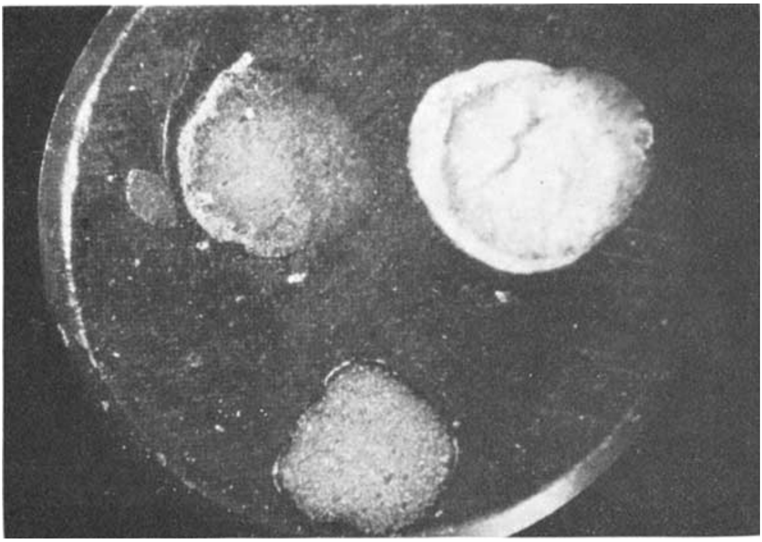

Fig. 4. Lapis substitute, action of diluted acids on the surface of a round stone
right: drop of sulphuric acid, very strong reaction
left: drop of nitric acid, medium reaction
below: drop of hydrochloric acid, fairly strong reaction; on this sample the reaction was immediate and stronger than on natural lapis. (*Photo. C. A. Schiffmann*)

already in 1957 by Reese and reported upon by W. F. Eppler(2) As far as we know, the present material is marketed by the firm of Gilem.

We should like to express our appreciation to Dr W. Oberholzer, of the Institute of Crystallography, Zürich, for his kind assistance in arranging the Gandolfi x-ray analysis and Mr K. Kunz, Reiden, for his careful preparation and carrying out of the infrared spectra.

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MOLDAVITES AND A SURVEY OF OTHER NATURALLY OCCURRING GLASSES

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INTRODUCTION

This paper surveys the occurrences of glass in nature with an emphasis placed on those materials which may be of interest to the gemmologist. The first section discusses tektites and, in particular, gem varieties of moldavites, with new information given on their geology and on their gemmological applications. The second part of the paper gives an inventory of all those natural or possibly natural glasses known to the authors. Some unusual materials are discussed, but emphasis is again placed on those substances of greatest interest to the gemmologist and it is pointed out that some attractive glasses have not found their way into jewellery due to the fact that there is at present no way to determine whether they are of natural origin.

TEKTITES

Tektites are enigmatic bits of natural glass which in many cases exhibit attractive sculptured forms. They are known from only a few areas or strewnfields and their varietal names have usually been taken from the regions in which they were found. *Moldavite* is the variety of tektite most commonly encountered by gemmologists, and moldavites were the first tektites to be studied scientifically. They were described by Professor Joseph Mayer in 1787, some fifteen years before the true nature of meteorites was recognized by the scientific community. The moldavites take their name from the river Moldau which is called the Vltava in Czech and the term *vltavite* shows up in some older publications. Moldavites occur in a scenic area approximately 100–150 miles north-west of Vienna and 60–100 miles south of Prague. About sixty years after Mayer's original publication, tektites were discovered in Australia (*australites*), and at the end of the 19th century discoveries were made in south-east Asia (*philippinites*, *javanites*, *billitonites*, *etc.*). Other discoveries followed.

Tektites can be divided into four groups in accordance with their potassium-argon ages: the oldest are *bediasites* from Texas and Georgia (with two unique specimens attributed to Martha's Vineyard, Massachusetts, and to Cuba) with a K/Ar age of about 35 million years. The name bediasite comes from Bedias, a proper name in Grimes County, Texas. The moldavites are the second oldest group of tektites at about 14·5 m.y., then *Ivory Coast tektites* which are dated at approximately 1·3 m.y. The youngest are the south-east Asian varieties and the australites with an age of about 700,000 years. It is interesting to note that these last two dates refer to periods when man or man-like beings were already in existence. A unique natural material from western Egypt is called *Libyan Desert Glass* and has a K/Ar age of about 35 m.y. It should almost certainly be classed with the tektites but, because of its high viscosity in a molten form, its physical appearance is quite different and it has been treated separately by many authors.

Origin—Hundreds of papers have dealt with the origin of tektites. Most of them can be summarized in the following table:

TABLE 1

Summarized hypotheses of the origin of tektites (after Mason, 1962).

A. Tektites have been formed from terrestrial materials by:

1. Impact (*a*) of meteorites; (*b*) of comets.
2. Lightning (*a*) fusing soil; (*b*) fusing dust particles in the atmosphere.
3. Natural fires: burning straw, forest fires, burning coal seams, etc.
4. Volcanic activity.
5. Human activity: furnace slags, glassworks, etc.

B. Tektites are of extra-terrestrial origin; they came from:

1. The moon, from (*a*) lunar volcanoes; (*b*) splashes from meteorite impact.
2. Comets.
3. A disrupted planetary body having a glassy surface layer.
4. Meteorites consisting of free Si, Al, Mg, etc.
5. Stony meteorites by fusion in the earth's atmosphere.

It is clear from the few facts already presented that many of these ideas are untenable; others are so speculative that they are exceedingly difficult to prove or to disprove. During the past two decades evidence has accumulated that indicates rather strongly that the tektites must have originated from impacts of large meteorites or other cosmic bodies. These impacts caused the rock on the ground at the site of impact to melt and material was ejected in some special manner that permitted the formation of the tektites. Scientists still argue whether the original impacts took place on the earth or on the moon, but almost all experimental data support a terrestrial impact site. Any theorizing along these lines must, however, take into account a troublesome aerodynamic consideration, namely, that tektites are invariably small and the earth's atmosphere is large, and the launching, splashing or throwing of the tektites in a liquid or solid form presents a problem analagous to throwing a feather a considerable distance. Somehow, the air resistance built up in front of the projectile of low mass must be removed or greatly attenuated in order to satisfy the aerodynamicists. Any successful theory of tektite formation at the surface of the earth must resolve this problem and most of the ways suggested to date entail extremely energetic events. Expressions such as "blowing a hole in the earth's atmosphere" are bandied about regularly.

According to Konta and Mraz (1975) many authors are wrong in postulating that tektites originated by a direct melting of terrestrial silicates to glass. At the 34th Annual Meeting of the Meteoritical Society, held at Tübingen, Germany, Gentner (1971) and Konta (1971) presented, independently of one another, a hypothesis based on experimental data in which it was suggested that the moldavite substance originated when terrestrial silicate material evaporated during the thermal shock which followed the impact of a large cosmic body. During the explosive ejection, the gaseous silicate phase seized some of the solid and liquid phases and quartz grains, in particular, were melted to lechatelierite. In the opinion of both authors moldavites were formed by the condensation of silicate vapours during their passage through the atmosphere. According to Konta and Mraz (1975) all the experimental data hitherto obtained indicate that the evaporated and condensed material in moldavites prevails over the material that passed directly from a solid state to a liquid one. The discrepancy emphasized by some authors between the chemical composition of impact glasses at the craters and that of the tektites assumed to be genetically related to them can now be understood better. The enrichment of silicate vapours in silica, in total FeO, and in Na_2O and the impoverishment of these vapours in CaO, MgO, K_2O, and Al_2O_3 which apparently took place during thermal shock can attain such a degree that the chemical composition of the glass condensed from the hot silicate vapour (e.g. the tektites) will differ substantially from the chemical composition of the original rock, as well as from glasses generated from it by direct melting.

A lunar site for the initial meteoritic impact now seems highly unlikely due to aerodynamic considerations which are as imposing as those involving a terrestrial site, plus a complete lack of chemical or isotopic similarity between tektites and the lunar rocks recovered by the Apollo program. An additional constraint is imposed by the fact that during their initial cooling, tektites were in a magnetic field comparable to that of the earth's (De Gasparis, Fuller and Cassidy, 1975).

Many researchers suppose that the well-known Ries crater in West Germany has been the source impact crater for the moldavites. Likewise, the Ivory Coast tektites are referred to the Lake Bosumtwi

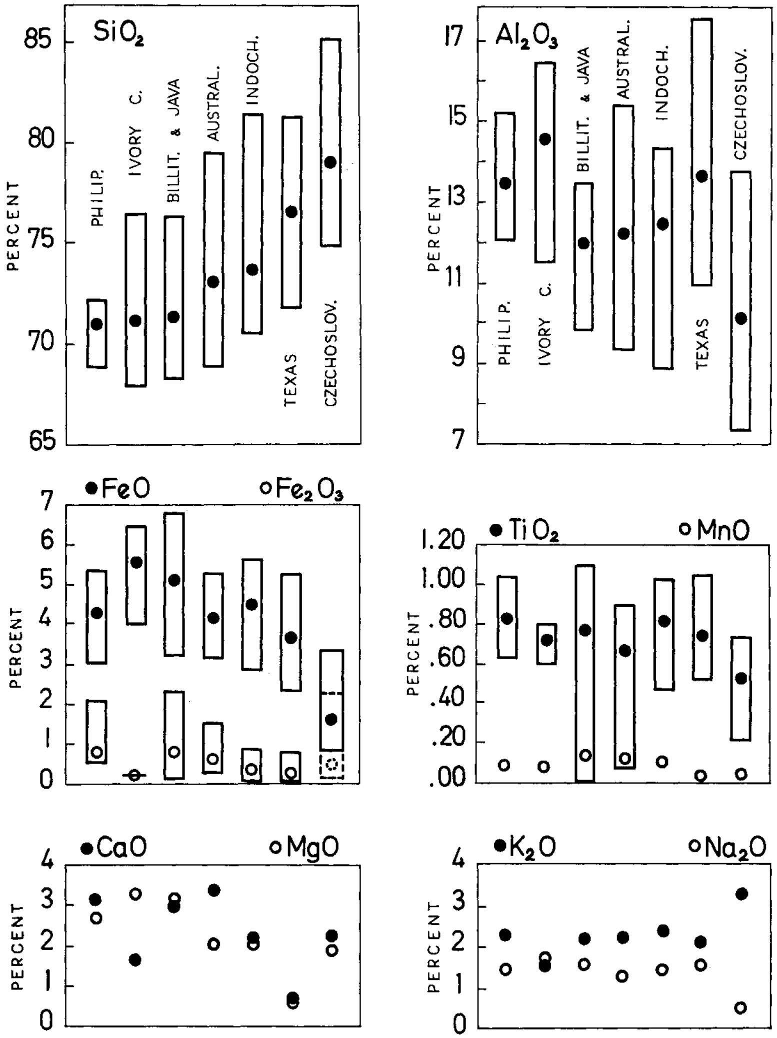


Fig. 1. Chemical composition of tektites from different areas.

crater in Ghana and in Libya there are two relatively unknown craters in a quartz sandstone, one of which, the "Oasis site", appears to explain the Libyan Desert Glass (Martin, 1969: French, Underwood and Fisk, 1972). The lack of any suitable impact site associated with the North American tektites or a definite site or sites related to the Australasian tektite strewnfields is evidence that the origin of tektites is still an unsolved problem.

Chemical composition—Fig. 1 shows the variation in chemical compositions of tektites from different areas. Silica is seen to be the major constituent in every case. On the vertical axes are plotted weight percentages of the respective oxides and the horizontal is used to show groups of tektites from different strewnfields. The size of the columns shows the known ranges of percentages of some oxides, and the circles indicate average values. The ranges and average values given for moldavites were calculated from more than fifty published chemical analyses. All tektites have a very high silica content and alumina ranks second in all cases. The prevalence of bivalent iron over trivalent iron and the absence of volatiles are also characteristic of all tektites.

