Gems & Gemology

VOLUME XVII WINTER 1981

A quarterly journal of the Gemological Institute of America

WINTER 1981
Volume 17 Number 4

Gems & Gemology

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ISSN 0016-62X

Gems & Gemology

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MANUSCRIPT SUBMISSIONS

Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors for preparing manuscripts in the Summer 1981 issue of the journal or contact the Managing Editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

Gems & Gemology is published quarterly by the Gemological Institute of America, a nonprofit educational organization for the jewelry industry, 1660 Stewart St., Santa Monica, CA 90404.

THE NEW GEMS & GEMOLOGY IS ONE YEAR OLD

RICHARD T. LIDDICOAT, Jr. Editor-in-Chief

With this issue *Gems & Gemology,* now in its 48th year as the quarterly journal of the Gemological Institute of America, completes its first year in the new size and format. The response to the new look has been very exciting. Not only has the journal enjoyed an almost 500% increase in subscribers, but the quality and quantity of the papers and other items submitted have grown significantly as well. Much of the credit for the transformation in appearance and quality of production goes to our managing editor, Alice Keller. The members of our Editorial Review Board also have proved invaluable in ensuring the accuracy and usefulness of the articles published. In addition to those individuals listed on the masthead, Brian Mason (of the National Museum of Natural History), Marty Prinz (of the American Museum of Natural History), Ed Wilson (of the Los Angeles County Museum of Natural History), and Wendell Wilson (of the *Mineralogical Record*) were kind enough to provide outside reviews on specific papers. The Gemological Abstracts, Gem Trade Lab Notes, and other regular features of the journal have benefited both from the strong editorial leadership of the section editors and from the contributions of their editorial staffs, most of whom also carry full-time responsibilities at GIA or in the GIA Gem Trade Laboratory, Inc.

Of singular importance to the success of any journal, however, are the authors of the articles that form the core of the publication. We have been fortunate to receive the contributions of established and new authors alike. We thank these authors for their support and continue to welcome contributions from the international gemological community. As the journal of the Gemological Institute of America, *Gems & Gemology* invites articles in jewelry manufacturing, retailing, and other aspects of the field in addition to the science of gems.

Plans are already well underway for the next four issues, with items of special value to those readers interested in jade, the latest developments in synthetic corundum, and the cultivation of the new 3/4 cultured blister pearls, among many other topics. We feel confident in promising a second year that will be even more exciting, more informative, and more beautiful than the first.

LAPIS-LAZULI FROM SAR-E-SANG, BADAKHSHAN, AFGHANISTAN

By Jean Wyart, Pierre Bariand, and Jean Filippi
Translated by Carol Stockton

The lapis-lazuli deposits at Sar-e-Sang in Badakhshan, Afghanistan, have provided the raw material for objects fashioned of this stone since the earliest civilizations. The mine, which lies in the Hindu-Kush mountains, is difficult to reach and, because of climatic conditions, is opened only a few months during the summer. The lapis is found in veins in which calcite and dolomite are intimately associated with silicates such as diopside, scapolite, and forsterite. Pyrite is always present; the pure blue mineral is lazurite. The color of the lapis-lazuli varies according to the amount of the various impurities contained therein. Well-formed crystals of lazurite with the dominant {110} shape are rarely found. This article examines the crystallographic properties of lapis-lazuli, the site of Sar-e-Sang and the lapis-lazuli deposits there, and offers an explanation for the genesis of the material.

ABOUT THE AUTHORS

Mr. Wyart and Mr. Bariand are associated with the Laboratoire de Minéralogie-Cristallographie, Université de Paris VI, France; Mr. Filippi is associated with the Laboratoire de Chimie, École Centrale, Paris, France.

The authors are very grateful to M. Said Hachem Mirzad and his collaborators for their help in enabling the visits to Sar-e-Sang that formed the basis of this article.

An earlier version of this article was published in French in the Revue de Géographie Physique et de Géologie Dynamique, *2. Serie, Vol. 14, No. 4, 1972, pp. 443–448.*

Lapis-lazuli is an ornamental stone (figure 1) that has been found in the artifacts of some of the oldest known civilizations. Necklaces of this material have been discovered in the neolithic tombs of Mauretania and the Caucasus. The appearance of lapis during archeological excavations in Mesopotamia marks the evolution, economically and artistically, of societies that flourished thousands of years ago in the region of Sumer.

In a well-documented work, Georgina Herrmann (1968) speculated on the possible origins of the mineral and concluded that it came from the mines of Badakhshan, in what is now Afghanistan. Mesopotomia was the commercial center for this treasured material, transformed by its artists into objects of luxury. Thus, more than 4,000 years ago, commercial relations were established between ancient Iraq and Afghanistan, more than 2500 km to the east. Importation of the blue stone was particularly important at the beginning of the 3rd Dynasty, which marked the apogee of the civilization of Ur, because of the various uses to which the material was put. In