Colour—In hand specimens, tektites from most localities are black or almost black and non-translucent. In thin sections they are translucent and usually brown or greenish brown. On the other hand, most Czechoslovakian moldavites and some specimens from the United States are translucent or transparent and many moldavites are greyish green or green, in various shades from deep to light; rarely, moldavites of bluish green colour can be found. The translucency of relatively thick specimens is due to the favourable chemical composition of particular moldavites. These contain the lowest amounts of iron oxides and of other colouring oxides (TiO_2, MnO) and the highest amounts of silica and potassium oxide of all tektites, the Libyan Desert Glass excluded.

Bouška, Faul and Naeser, 1968, p. 282–3, have studied 15,576 moldavites from 21 localities and report that: "In Bohemia 79% of the moldavites are bottle green; the percentage for individual localities varies from fifty-four to ninety-three. Olive green and light and pale green are the next most important Bohemian colours, with brown and intensive green ('poisonous' green) each being usually less than two per cent at each locality . . . Two colours predominate in Moravia; 89% of the moldavites are olive green and brown.

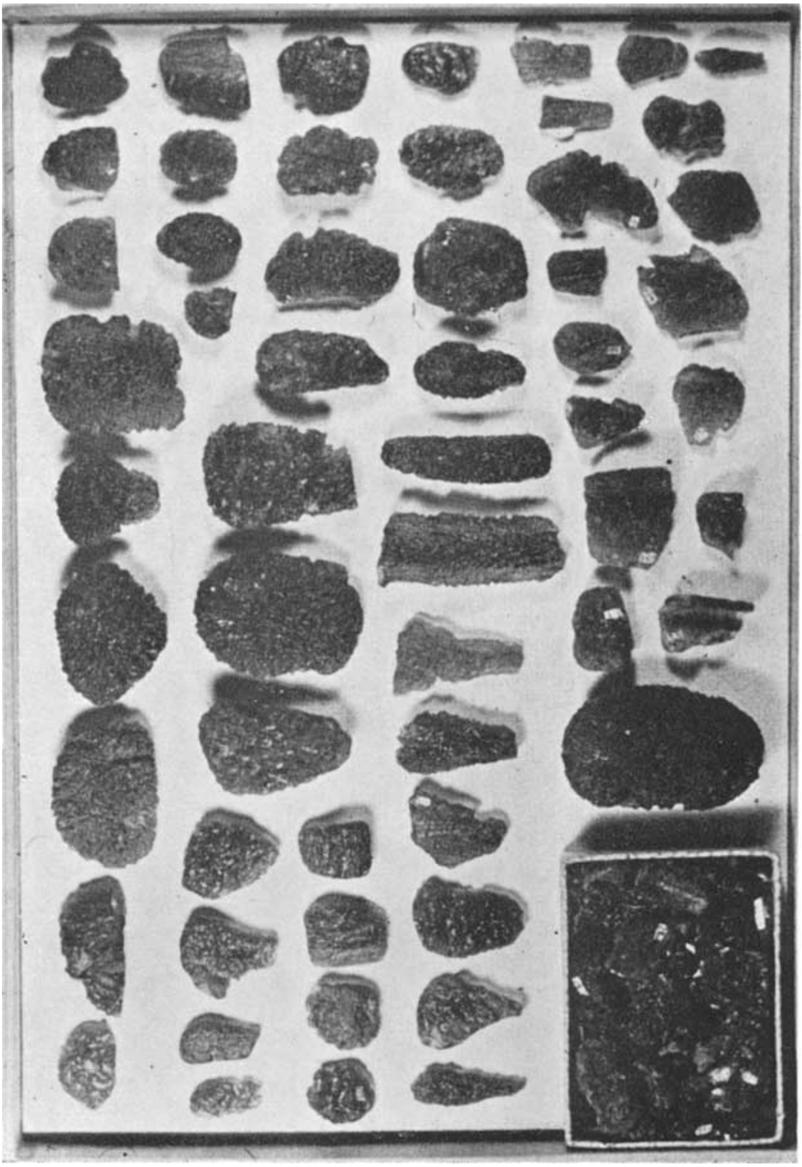


Fig. 2. Some typical forms of moldavites from southern Bohemia. Some of them are of gem quality. (Half natural size).

Bottle green, the dominant colour in Bohemia, is the colour of only five per cent of the Moravian moldavites, light and pale green accounts for five per cent, and the remaining one per cent is made up of intensive ('poisonous') green." Bicoloured, green and brown moldavites are known but are exceedingly rare. The translucency, bright colours, diversified shapes and surface features, along with their mysterious origin, are the main reasons why Czechoslovak tektites have become a material in wide demand for jewellery. Not all moldavites, however, can meet gem standards. One top-quality moldavite may be selected from as many as fifty to seventy specimens found in the field.

The number of areas from which tektites are known is very small and a gemmologist will note that deposits of sapphire and emerald, not to mention tourmaline or garnet, are much more numerous.

Physical properties of tektites—Size and shape of moldavites—Moldavites usually occur as irregular fragments ranging from ten to fifty millimetres in size. We can reconstruct the original shape of most of them, partly because original whole forms have been found, and partly because matching fragments occur in some localities (Fig. 2). The most frequent whole forms of moldavites from southern Bohemia are drops (Fig. 3), flat discs, and rod-like forms. In

FIG. 3. The most frequent complete forms of moldavites from southern Bohemia. (Nearly natural size).

Moravian localities the shapes are more spherical and the drops are short and thick. All of these forms are the result of aerodynamic forces. Tektites from other localities, australites in particular, show even more dramatic evidence of aerodynamic shaping. These aerodynamic forms should not be confused with the secondary surface features which result from weathering and which are discussed below.

Bulk density varies in a direct relationship with the refractive index. Both of these properties show an inverse relationship to silica content; that is, the lower the silica content, the higher the bulk density and refractive index. Javanites have the highest average bulk density of all tektite groups (between 2·40–2·55), followed closely by australites and philippinites. Bediasites have a lower bulk density and the moldavites are lower still with figures between 2·30 and 2·40. Within the moldavites, the mean bulk density of those from Moravia is slightly lower than of those from Bohemia. The refractive index of moldavites is low, ranging from 1·475 to 1·500. Libyan Desert Glass, which in common with other tektites may contain voids, has a bulk density of about 2·21 and a refractive index of 1·459 to 1·465. The hardness of tektites ranges from 6 to 7.

FIG. 4. Deeply grooved moldavites with very sharp surfaces, Besednice (left) and Nesmen (right) southern Bohemia. (Nearly natural size). First photo taken in incident light, the second one by transmitted light.

Secondary surface features of moldavites—A terrestrial sculpturing of the surfaces of moldavites has taken place through the action of weak aqueous solutions which percolated through the clay sediments in which the moldavites were originally deposited. This corrosive activity formed deep grooves and depressions, the peculiar character of which is a result of the chemically and physically inhomogeneous nature of the moldavites. The vast majority of moldavites contain grains and elongated schlieren of lechatelierite, a pure silica glass. The remaining portions of the moldavites have an increased content of the oxides of Fe, Al, Ca, Mg, K, Na and Ti, and a correspondingly lower percentage of the predominant silica.

Moldavites which have been buried in a fine-grained sediment such as the gravelly-sandy clay at Besednice and other localities, for the better part of fifteen million years (from the Upper Miocene until comparatively recent times), were deeply grooved and their surfaces contain sharp points (Fig. 4). The surfaces of most of these moldavites are dull and without glassy lustre even after all the clay material has been washed away (Fig. 5). Some of the moldavites

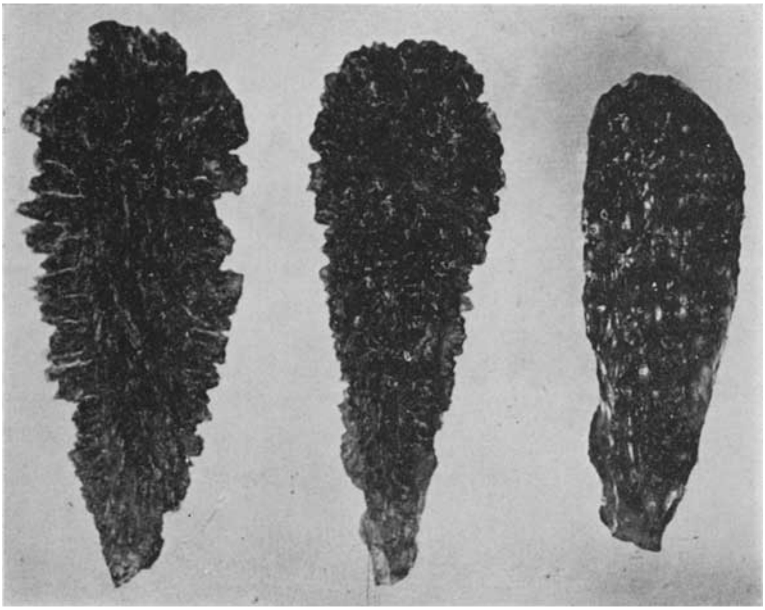


FIG. 5. The surfaces of moldavite drops after stream transport over various distances. Southern Bohemia.

were later transported after the Upper-Miocene clay had been denuded and were abraded to various extents during this transport. Together with gravel fragments and sand grains they were redeposited in younger Miocene, and in Pliocene to Quaternary strata. Most of the clay material was transported by streams into other areas and only a small portion of the clay material was deposited together with the sand and gravel. The surfaces of moldavites that were transported approximately five miles or more are subrounded or rounded (see the drop-shaped moldavite on the right in Fig. 5). If the moldavites were transported over a distance of only several hundred metres, however, their surfaces remained rough, and only the sharpest points and edges were rounded as is shown by the drop in the middle of Fig. 5.

In order to become glossy and to retain its deeply grooved surface, a moldavite had to lie in a clay sediment for several million years, and then after corrosion the moldavite had to be freed from the clay material and redeposited with gravel fragments and sand grains not far from its original sedimentary position. In the new sedimentary environment where there are relatively sizeable pores enabling an easy percolation of water and in which there is an insignificant admixture of clay matter, the moldavites are washed for hundreds of thousands or millions of years. The dull and rough surfaces turn smoother and lustrous. Seeping rain-water contains some aggressive compounds and it penetrates thoroughly into all the grooves and depressions, uniformly treating the entire surfaces.

Searching for moldavites—Moldavites can be found most easily in the fields after the spring thaw or in late fall after strong rains, when the surfaces of the fields are mostly free of vegetation. This seasonal water washes out the finest soil material; loam lumps and clods are elutriated, and all bigger solid fragments remain on the surface of the fields. The moldavites are well washed, as are other stones, and are found thinly scattered over the surface. Moldavites are recognized because of their green-black colour and their distinctive grooved sculpture. The best conditions for moldavite hunting are immediately after the rain or the morning dew, at which times the surfaces of the washed moldavites exhibit a glassy lustre. Under optimum conditions and in the richest localities an experienced collector can obtain as many as 30 to 60 pieces in one day from an area of approximately 300 × 900 metres. In other localities, however, the search may be unsuccessful for several years. Of 30–60 moldavites, usually only one is suitable for jewellery as a gem variety. All collected specimens do, however, represent valuable material for scientific purposes, especially if details of the find are recorded. Why are the gem moldavites so rare? The reason is that the gravelly sands that contain moldavites also contain quartz, feldspars, and fragments of acid igneous rocks. As a result of the weathering of the feldspars a soil profile is formed which contains an increased portion of clay particles and humus. These fine particles retard the percolation of water and form a clay environment somewhat similar to the Upper-Miocene clay sediment environment. The surfaces of the moldavites from such soils thus become dull again. In addition, a not inconsiderable number of moldavites get scratched or broken in the course of agricultural work on the fields.

The finding of gem varieties of moldavites—A reliable, although time-consuming, way of finding gem varieties of moldavites is digging in sand pits. The gem varieties of moldavites occur in those layers which are rich in gravel fragments. They are relatively little worn in those localities in which the gravel fragments of quartz, rocks, and feldspars are themselves but little rounded. Fig. 6 shows a section

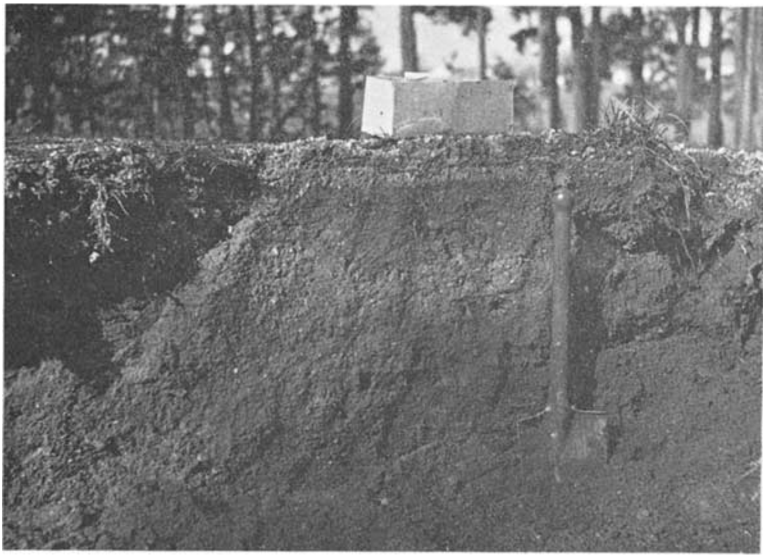


Fig. 6. A section of tektite-bearing sediments in the sand pit at Nesmen, southern Bohemia.

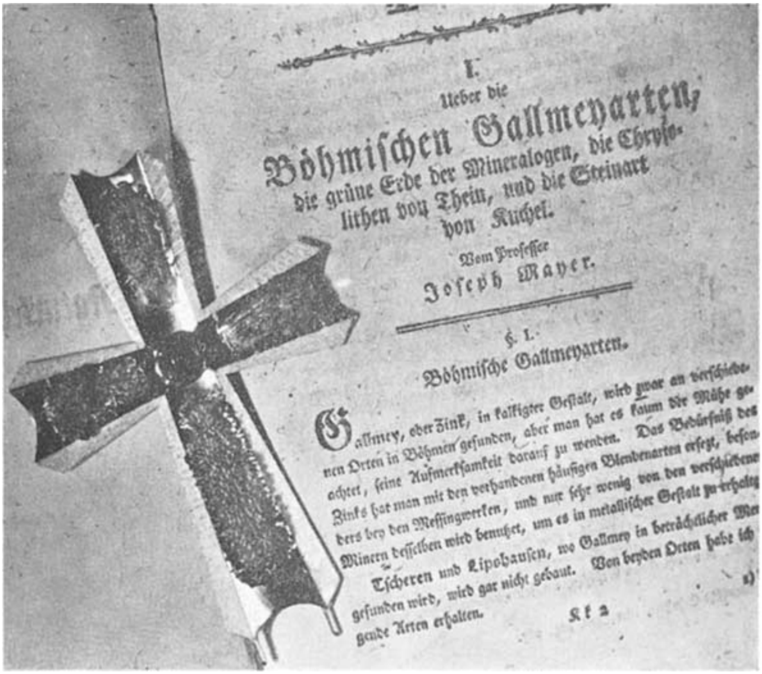
from the well-known sand pit at Nesmen in southern Bohemia. Moldavites are accumulated in those horizons which contain high amounts of gravel. All moldavite-bearing sediments are rusty brown in colour except those with a considerable content of clay, which are deep brown.

The sedimentary profile at Ločenice, about one mile from Nesměň is comparatively rich in moldavites, and yields one to three moldavites per 30 cubic feet. A group from Charles University (Prague) studied the section at Nesměň and Ločenice and searched for moldavites several years ago. Several beautiful moldavites were found in each of these sand pits. Twelve people digging in three pits for eight days found 43 moldavites. A total of 600 cubic feet of gravelly sand and 240 cubic feet of gravelly clay were dug and carefully examined. Forty-three moldavites weighing 118 grams were found and, of these, 30 specimens were of gem quality and weighed a total of 98 grams. The weight of the heaviest one was 13·276 grams and its size was 26·3 × 21·9 × 18·8 millimetres; the weight of the lightest one was 0·391 gram.

Gem moldavites as gemstones—Most varieties of gemstones undergo cutting and polishing in one manner or another in order to take full advantage of their colour, lustre, or internal reflections. Pearls typify another class of gems in which the raw material is not cut or polished and in which the jeweller makes use of the natural lustre and the original form of his raw material.

The Czech gem-cutters and jewellers feel that moldavites, in common with pearls, should be used in their original forms with their naturally appealing surface characteristics. Particularly popular in Czechoslovakia are the flat sword-like shapes, which represent the blades of elongated drops (Fig. 7). These occur mainly in the southernmost part of the Bohemian moldavite strewn-field. The blade-like shapes and similar forms displaying high translucency or transparency are usually incorporated in pieces of jewellery whose structure and form make use of transmitted light. Crosses, ear-rings, necklaces, and brooches are particularly popular. Thick and dark-coloured moldavites are often set with a reflecting metal placed behind them.

Cutting and polishing of moldavites are not advisable because they deprive the stones of their original surface features and charm. Polishing cannot achieve a more beautiful surface than a high



I.
Ueber die
Böhmiſchen Gallmeyarten,
die grüne Erde der Mineralogen, die Chryſo-
lithen von Thein, und die Steinart
von Kuchel.
Vom Profeſſor
Joſeph Mayer.

§. 1.
Böhmiſche Gallmeyarten.

Gallmey, oder Zink, in kalkigter Geſtalt, wird zwar an verſchiede-
nen Orten in Böhmen gefunden, aber man hat es kaum die Mühe ge-
achtet, ſeine Aufmerkſamkeit darauf zu wenden. Das Bedürfniß des
Zinks hat man mit den vorhandenen häufigen Blendenarten erſetzt, beſon-
ders bey den Meſſingwerken, und nur ſehr wenig von den verſchiedene
Minern deſſelben wird benutzet, um es in metalliſcher Geſtalt zu erhalt
Tſcheren und Lipobauſen, wo Gallmey in beträchtlicher Me
gefunden wird, wird gar nicht gebaut. Von beyden Orten habe ich
gende Arten erhalten.

Kk 2 a)

FIG. 7. Flat, sword-like shapes or elongated drops of gem moldavites, southern Bohemia. The text is the first recorded description of tektites (Mayer, 1788). (Half natural size).

quality moldavite has already acquired by chemical corrosion during its many hundreds of thousands of years of burial in gravelly sand. Facets or polished free-form depressions are suitable only for those moldavites whose surfaces are dull or have a very rough relief, or for those whose excessive thickness causes a very low transmittal of light. Two additional considerations play a role in our suggestion that moldavites be mounted in their natural state rather than as faceted stones. One of these is the low index of refraction of moldavites (and of all other tektites) which will cause any faceted stone to have no more than a minimum of appeal. The other consideration is of quite a different nature. As outlined in previous sections, the origin of tektites is still an open question and much research is still going on. The definitive answers to our questions may come from any one of several possible lines of enquiry and it may be that there are rare classes or categories of tektites, as yet unstudied or undefined, which will be of great scientific value. By mounting tektites as undamaged whole pieces, we also preserve them for possible future research, especially in those cases where the locality of the place of find is still known. This may appear far-fetched, but an example will show that it is not. As an example of a truly unusual physical property, we note that about one gem moldavite in two hundred has such great internal strain that it will ring like a coin when dropped, a unique property amongst gems. A greater knowledge of the specific origins of these rare specimens might throw light on the entire tektite problem. The high-strain specimens cannot be faceted in any case; they shatter immediately when cut into. The bicoloured moldavites also constitute a special class of particular scientific potential.

Some other minor gem applications have been made of tektites. Tektites from south-east Asia have been cut into black cabochons, difficult to distinguish from cabochoned obsidian. Libyan Desert Glass has been faceted, but with its very low refractive index, its unattractive colour, and its potential scientific value, this can scarcely be recommended. Libyan Desert Glass does not exhibit moldavite-like surface features, although sand blasting by the desert wind has given rise to some curious surface features and textures.

Other names for tektites which have appeared in various publications include: "*Agni Mani*", *Fire Pearl*, *glass meteorites*, "*Bouteillenstein*" (especially for moldavite), *bottle stone* (for moldavite), *water-chrysolite*, *pseudo-chrysolite*, *obsidian buttons*, *Blackfellows' buttons* (for australites), and, no doubt, other unfortunate terms as well. Valid names for tektites in other languages, including "*buga*" (in the language of the Ifugaos people of northern Luzon) and "*agna*" (in the Agni and Baoulé languages of the Ivory Coast), have also found their way into print and are of great use in carrying out field work.

OTHER CLASSES OF NATURAL AND SUPPOSEDLY NATURAL GLASSES

In the years preceding the landing of men on the moon there was considerable activity in scientific circles to determine whether tektites or any other material found on earth might have come from the moon. None was found and recognized as such. The search concentrated on ash-like and tektite-like (glassy) substances. Some of the materials that turned up during this period may have come to the attention of gemmologists and a brief and probably incomplete survey is given below. A few of the materials noted have the potential of eventually becoming gemstones in their own right, but most are either curiosities or materials on which more research is required to determine whether or not they are natural in origin. In the same listing we have thought it appropriate to include all other natural glasses or possibly natural glasses and to comment on the gemmological potential of some of them.

Any theory relating to the origin of tektites must also be consistent with the existence of *microtektites*, small (under 1 mm) glassy objects discovered in deep-sea sediments in 1968 by B. P. Glass. Microtektites are known from sediments off the coast of the Ivory Coast and also in and to the west of the Australasian tektite strewnfield.

Bentonite is a clay mineral which is formed as a decomposition product of volcanic ashes and glasses. In 1970 Storzer and Gentner suggested that bentonite glasses which they studied in Bavaria and which they had dated at 14·5 million years were in fact identifiable as corroded relics of *micromoldavites*.

Impactites or *impact glasses* are known from the sites of several recognized meteorite impact craters. They are usually very heterogeneous, vesicular and mixed with crystalline fragments. Although massive brown and black specimens have been recorded, impactites are in no way suitable for lapidary purposes. *Darwin Glass*, from Mt Darwin in Australia, and the closely related *Macedon Glass* are impactites which are being extensively studied to see if they shed any light on the problem of the place of origin of the Australian tektites. The Darwin Glass is a dark brown, black, colourless or pale green, slaggy vesicular material with a very high SiO_2 content. It may well be related to a sizeable impact crater whose symmetrical form has been obscured by erosion (Ford, 1972). *Queenstownite* is a former name used for Darwin Glass. Impactites exhibit a range of refractive index from 1·46 to 1·55 and have a bulk specific gravity of "generally less than 2·3" according to Chao (in O'Keefe, 1963). Our own experience has included specimens with bulk specific gravity values up to 2·5 but any specimens that might come to the attention of a gemmologist would be unusual and might exceed even this higher figure.

Of no direct professional interest to the gemmologist are the glass minerals such as *lechatelierite* (with the composition of quartz) and *maskelynite* (with the composition of plagioclase) which are products of shock metamorphism and which are found in meteorites, tektites and impactites, and at nuclear test sites. These materials will not be encountered on their own.

The *Sakato* or *Sakado Glass*, said to have fallen from the sky over Tokyo in 1910, has been identified as a glass-coated albite-quartz schist which had been greatly heated by a process that was never identified (Okashi, 1936). It is not classed with either the meteorites or the tektites and its formation is most probably related to human activity. It is amusing to note that this object "fell" at a time when there was great excitement relating to the return of Halley's Comet, that it was subsequently buried in the scientific literature and was only revived, and very briefly at that, when the first explorations of the space age commenced.

Schonite is reported as a unique glassy material from Sweden. Although it has made its way into the literature concerning tektites, it is probably man-made, possibly part of a bottle, and is of no interest in the field of gemmology. The unique specimen has, in any case, disappeared (Wiman, 1941 and Zenzén, 1940).

Fulgurites are small-diameter tubes of glassy rock formed as a result of lightning striking rock or sand. Some fulgurites formed by lightning striking a sand dune may be over five metres in length but the inner fused portion appears never to contain clear glass fragments much greater than 3 mm in thickness. The refractive index of this glass is around 1·46. Certain mountain peaks exhibit unusual clinker-like altered rocks that contain even smaller bits of glass and these may be due to multiple lightning strokes, ball lightning or other electrical phenomena. (Bruce, 1958 and Lacroix, 1942).

Obsidian is volcanic glass and is usually black, although red, green and brown varieties are known. These have minor gem uses as cabochons, faceted stones, and as "*Apache teardrops*". The dark colours, low refractive index and usually unattractive natural shapes make obsidian in small demand as a gem material. In a few deposits attractive shapes, not unlike tektites, are known. The term *Valverdite* was applied to one attractively shaped variety of Texas obsidian which had been mistaken for a tektite. Neither the term nor the material it referred to were properly defined and confusion and acrimony resulted (La Paz, 1948). *Pitchstone* is a volcanic glass with a pitchy rather than a glassy lustre.

Macusanite, formerly known as *americanite* or *amerikanite*, is a green-grey to nearly colourless variety of obsidian known from Macusani and Paucartambo in Peru, and probably also from the Philippines and perhaps from other localities in western South America. A red-brown variety is also known from a Peruvian locality. A somewhat different obsidian exists near Popayan, Colombia. Macusanite is an unusual material, certainly facetable as a collector's stone, but with no attributes that would commend it to the trade.

Bruce (1958) gives analyses, refractive index, and specific gravity data for two types of "pseudo-tektites" from the Philippines which are reproduced in part below in a combined table with partial data from Barnes *et al.* (1970) for Macusani and Paucartambo. Barnes *et al.* state that the obsidian pebbles from near Popayan, Colombia, differ from Macusanite in chemical composition, absence of inclusions of high-alumina minerals and the general absence of the typical macusanite etched surface. It thus appears as though there are at least two, and probably three, four or five different unusual obsidians which have been reported in the literature. The term *obsidianite* which is sometimes encountered in the older literature as a synonym for tektites or other unusual glasses would appear to be a usable term in describing members of this poorly understood subgroup of igneous glasses.

Table 2

	Philippine "Pseudo-Tektites"		Macusanite from Peru	
	Type I	Type II	Macusani	Paucartambo
	(Bruce, 1958)		(Barnes *et al.*, 1970)	
S.G.	2·323–2·59	2·77–2·912	2·345–2·361	
R.I.	1·53	1·57–1·61	1·4831–1·4862	
SiO_2	73·56%	50·12%	70·67–72·8%	70·56%
Al_2O_3	14·11%	14·02%	16·12–16·93%	20·54%
Fe_2O_3	1·65%	5·85%	0·29–1·33%	—
FeO	1·18%	7·20%	0·30–0·6%	0·96%
MgO	0·55%	6·27%	0·00–0·19%	0·11%
CaO	1·33%	10·39%	0·16–2·07%	0·78%
K/Ar age			4·2 m.y.	

The reader is referred to the original references for more detailed data. Dr Charles W. Naeser, of the United States Geological Survey, has made nine fission-track age determinations of macusanite and gives a best estimate for the age of this material as 4·39 ± 0·07 million years.

Pele's Hair, a filamentous glass of volcanic origin, may be several metres long but almost never exceeds 0·1 millimetre in diameter.

"*Pit glass*" is a name applied to glass pebbles reported from the gem pits of Sri Lanka. Many specimens of pit glass are surely manufactured objects which were salted in fields in order to enhance their value in the eyes of prospective fee miners. There are many reasons to believe that pit glass pebbles are man-made, but there are also several reasons to believe that some specimens may be natural, that the term "pit glass" is an uninformative catch-all term, and that more work should be carried out. Unfortunately, there seems to be no set of criteria to make the general distinction between natural and man-made glasses and it is doubtful that there will be until some more thought is given to just what materials can fall into the category of "natural glasses". For the moment, fission-track age dating is the most promising but fission-track dates on glasses can only give a minimum age date. Obsidians which have been collected from a desert environment show definite indications of annealing and therefore give a reduced age. Apparently hot sunny days can cause track annealing in glass and obsidians collected from underground give older ages than identical materials collected from outcrop. (C. W. Naeser, personal communication, October 1975). Heating, possibly even heating in the course of cutting and polishing, would cause a reduction in track density and apparent age.

Information is given on pages 198-199 (Table 3) in a consolidated form on seventeen specimens of pit glass which have been reported in the literature or obtained by one of us (J.M.S.). The information is confusing and to some extent internally contradictory but it should be appreciated that glasses, whether man-made or natural, may exhibit a great range in properties. All the specimens listed were gemmy or described as gemmy.

An uncertain reference to a pit glass specimen with a specific gravity of 2·34 also exists. It is possibly significant that some of the colours of stones listed in Table 3 are very unattractive and would do little to attract a gem digger unless he made the assumption that the unattractive stones and the marketable colours would be found together. Specimens W5 and W6 have an indicated melting point of 1500–1600°C, higher than that of normal man-made glass.

Geological Setting:—In an appendix to an article entitled "Aspects of the fauna of Ceylon", Dr P. E. P. Deraniyagala, a highly respected scientist, reports:" It is probable that natural glass which is proof of former volcanic activity occurs in Ceylon. Sinhala gem miners recognize seven varieties of Ceylon's natural glass which they term *Bim viduru* = earth-glass. Their colors may be either dull red, yellow, light green, faint green, dark blue or luminous cornflower

TABLE 3

"PIT GLASS" SRI LANKA

Specimen Number	S.G.	R.I.	Wt grams*	Colour	Bubbles	Additional data and comments
W1	2·459	1·511	(0·524)	pale turquoise blue	One large and some very small	1·83% K_2O, 10·06% Na_2O. No strain birefringence. No absorption spectrum with direct vision hand spectroscope. Greenish glow under long wavelength UV. Very weak greenish glow under short wavelength UV. Bright green under x-ray.
W2	2·570	1·533	(0·651)	dark green	None seen	1·70% K_2O, 7·20% Na_2O. No strain birefringence. No absorption spectrum with direct vision hand spectroscope. Dull orange under long wavelength UV. Very weak orange under short wavelength UV. Weak misty glow under x-ray. No fission-tracks after 5 sec. and 10 sec. exposures to 40% HF.
W3	2·664	1·567	(0·466)	pale green	scattered small spherical	1·79% K_2O, 3·00% Na_2O. No strain birefringence. No absorption spectrum with direct vision hand spectroscope. Reaction to UV and x-ray identical to specimen W2 but slightly less weak with short wavelength UV.
W4	2·695	1·569	(0·609)	green	scattered spherical and ellipsoidal	0·43% K_2O, 4·94% Na_2O. Other observations identical to those made on specimen W3.
B1	2·735+	1·5751 –	(0·785)	dark olive green	absent or very small	Cut stone. H = 5½.

*Figures in brackets are for incomplete specimens.

Specimen Number	S.G.	R.I.	Wt grams*	Colour	Bubbles	Additional data and comments
B2	2·746	1·585	(0·821)	dark olive green	absent or very small	Cut stone. H = $5\frac{1}{2}$.
W5	2·61			green		(One of these specimens was the one with a liquidus at 1260–1280°C. Both specimens are rough pebbles.
W6	2·817			green		
P1			7·9	green	several scattered	1·20% K_2O, 5·50% Na_2O. No fission-tracks after 1 sec. and 5 sec. exposures to 40% HF. Rounded pebble.
P2			20–40	bright blue	One very large; probably others also	Rounded pebble. Colour said not to be due to cobalt.
P3				light green	scattered and small	Incomplete pebble with abraded surface. No fission-tracks after 2 sec., 5 sec. and 10 sec. exposures to 40% HF.
P4				very pale green		Almost colourless incomplete (?) pebble.
P5	2·6	1·54	(0·905)	olive brown	none	Cut stone. Exhibits some streaks or spicules.
P6				greenish	scattered and small	Pebble.
P7				greenish	scattered and small	Pebble.
AM1				blue		Blue beads recognized by K. Parkinson as identical to specimen P2. Anuradhapura Museum label indicates provenance from a dagoba with 2000 + years before present date.
AM2				green		Green beads in Anuradhapura Museum. Doubtful if pit glass.

*Figures in brackets are for incomplete specimens.

blue. It occurs in the gem sand at about 15 feet below the surface and in association with fossils of extinct mammals of late middle Pleistocene and upper Pleistocene age. This glass contains spheroid gas vesicles and spicule-like structures. All are more or less transparent when fractured. Four specimens, two of which were considered to be natural glass and one a tektite by me were secured from gem miners. . . ." (Deraniyagala, 1965).

Dr Deraniyagala informed one of us (J.M.S.) that the supposed tektite was in fact an agate and so it is difficult to know just what weight to place on the rest of his statement which may in fact refer to information that reached him second or third hand.

Pit glass is referred to by Smith (1913) but was not mentioned in recent editions of the same work. Church (1924) makes a brief reference to the rolled glass pebbles from Ceylon to strengthen his opinion that moldavites are natural in origin! Webster (1962) expands somewhat on Church's comments and concludes that the question is unresolved. Vorobiev (1965) refers to a dark green glass found in matrix in Ceylon which was discarded by either the miners or the lapidary. Other tangential references to pit glass exist. Deraniyagala in a 1958 publication referred to a strongly water-worn paleolithic pebble artifact from the gem gravel forming part of the Ratnapura Phase II. A gemmologist who examined this specimen through a display case was convinced that it was in fact an object made of glass. Dr S. Cavenago-Bignami Moneta, author of the encyclopedic "Gemmologia", has mentioned in a discussion of pit glass that she has seen a red specimen, apparently similar in nature, in an Indonesian museum.

Pit glass specimens W1, W3 and W4 have been dated by the fission track method by Dr Charles W. Naeser and no tracks were found. This indicates a very young age, and a man-made origin seems likely.

East African Glass, in several varieties, has been brought into Nairobi by African prospectors from the bush. All specimens obtained were massive chunks in attractive shades of bright blue or bright green. A pale yellow-brown variety with long, hair-like inclusions was seen on several occasions but not obtained from the prospectors. Many of the bright-coloured specimens exhibited fractures which contained a white powdery substance which was moist to the touch when the glass was broken open, but which dried within seconds. The SiO_2 contents of these glasses as determined by

Dr T. Bunch fall into two groups clustered around 56% and 67%, indicating that at least two different types of material are probably present. These glasses are stated to come from both Kenya and Tanzania and are often stated to come from areas rich in marble but not far from recent volcanic centres. The glasses might be man-made, or volcanic, or possibly some sort of immiscibility product at the contact between a marble and a lava. If this glass, or these glasses, proved to be natural, they would certainly be of interest to both hobbyists and commercial gemstone traders, with their low refractive index and relative softness being amply compensated for by their very bright and attractive colours.

An interesting parallel can be suggested between the East African glasses and the pit glass of Sri Lanka. The general geology of the gem areas in Sri Lanka and those of Kenya/Tanzania is extremely similar, with the major geological difference being that the gem area in Sri Lanka is peneplaned and weathered to a much greater depth. As a consequence, the gems in Sri Lanka appear as rounded pebbles as a constituent of gravels. In East Africa the gemstones are usually known from a host rock, which may or may not have an alluvial deposit associated with it. Since the glasses in Sri Lanka appear as pebbles and those in Kenya and Tanzania as massive chunks, we can at least note that there is a certain consistency with the weathering histories of the two areas.

Seven samples of various East African glasses were selected by Dr Charles W. Naeser for fission-track dating. Three showed no tracks and are therefore of very recent age and four specimens could not be dated because of their extreme solubility and very low etching efficiencies. Natural glasses have not been reported with such characteristics and a man-made origin does seem likely. The young age and unusual chemistry are, however, also consistent with a natural origin at the contact between a marble and a recent lava. Recent lavas are numerous in the areas in question.

Malawi Glass is a glass obtained under similar circumstances to the East African glass. It is a totally different material however, almost colourless, full of bubbles and with a SiO_2 content ranging as high as 93% (partial analysis by Dr T. Bunch). Dr C. W. Naeser's fission-track work also covered one specimen of Malawi glass which was of very recent age and most probably man-made.

Specimen of *Glass from South West Africa:* This interesting glass is represented by a single specimen which weighed about a hundred grams. It was picked up off the surface by a knowledgeable mineral collector (Jerry Rossouw, of Florida, Transvaal) several decades ago, before much industry, aside from mining, had come to the area. The locality of the find was "100 miles north of Uppington", an area far from any known volcanism. The material is an attractive brown, much like the darkest of smoky quartzes. A light dirt-brown weathering crust, a fraction of a millimetre in thickness, covered the specimen and, although it was angular, it presented no edges sharp enough to cut a person handling it. A shard of this glass was tested by heating with a blowtorch but it melted without evolving any gases; in this respect the specimen behaved like a tektite rather than like a man-made glass or an obsidian. The material, however, has no other tektite-like features. Work is continuing on this specimen which does not seem to fall in the same class as any of the glasses enumerated above. If a natural supply of this material came on the gem market it would be traded commercially, but not at high prices.

Fission-track dating by Dr C. W. Naeser on a fragment of the glass from South West Africa gave an age of 4·1 million years, with a standard deviation of ±0·6 million years. This specimen with its date is not relatable to any geological formation or geological event indicated on the 1963 Geological Map of South West Africa.

A purist might want to consider the glass which can be generated from the burning of a haystack as a potentially natural substance if the hay was set afire by lightning. Such material is normally slaglike in nature but smoky-grey and brownish pieces have been faceted. Glassy materials may also have their origins from the burning of termite nests, bamboo thickets, forests, underground coal seams, etc. and it is possible that some of these fires could be natural in origin.

An object was reported to have fallen from the sky over Igast, Estonia, in 1855 which may have been of a glassy or, more likely, a slaggy nature. Very little can be said about it inasmuch as there was a mix-up amongst different specimens or perhaps a mislabelling at an early date and various studies reportedly made on this object were evidently carried out on totally different materials. An informal study of the Igast object carried out by O'Keefe and Lowman led to the suggestion that museum collections of "pseudometeorites" might shed light on the tektite problem. The present authors would like to conclude with the suggestion that readers of this article with access to museum collections around the world might be able to find glassy objects which can throw some light on the nature of some of the poorly understood glassy materials mentioned in our review.

The authors are grateful to William A. Cassidy, P. E. P. Deraniyagala, L. J. D. Fernando, Kenneth Parkinson, John B. Southard and the late Robert Webster for useful correspondence and discussion. We are additionally indebted to Mr Parkinson and Mr Webster for the generous donation of their specimens. Paul Pellas was kind enough to etch the pit glass specimens for us and we are particularly indebted to Theodore E. Bunch who determined the silica content of several of the glasses. Charles W. Naeser added much to our review by his active interest in the subject and his determination of the fission-track ages of several of the less well-known glasses. We are very grateful to him for his work and for permission to use his results freely. We thank Ruth L. Saul for a meticulous job of proof-reading and editing.

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PROSOPITE, AN EFFECTIVE TURQUOISE SUBSTITUTE

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INTRODUCTION

Prosopite, a calcium aluminium hydroxide fluoride, is not often thought of as a gem material, inasmuch as it is an uncommon mineral, usually occurring in a light grey colour, and with no distinctive properties to give it any gemmological status.

Blue prosopite, however, has been found associated with azurite near Santa Rosa, Zacatecas, Mexico, and a preliminary report on this material was made by Liddicoat and Fryer (1974). A similar prosopite, but more greenish in colour, was discovered in 1895 in the Dugway mining district, Torvel County, Utah, and was described by Hillebrand (1899). Hillebrand's analysis indicated the presence of 0·17% Cu and the bluish-green colour of this Utah prosopite may have been due to this small amount of copper.

The intimate association of the Santa Rosa prosopite with azurite prompted a detailed chemical investigation of this material to ascertain if there was copper present which might explain the beautiful turquoise-blue colour of the material. Also, since hydroxyl and fluorine substitute mutually in many minerals, it was also desirable to examine the material in light of the possibility of the existence of a hydroxyl analogue of prosopite. The association with azurite, $Cu_3(CO_3)_2(OH)_2$, also suggested this possibility.

PHYSICAL PROPERTIES

Inasmuch as the density of prosopite ($\sim$2·88) is very close to the higher limits of turquoise's variable density (2·6–2·8), routine specific gravity measurements are not alone sufficient for the detection of prosopite. The density of Santa Rosa prosopite varied from 2·69 to 2·85. Prosopite ($H = 4\frac{1}{2}$) is slightly softer than turquoise ($H = 5$–6), but the difference is not too useful in gemmological testing.

Refractive index determinations, even though the gemmologist may use the distant-vision method on this opaque material, remain

TABLE I

ANALYSES OF PROSOPITE

	Ca	Al	F	H_2O	Mg	Cu	Na_2O	Y_2O_3	O	Total	Remarks
Theoretical	16·84	22·66	31·92	15·14					13·44	100·00	F:OH = 1:1
Santa Rosa, Zacatecas, Mexico**	15·37	20·65	30·16	16·78*	tr	1·39	tr	0·00			Partial analysis
Dugway district, Torvel County, Utah Hillebrand (1899)	16·85	22·74	29·95	16·12		0·17			14·34	100·17	Recalculated analysis
St. Peter's Dome, Colorado Cross & Hillebrand (1885)	17·28	22·02	33·18	13·46	0·17		0·48		13·41	100·00	Mean analysis

*Average of two analyses for H_2O of 16·88% and 16·69%.

**Partial microprobe analysis; average of four closely agreeing analyses.
Accuracy of data—±2% of the amount present.
Copper content is an approximation.

the most reliable gemmological detection method. The mean refractive index for prosopite is ~1·50, and for turquoise the mean index is ~1·62.

X-RAY DIFFRACTION

X-ray powder patterns were obtained, using Cu Kα x-radiation and Gandolfi powder cameras, of three samples of the Santa Rosa prosopite, which were all identical and also identical with those of prosopite from the Eureka Tunnel, St Peter's Dome, El Paso County, Colorado, and the Dugway, Utah, material described by Hillebrand (1899). There was no noticeable difference in the cell-edge of these prosopites, as revealed by x-ray powder patterns.

CHEMISTRY

The Santa Rosa prosopite was analysed with an ARL-SEMQ electron microprobe utilizing an operating voltage of 15kV and a sample current of 0·15 μA. Standards used included the Colorado prosopite and pachnolite described and analysed by Cross and Hillebrand (1885), and other NMNH microprobe standards of high reliability. Total water was determined using the standard Penfield method by Miss Julie Norberg, of the Chemical Laboratory, Department of Mineral Sciences, Smithsonian Institution, Washington, D.C.

A partial microprobe analysis for the Santa Rosa prosopite is given in Table I, together with analyses of the bluish-green Utah prosopite, and the Colorado prosopite used as a standard in this work. The Santa Rosa analysis is an average of four closely agreeing analyses.

The Santa Rosa material is lower in calcium than the other cited analyses, and higher in total H_2O. The anticipated low fluorine content of this prosopite was not confirmed, and the mineral has a "normal" amount of fluorine. Copper was present in small amounts and the given figure of 1·39% CuO is an approximation. The copper may be responsible for the coloration of the material. Yttrium, previously noted as a possible constituent, is absent.

In summary, blue prosopite from Santa Rosa is an effective turquoise substitute and a very attractive, uniformly coloured gem material. No significant compositional variations were observed, and the material appears to be a rather normal prosopite. The original designation of the name prosopite was from the Greek for "mask" in allusion to its deceptive character. Although its use as a turquoise substitute could not have been foreseen, the name is still quite fully appropriate!

ACKNOWLEDGEMENTS

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THE "BLACK PEARL" OF GUYANA

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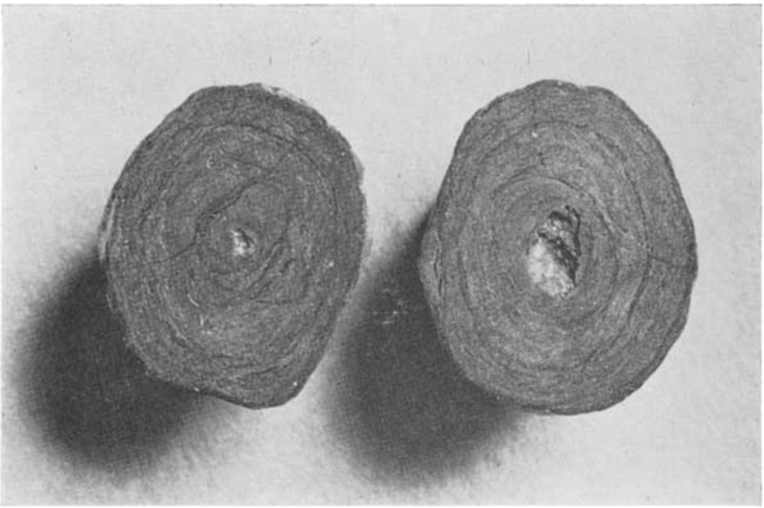
DURING 1973 the author was privileged to be asked to set up a lapidary workshop in South America and train a substantial number of students in Georgetown, Guyana, under a British Government Technical Assistance project. During the field surveys for the collection of suitable rough specimens for cutting and polishing, a number of interesting new materials were brought to light.

One of these was the "Black Pearl of Guyana." The origin of the name has not been discovered, but it is reported that when the first European explorers came to Guyana they were met by Amerindians wearing black stones around their necks. The Indians believed that each stone had an individual shape which contained its own spirit. Thus a stone with the shape of a bird contained the spirit and power of a bird—a stone the shape of a reptile contained the spirit, wisdom and power of a reptile—the stone which resembled the male genitalia possessed the power of bestowing virility on the one who was fortunate enough to possess such a stone!

One of the areas in which these stones are found is Aranka, one of the richest of the old gold-fields of the former British Guiana, and for this reason it was selected in 1963 for a copper—lead—zinc prospecting programme. Some fifty square miles were covered by the preliminary sediment-sampling programme, in the course of which a few rounded pieces of "Black Pearl" were picked up in the concentrates of Consolation Creek, a branch of the Aranka River, some four miles from its junction with the Cuyuni River.

Aranka may be reached from Bartica by a powered boat in about three to four days, but on our visit we used a small amphibious aircraft and then cut our way into the jungle for about two to three miles. At this point and as far as Consolation Creek to the north, rounded nodules of "Black Pearl" (2 mm—20 mm) are found embedded in a light yellowish clay along with subangular quartz pebbles. These "pearls" are more abundant on the gently sloping banks of the creeks but are more concentrated at the heads of the smaller creeks. It would appear that these nodules are only found to a depth of some fourteen inches from the surface, although some large fragments of quartz partly encrusted with limonite were found at a lower level. The method of extraction is to dig out the yellowish clay containing the "pearls" and place it on a set of Brazilian sieves and wash out the clay. My companion, S. W. Nerine, and I found the extraction and washing comparatively easy, but carrying all the raw material back to the aircraft seemed far more exhausting, as we had to surmount a number of natural hazards in the jungle.

Polished sections (Fig. 1), for which I am indebted to E. A. Jobbins, of the Institute of Geological Sciences, reveal concentric bands of limonite around a nucleus of clayey material. It has been suggested that these concretionary nodules of limonite (or more precisely goethite FeO(OH)) are formed as a result of changes of the water table during the heavy rainy seasons and shrinkage cracks are also prominent. When this material was tested, it was found that the hardness varied between 5 and 6 according to the composition of the nucleus. Likewise the specific gravity was found to vary between 2·64 and 3·52; the polished surface appeared to be a very dark brown (Fig. 2), but on scratching, the streak was orange-yellow.



Institute of Geological Sciences Photo.

Fig. 1. Sections of "Black Pearl" concretions showing concentric layered structure and hollow centres originally filled with clayey material.

Institute of Geological Sciences Photo.

FIG. 2. "Black Pearls of Guyana" showing 'raw' concretions and partly polished, polished and sectioned examples.

Thus we have a new material that should give our more *avant-garde* jewellery designers a fresh source of inspiration. Although not a true black pearl, of course, it appears an attractive lustrous black when polished, but the difficulty of obtaining good specimens means that this material is not likely to become plentiful for some time.

When "Black Pearls" were first discovered, a few were polished and the resulting "pearls" with their black lustre looked so attractive that it was suggested to the Prime Minister of Guyana, who was about to embark on a tour of the East African countries, that some should be mounted on pendants, ear-rings, tie clips etc. and presented to the heads of the African countries he visited. After this a small commercial enterprise was set up to supply items of jewellery for sale in Georgetown.

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Gemmological Abstracts

Akizuki (M.). *Gemstones with optical effect: pt. 2.* Journal of the Gemmological Society of Japan, 1976, 3, 1, 3–13. (In Japanese).

The phenomenon of schiller in feldspar is examined and attributed to the dispersion of light from the lamellar texture. Where the dispersion is strong the colour is reddish and where it is weak the colour is more inclined to blue. Electron micrography has been used to examine thin plates of moonstone. M.O'D.

Andersen (H.). *A study of Gilson synthetic lapis lazuli.* Lapidary Journal, 1976, 30, 1, 412–413.

The colour is very dark blue and close to that of the best quality natural material and the supposed pyrite inclusions may be scratched with a needle. The S.G. at 2·38 is closer to that of sodalite and an x-ray diffraction test showed the presence of a quantity of amorphous material. M.O'D.

Broughton (P. L.). *Robin's Buchanan thundereggs, a new Oregon mining venture.* Rocks & Min., 1975, 50, 75–79. 6 figs.

"Thunder-egg" agates occur in a rhyolitic flow that crops out along the east side of the Harney Basin near Buchanan, Harney County, Oregon. The specimens usually weigh 1–80 lbs, although some weigh several hundred pounds. Hollow specimens are lined with quartz crystals. Those which are solid are filled with agate (black, blue, white, brown) and opal (yellow to blue) in banded, swirl, and brecciated patterns. Cinnabar and manganese oxide stains are in some of the specimens. The site is described in detail. R.S.M.

Cassedanne (J. P.) and (J. O.). *Quelques gîtes d'améthyste à l'ouest de Vitoria da Conquista (Brésil).* (Some sources of amethyst to the west of Vitoria da Conquista, Brazil.) Revue de Gemmologie, 1976, 47, 6–9.

The area described lies in the state of Bahia and contains the mines Fazenda Joanina, Coruja, Baixinha and Montezuma. Typical crystals from these mines are illustrated; in general those from Montezuma make the best gems, most production from the other mines being pale in colour. M.O'D.

Chermette (A.). *L'améthyste d'Auvergne.* (Amethyst from Auvergne.) Revue de Gemmologie, 1976, 47, 2–5.

Amethyst from this region has been known since Roman times, although production only got under way in 1860–70. The area in question lies in the south of the Département of Puy-de-Dôme and forms part of the Livradois mountains. These are granitic formations in which the amethyst veins may attain several metres in length. The colour is normally inhomogeneous and is best in small stones. M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems and Gemology, 1975, XV, 3, 89–94. 13 illus.

Flux-grown synthetic rubies cut in Thailand are described. A quench-crackled Verneuil synthetic ruby with a heavily scratched pavilion looked natural. Another showing curved striae running "in opposite directions from the centre of the stone" is described but not clearly illustrated. Bubble-like negative crystals in a natural sapphire are illustrated; healed crack feathers in the same stone confirm it as natural beyond doubt. A light brownish-orange gem with R.I. 1·755–1·763 proved to be a low reading (!) synthetic corundum; while a melon-cut (ribbed oval cabochon) "chalcedony" proved to be a Ceylon sapphire. Green enamel baked onto pale green beryl crystals is reported sold as "uncut emerald". A sky-blue YAG with a cobalt-like spectrum is reported with the comment that few coloured YAGs are seen. Cat's-eye and faceted vanadium green kornerupine from Kenya and a brown kornerupine cat's-eye from Ceylon are reported. Prosopite resembling turquoise is described with R.I. 1·51, S.G. 2·65 and no absorption spectrum. It appears to be absorbant since it became mottled during testing. A suspect deep red "cuprite" proved to be an almandite (almandine) garnet which had been sputtered with a metallic coating. R.K.M.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York* Gems and Gemology, XV, 4, 123–127. 12 illus.

Diamonds with interesting inclusions are again described. One with an "insect-like" cloud; another with two included octahedra, one with trigons to be seen on its faces; a third with green (chrome enstatite or diopside) and brown (garnet) crystals in the same stone. Yet another diamond was found to have seventeen laser holes (drilled to reduce the effect of natural inclusions)—scarcely worth the expense, since in addition to the multiple reflections of the natural inclusions the stone now has 17 white drill holes to reflect around it. A large blue diamond proved to be non-conductive and had a Cape spectrum. It was a painted stone. Gadolinium gallium oxide (the garnet-structured synthetic GGG) is said to be perhaps the most convincing diamond imitation yet marketed. Although brownish in colour and inclined to darken under UV exposure, this is already appearing fraudulently. An instance where a setter damaged a GGG in the belief it was diamond and capable of withstanding heavy pressure is cited and illustrated. Hexagonal colour patches and porosity in Gilson synthetic opal are mentioned with the comment that the porosity would render the material unsuitable for use in jewellery. The writer recognizes that this fault may be confined to one particular run or batch of stones. Flux-grown rubies were found which looked very natural but showed the characteristic seed crystal and bluish separation layer on closer examination. Colour generally was dark red and oversaturated. One instance of apparent fraudulent use is cited. (The stone was in "an old platinum lady's" ring; which conjures up an amusing picture!) R.K.M.

DUNN (P.J.). *On gem orthopyroxenes.* Gems and Gemology, 1975, XV, 4, 118–122.

An investigation of stones sold as "hypersthene" establishes that this gem is more correctly named bronzite. Their relationship to the enstatite-hypersthene isomorphous group is discussed in detail. R.K.M.

EULITZ (W. R.). *The variable effects of faceted gemstones.* Gems and Gemology, XV, 4, 98–112. 9 diagrams.

In some ways a sequel to Harding's paper in the previous issue, this examines the theory and facts behind the complex matters of brilliance, reflection and dispersion in a multifacet gem exhaustively and in depth. Diagrams are complex and lack clarity for the less erudite reader. The usefulness of this dissertation to either the ordinary cutter or gemmologist is questionable. R.K.M.

FESQ (H. W.), BIDDY (D. M.), ERASMUS (C. S.), KABLE (E. J. D.) and SELLSCHOP (J. P. F.). *A comparative trace element study of diamonds from Premier, Finsch and Jagersfontein mines, South Africa.* Physics and Chemistry of the Earth, 1975, 9, 817–836. 7 figs.

Neutron activation studies of the trace elements in 1500 diamonds from these three kimberlite sources provide evidence for the presence of sub-microscopic inclusions of a quenched or temperature-re-equilibrated melt from which these diamonds crystallized. These micro-inclusions of parental magma contain variable amounts of H_2O-CO_2-rich fluids and Fe-Ni-Cu-Co sulphides in addition to a major silicate phase which is relatively constant in composition irrespective of the source of the diamonds and the age of emplacement of their host kimberlite. R.A.H.

HARDING (B. L.). *Faceting limits.* Gems and Gemology, 1975, XV, 3, 78–87.

An exhaustive and complex attempt to define optimum angles and proportions for gem faceting and to grade other angles according to their effectiveness. The text is backed up by 24 graphs of some complexity. R.K.M.

HARRIS (J. W.), HAWTHORNE (J. B. X.), OOSTERVELD (M. M.) and WEHMEYER (E.). *A classification scheme for diamond and a comparative study of South African diamond characteristics.* Physics and Chemistry of the Earth, 1975, 9, 765–783. 5 figs.

A diamond classification system based on the physical features of uncut diamond as a function of size is described; crystal form, crystal angularity, and crystal regularity determine the major divisions, but transparency, colour, number of inclusions, and surface features allow further subdivision. The system has been used to define uniquely samples of diamonds from three kimberlite diatremes, Premier, Finsch, and Koffyfontein, and an alluvial source, Dreyers Pan, based on a study of over 68000 crystals. For the kimberlite sources, variations in crystal shape versus size are considered in terms of a primary crystal population of octahedra and twinned crystals (macles) subsequently altered by secondary processes in the kimberlite magma. Variations in colour are discussed in terms of aggregation of nitrogen into platelets in the crystal lattice as the diamond grew. Characteristic features of the Dreyers Pan alluvial diamonds give indications of the nature of the original source from which these diamonds were derived. R.A.H.

Hirose (M.). *Early stage of Verneuil method.* Journal of the Gemmological Society of Japan, 1976, 3, 1, 17–24. (In Japanese).

The flame-fusion method perfected by Verneuil is traced through its applications in Europe, the U.S.A. and Japan. Plants in the U.S.A. are reported to have virtually ceased production. M.O'D.

Hurlbut (C. S.). *A device for obtaining interference figures for gemstones.* Gems and Gemology, 1975, XV, 3, 66–71. 5 illus.

Describes a simple "crystal orienter" which allows rotation of a cut gem about two axes mutually at right angles and discusses its use with convergent polarized light to obtain interference figures. R.K.M.

Jensen (D. E.). *Minerals and gem materials from New York State.* Lapidary Journal, 1976, 30, 1, 82–94. Illus. in colour.

Reviewed are Herkimer diamonds (rock crystal), fluorite, rose quartz, celestine, diopside from Dekalb, and a chatoyant labradorite. M.O'D.

Khorassani (A.) and Abedini (M.). *A new study of turquoise from Iran.* Min. Mag., 1976, 40, 640–642. 1 fig.

Four new chemical analyses are given for sky-blue and apple-green turquoise from the classical localities of Nishapur and Damghan, north-east Iran. The finest sky blue turquoise is lowest in iron. DTA results are given and IR spectra are figured for unheated material and for material after heating to 400 and 800°C. The latter sample gave the x-ray pattern of phosphocristobalite.

R.A.H.

Liddicoat (R. T.). *Developments and highlights at GIA's Lab in Los Angeles.* Gems and Gemology, 1975, XV, 3, 72–77. 17 illus.

A brown cyclotron-treated diamond looked natural, but sharp colour zones showed that it had been treated unusually from one side only with light-weight particles which had penetrated only fractionally. An attractively coloured emerald showed sharp zoning with zig-zag margins to colourless areas visible from the pavilion direction. An extraordinary "ravelled thread" cloud inclusion in topaz is illustrated without giving colour of the stone. A faceted semi-transparent grey jadeite, a carved marble "sword" or knife and a moldavite are briefly described and illustrated. Rhombohedrally oriented two-phase channels seen in a natural amethyst are likened to inclusions seen in flux-grown synthetic material (without indicating which synthetic). White "cottony" inclusions outlined a Maltese Cross shape in a dark green nuclear treated diamond. A white acicular inclusion sprouting from a square cluster of sugary inclusions in a colourless diamond is described and illustrated (no magnification quoted). A dark brown baroque "gem" proved to be limonite. R.K.M.

Liddicoat (R. T.). *Developments and highlights at GIA's Lab in Los Angeles.* Gems and Gemology, 1975, XV, 4, 113–117. 11 illus.

A somewhat gruesome testing of blue tesserae overlaid on the front half of a human skull showed them to be plastic (type?). A "two-phase" inclusion in diamond (liquid with bubble) was shown to be a natural cavity which was open to the surface of the stone in which liquid had become trapped fortuitously. A needle- or graver-like inclusion and another shaped like a horse's head were also seen in diamonds and illustrated. Opal cemented to irregular surfaced iron-stone to simulate boulder opal is also depicted. Heavily banded and speckled grey-green material used in a carving of a horse and foal looked like aventurine or quartzite but proved to be nephrite. R.K.M.

MACFALL (R. P.). *Wyoming jade.* Lapidary Journal, 1976, 30, 1, 182–193.

A history of the discovery and exploitation of the various Wyoming jade fields. All the occurrences are of nephrite, though unconfirmed reports suggest that jadeite might be available in one or two places. Most of the nephrite originated in the Granite Mountains area. The best colours are an apple green and a black, though most of the material recovered is a darker olive-green. A bibliography concludes the article. M.O'D.

MEYER (H. O. A.) and SVISERO (D. P.). *Mineral inclusions in Brazilian diamonds.* Physics and Chemistry of the Earth, 1975, 9, 785–795. 3 figs.

Microprobe analyses are reported for olivine (5), enstatite (5), garnet (8), rutile (2), ilmenite (3), zircon (1), and pyrrhotite (2) found as inclusions in diamonds from several localities in Brazil; this is the first record of ilmenite and zircon in natural diamond. The ilmenite differs from that of most kimberlites in that it contains no appreciable Mg. R.A.H.

NASSAU (K.). *Synthetic emerald: the confusing history and the current technologies. Part 1.* Lapidary Journal, 1976, 30, 1, 196–202.

In the past there has been confusion between the flux growth and the hydrothermal methods of growing synthetic emeralds. A number of early products, once ascribed to the hydrothermal method, are in fact flux-growth pieces. Those emeralds made by Nacken are an example; examination of the specimens and of the literature proves that his emeralds are made with a lithium molybdate or potassium vanadate flux and that the lack of indications of water in the infrared spectrum shows their true origin. Much of the confusion springs from a misreading of a post-war intelligence report dealing with the German crystal growth industry. A table summarizes the various growth methods and the workers concerned, and there is a bibliography. The article will be continued in a later issue. M.O'D.

POIROT (J.-P.). *Amblygonite ou montebrasite?* (Amblygonite or montebrasite?). Revue de Gemmologie, 1976, 40, 12–13.

A faceted stone of about 5 ct was submitted to the Paris laboratory for identification. The following features were observed: R.I. n_m 1·625; n_p 1·615–1·618; n_o 1·642–1·645: D.R. 0·024–0·030. Biaxial positive. Dichroism in two shades of yellow; no perceptible absorption spectrum; no fluorescence under either form of ultraviolet light, but a slight greenish-blue fluorescence under x-rays. S.G. 3·0. H. 5½–6. Two-phase inclusions and indications of perfect cleavage could be seen. These constants agree with those published for amblygonite. However, montebrasite from Creuse, France, with similar constants, is biaxial negative. Tables give relative constants for amblygonite from Utö, Sweden, montebrasite from Karibib, South Africa, and montebrasite from Kimito, Finland. Optic axial angle alters with change in hydroxyl content. M.O'D.

Prinz (M.), Manson (D. V.), Hlava (P. F.) and Keil (K.). *Inclusions in diamonds: garnet lherzolite and eclogite assemblages.* Physics and Chemistry of the Earth, 1975, 9, 797–815. 2 figs.

Inclusions from 29 diamonds, mainly African, were studied with the aid of electron microprobe analyses of garnet (15), calcic pyroxene (11), Ca-poor pyroxene (4), olivine (6), magnetite (6), rutile (2), chromite, kyanite, hornblende, actinolite, phlogopite, muscovite, sanidine, pentlandite, and chalcopyrite. Those interpreted as syngenetic with diamond (e.g. garnet, pyroxene, olivine) frequently have crystal faces related to the diamond rather than to their own structure and are termed xenohedral. Ten diamonds contain minerals comparable to those in garnet lherzolite assemblages and 15 diamonds have minerals comparable to those in eclogites enclosed in kimberlites. In the garnet lherzolite suite, subcalcic diopside assemblages may have formed in the sheared lherzolite zone at 1200–1400°C, and re-equilibrated in the granular lherzolite zone at 1000°C, of the upper mantle. Three of the clinopyroxene inclusions analysed are omphacite unusually rich in K_2O (0·62–0·87%). The presence of kyanite is the first record of this eclogite mineral in diamond. R.A.H.

Ziegler (M.). *Sunstones—out where the desert sparkles.* Rocks & Min., 1975, 50, 59.

Clear to pink and green plagioclase phenocrysts ("sunstone") occur in lava north of Plush, Oregon. These shiny crystals, less than an inch across, are used as gems. R.S.M.

BOOK REVIEWS

Accord (W. J. and J. P.). *Main Trails to Maine minerals.* Revised. Published from RFD 2, Litchfield, Maine, U.S.A. Undated and unpaginated. Price on application.

A typewritten guide with freehand sketches of some of the more important Maine mineral collecting areas. M.O'D.

Bond (W. L.). *Crystal technology.* John Wiley & Sons, New York, 1976. pp. xi, 342. Price on application.

Although this book is intended to show how to cut plates from crystals for electric and electronic use, there is a large amount of information on allied topics such as crystal growth and symmetry. Particularly useful are the sections on etching and polarization of light. M.O'D.

ELWELL (D.) and SCHEEL (H.-J.). *Crystal growth from high-temperature solutions.* Academic Press, London, 1975. pp. xi, 634. £19·80.

This is altogether an exceptional book. No previous work has brought together so large an amount of information on crystal growth theory and techniques and there is in fact no monograph solely devoted to the growth of crystals from molten salt and metallic solutions. Each individual chapter has its own very extensive bibliography, and there is a general index. Although a certain acquaintance with crystal growth concepts is assumed, there is no reason why the educated gemmologist should not attempt this book. Those engaged on actual growth will find complete reviews of experimental techniques and those dealing with synthetic gemstones will find (at last) correct versions of the apparatus and methods of flux growth so frequently and inadequately covered by the average gemmology textbook. Although some previous knowledge is assumed, this does not need to be exhaustive, since such basic topics as dislocations are mentioned and illustrated. Especially valuable is the chapter on characterization (the full description of a material based on the widest possible variety of appraisal techniques). These include chemical analysis, coulometry, polarography, optical emission spectrography, atomic absorption spectrometry, x-ray fluorescence analysis and electron probe microanalysis. Each of these methods is briefly described. Diagrams illustrating theoretical points and growth apparatus are to be found in profusion and the photographs are of very high quality. The final chapter lists all the materials so far known to have been grown from high-temperature solutions with references to the literature in each case. Earlier tabulations by Laurent (1969), Wanklyn (1974) and Wilke (1973) are included. M.O'D.

FARMER (V. C.), ed. *The infrared spectra of minerals.* Mineralogical Society, London, 1974. pp. x, 539. Price to non-members of the Society, £16·00.

The first chapters of this large and important book describe the theoretical aspects and instrumentation of infrared and Raman spectroscopy. They are followed by chapters covering different mineral groups in which are described the various effects observable in the infrared range. Later chapters include such topics as cements and glasses. Each chapter includes its own bibliography and there is cross-referencing between chapters. One of the most important features of infrared spectroscopy is its ability to reveal the presence of water and this subject may be studied exhaustively here. Approximately 100 pages are devoted to the silicates and there are interesting points made on the presence of water in beryl and cordierite. There is an adequate index; the binding is a little flimsy for so large a book and one could wish that it had been taped to the text. M.O'D.

PATCH (Susanne Steinem). *Blue mystery: the story of the Hope diamond.* Smithsonian Institution Press, Washington, D.C., 1976. pp. 64. Illustrated in black-and-white and in colour. Price on application.

An excellent short guide which explodes some of the less reputable stories about this celebrated stone and gives as much as is known about its provenance, which is well worked out. The stone was tested free from its setting in November 1975, when it was found to weigh 45·52 ct and to phosphoresce red after illumination with ultraviolet radiation of less than 3,500 Å. The colour is described as dark or steel blue, and this comes over well in the photograph. M.O'D.

PSCHICHHOLZ (D.). *Schedule of ornamental and gem stones.* Rühle-Diebener-Verlag, Stuttgart, 1976. pp. 30. Price on application.

This handy book consists largely of identification tables in which 14 different properties are enumerated. Although the tables are in German the introductory matter is in English; absorption bands and lines are quoted in nm (according to the now standard practice) and the whole arrangement is in ascending order of refractive index. At the end are coloured drawings of the commoner absorption spectra, in which that of high zircon does not show all the possible regions of absorption, although, in fairness, sufficient of them to identify the stone. One or two illustrations of the absorption spectra of the rare-earth-doped synthetics would be a useful addition to later editions, information for which is solicited and for which application cards are included. There is a short bibliography. Altogether an excellent production. M.O'D.

SHEFTAL' (N. N.) and GIVARGIZOV (E. I.). *Growth of crystals: vol. 9.* Consultants Bureau, New York and London, 1975. pp. x, 329. Illustrated in black-and-white. £18·55.

Although published in an English translation last year, this volume of Growth of Crystals represents the proceedings of the E. S. Fedorov All-Union Symposium on Crystal Growth held in May 1969, so that some of the papers, although revised by the editors in 1972, may be somewhat out-of-date. None the less, many of them contain basic information for the time, which is now lost in more recent developments or submerged in chapter bibliographies in Russian monographs. Papers are grouped into sections covering hydrothermal growth, growth from solution, growth from molten solutions, growth from melts, growth from vapour, and theory of crystal growth. Each chapter includes a short bibliography in which most but not all of the works cited are in Russian. Most papers are short and deal with specific aspects of crystal growth. Of some interest is the growth of scheelite-group tungstate and molybdate single crystals from molten solutions; these crystals cannot easily be grown from pure melts, since there are difficulties in association with the need to maintain high temperatures; nor can they easily be made hydrothermally, since the vessel needs to be thermally stable and uncorroded. Crystals grown at atmospheric pressures and quite low temperatures have been successfully synthesized from solution, making use of temperature difference methods. A large number of dopants can be accepted by the crystals but need to be introduced as chlorides rather than as oxides. Beta-spodumene has been made by crystallization from fluxes in platinum crucibles by programmed temperature reductions; using seeds, crystals up to 15 mm in length were obtained during the manufacture of beta-eucryptite and up to 6 mm for beta-spodumene. The latter was grown in lithium vanadate, spectral analysis showing that 0·2–0·3 wt% vanadium had entered the crystal; only 0·01 wt% Fe^{3+} was accepted and the authors hazard that the presence of a relatively large amount of vanadium hindered acceptance.

The topics quoted above illustrate the range contained in this excellent book; other volumes in the series are still in print. M.O'D.

ASSOCIATION NOTICES

SIR FRANK CLARINGBULL

Sir Frank Claringbull, President of the Association, has recently retired as Director of the British Museum (Natural History), a position which he had held since December, 1968.

ACTIVITIES BY FELLOWS

Mr Norman Harper, F.G.A., Chairman of the Council of the Association, was elected to the Management Committee of the Birmingham Assay Office at their annual meeting on 16th July, 1976.

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., a member of the Council of the Association, has been elected to the Beirat (Council) of the Deutsche Gemmologische Gesellschaft in Idar-Oberstein.

FINCH LECTURE

The Finch Lecture, an annual lecture since 1506 of the Clothworkers' Company, will be delivered this year by the Rev. S. B. Nikon Cooper, B.D., F.G.A., at St Margaret Pattens, Eastcheap, at 1.10 p.m. on Tuesday, 23rd November. The subject will be: "Precious Stones of the Bible, and their significance". Visitors will be welcome.

SECRETARY'S VISIT TO JAPAN

The Gemmological Association of All Japan celebrated its tenth anniversary in June, 1976. During its formation Mr Harry Wheeler had given a great deal of help, and he was personally invited to go to Japan as a guest. During his eight days in that country he invigilated at our own examinations at the Tokyo Centre and saw the excellent conditions available there for the practical examination.

During the visit, the Officers of the G.A. of All Japan arranged a special dinner at which Mr Wheeler was the principal guest. A silver dish engraved with the Association's Crest and Coat of Arms and bearing the inscription "Presented by the Gemmological Association of Great Britain to commemorate the 10th Anniversary of the Gemmological Association of All Japan" was given to Mr A. Yamada, Chairman of the Japanese Association. On behalf of the Association Mr Wheeler was presented with a Diamond Proportion Hand Scope and a book containing many excellent coloured illustrations of gems and jewellery. In a talk given during the visit Mr Wheeler referred to the history of gemmology and suggested that it was due to Mr Kokichi Mikimoto having produced cultured pearls that a testing laboratory was set up in London in 1925 and we were fortunate enough to have Mr B. W. Anderson appointed as the Director: that laboratory extended its work to include the testing of gemstones and considerably helped to put gemmology in the strong position in which it finds itself today.

A day visit was made to Kofu to the Yamanashi Lapidary and Gem Research Institute, followed by a tour of a local gem-carving workshop and a jewellery-making factory. Then the Yamanashi Jewellery Museum was visited, where some excellent crystal specimens were exhibited, many of them mined locally. A meeting also took place with senior local government officials who wished to know more about training facilities in the U.K.

Three days were spent on a visit to the Toba Bay area—the centre for Japanese cultured pearls. There was a first class exhibition for tourists on Mikimoto Pearl Island and the Ama girls were seen diving for pearl oysters. A special visit to the Cultured Pearl Research Institute at Kashikojima, which was most interesting, was arranged, followed by a trip in a small boat around the bay to get a close-up view of the rafts. The cages in which the treated oysters are placed before being lowered into the sea and suspended from the rafts are now made of nylon net with a metal wire framework: this construction saves a considerable amount of weight and makes for easier handling.

After leaving the Toba Bay area there was a full day sight-seeing visit to Kyoto, the ancient capital of Japan. The return train journey to Tokyo afforded a view of Lake Biwa, where freshwater cultured pearls are produced. Before leaving Tokyo a press conference was held at which most interest was shown in the CIBJO grading scales for gem diamonds and the issue of grading certificates.

A stop at Hong Kong provided the opportunity for a tour of what is claimed to be the largest diamond cutting and polishing factory in the Far East. Automatic machinery was in use for small stones and some female labour was employed for the cutting and polishing of larger stones. The last trip of the homeward journey included a stop over at Bangkok.

MEMBERS' MEETINGS

Midlands Branch

The Annual General Meeting of the Branch was held on the 9th June, 1976, at the Royal Institution of Chartered Surveyors Headquarters, Birmingham.

On the proposal of Mr M. Kirkpatrick, seconded by Mrs S. Hiscox, Rule 5 was amended and now reads as follows: "An Annual General Meeting of the Branch Members shall be held to elect a Chairman, Chairman-elect, Honorary Secretary and Committee for the year. A Chairman shall not be eligible for re-election within a period of three years after completing his term of office."

The A.G.M. was followed by a talk by Mr B. W. Anderson, B.Sc., F.G.A.

North-West Branch

A meeting of the Branch was held on 16th September, 1976, at The Royal Institute, Liverpool, when Mr A. E. Farn, F.G.A., Head of the Gem Testing Laboratory of the London Chamber of Commerce, gave a talk entitled "Jade and Jadeite".

COUNCIL MEETING

At the meeting of the Council held on Tuesday, 22nd June, 1976, at Saint Dunstan's House, the following were elected to membership:

FELLOWSHIP

Roine, Kalevi U., Jarvenpaa, Finland. D. 1975
Sanchez Garcia, Paloma, Valencia, Spain. D. 1975
Van der Heyden, Eveline L., Barcelona, Spain. D. 1975
Warren, Lois F., Sacramento, Cal., U.S.A. D. 1965

ORDINARY

Arnold, Thomas E., Memphis, Tenn., U.S.A.
Bagnato, Ugo, Milan, Italy.
Bartlett, Jennifer, Hong Kong.
Bin Ibrahim, Mamat Mukhtar, Kuala Lumpur, Malaysia.
Birch, Walter J.De-G., Port of Spain, Trinidad.
Boraston, Peter George, Kenley, Surrey.
Brenton-Coward, Richard I., Otford, nr Sevenoaks.
Campbell, S., Hong Kong.
Chou, Elizabeth, Hong Kong.
Clarke, Donald Hugh, Northcliff, Transvaal, S. Africa.
Clarke, David R., Camperdown, Natal, S. Africa.
Cox, Harold M., Ahwaz, Iran.
Danker, Joy L., Dublin, Eire.
Dennis, Jillian A., Sandown.
D'Esterno, Guek N., Repulse Bay, Hong Kong.
Fearn, Barry J., Billericay.
Flewelling, Arthur G., Arthur, Ont., Canada.
Fritsche-Haberle, Margret, Rorschach, Switzerland.
Furniss, Ronald A., Sutton-cum-Lound, Retford.
Gant, Richard D., Orpington.
Gorg, Ulrike, Idar-Oberstein, W. Germany.
Grant, William T., Salisbury, Rhodesia.
Gray, Robert I., Edinburgh.
Green, Colin R., Evington.
Green, Michael, Kuala Lumpur, Malaysia.
Hamilton, Christopher N., Edinburgh.
Harding, Bruce L., Holden, Mass., U.S.A.
Harris, Harry B., Alexandria, Va, U.S.A.
Henrick, Michael T., Bournville, Birmingham.
Hume, James N., Jacksonville, Fla, U.S.A.
Husain, Nawab S. F., Bombay, India.
Ingamells, Roy, Barnsley.
Karten, Joel, New Bedford, Mass., U.S.A.
Kim, Young C., Seoul, Korea.
Karakas, Onnik V., Willowdale, Ont., Canada.
Kodama, Katsuyoshi, Tokyo, Japan.
Krauss, Philip, Springfield, Ohio, U.S.A.
Kulanayagam, Kanthasamy, Point Pedro, Sri Lanka.
Levi, Doran, London.
Louie, Ma Paz C. G., Hong Kong.
Lowe, Sylvia J., Harrow.
McLellan, Elizabeth A. H., Hong Kong.
Masuda, Hideyo, Shizuoka-shi, Japan.
Mawji, Roshanali R. A., Tanga, Tanzania.

Meeran, Mohamed H. M., Ndola, Zambia.
Metzka, Carolyn, Davis, Cal., U.S.A.
Mohamedally, Hatim, Colombo, Sri Lanka.
Mohideen, Mohamed F., Kelaniya, Sri Lanka.
Montagu, Christopher R., Bournemouth.
Moran, Vincent P., Salisbury, Rhodesia.
Murakami, Nobuko, Fukuyama City, Hiroshima-ken, Japan.
Nak, Judy, Hong Kong.
Noble, George E., London.
Palihawadana, Jithendri, Borella, Sri Lanka.
Pomroy, Pauline M., Newbury.
Preckler, Joseph C., Ouro Preto, Brazil.
Reynolds, John P., Sherborne.
Roberts, Atie, Cwmbran, Gwent.
Robertson, Margaret M., Edinburgh.
Roelens, Tim, Deinze, Belgium.
Ryan, Thomas G., Salisbury, Rhodesia.
Saleem, Mohamed K. M., Colombo, Sri Lanka.
Smart, Denis O., Kettering.
Symons, Marion H., Hong Kong.
Tan, Beng Lew, Singapore.
Tawn, Edward P., Colchester.
Trowell, Eric, Haywards Heath.
Walkingshaw, Kenneth C., Forres.
Wheeler, Eric E., Dagenham.
White, Alison R., Leeds.
Wong, Beverly G. J., Hong Kong.
Wills, Stiart S., Ayrville, Queensland, Australia.
Zandstra, Ilse, Surbiton.
Zimmermann, Michel, Paris, France.

OBITUARY

We regret to record the death of the distinguished mineralogist and gemmologist, Dr Karl Chudoba, on 14th March, 1976, in his 79th year. An appreciation of his work for gemmology will be published in a later issue of the *Journal.*

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Professor A. Chikayama, F.G.A., Gemmological Association of All Japan, for an oval cabochon green jade, weighing 7·04 ct, showing chatoyancy.

Mr B. D. Fernando, F.G.A., Sri Lanka, for first-day cover with four new postage stamps depicting a blue sapphire, ruby, cat's-eye and star sapphire.

Mr Norman Harper, F.G.A., Chairman of the Association, for a cabochon almandine garnet showing asterism, weighing 141·5 ct.

Mr R. Holt, F.G.A., London, for a large thin slice of banded agate (first piece to be cut and polished in the new workshop of R. Holt & Co.).

Mrs Jill Rutland, Dorset, for a silver dish, which had been presented to her husband, the late Dr Ernest Rutland, on his retirement as a lecturer from the Sir John Cass College, and also the Tully Medal which he had received in 1947.

GEMMOLOGICAL INSTITUTE OF INDIA

The Gemmological Institute of India, founded in 1971 as a trust for the promotion and encouragement of study and research in gemmology, established in that year the first gem-testing laboratory in India, which now tests on average 1,200 stones a year. It has also built up the nucleus of a museum, where rough gemstones of various species are displayed, and formed a library in which foreign and Indian periodicals as well as authoritative textbooks are available and freely made use of by the trade. The Institute has now decided to provide short (three months) courses in gemmology to give theoretical knowledge to those who have acquired practical experience of gemstones in the trade. The training is designed to cover the origin, forms, characteristics and special properties of gemstones and the use of modern appliances and equipment for their identification. Applications for admission to the courses should be made to the Secretary, Gemmological Institute of India, 29/30 Gurukul Chambers, 187/189 Mumbadevi Road, Bombay-2.

ASSOCIATION TIE

An Association tie is available for Fellows. The tie is dark blue and bears the crest of the Association in golden yellow.

The price including postage is:

U.K.	£2·25
Europe	£2·50
Other countries (air mail)	£3·50

Please send money with order and also state year diploma was awarded.

ERRATUM

In line 12 of page 157 *ante*, Mr H. B. Crawford was wrongly described as F.G.A.

Vol. XV
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CONTENTS

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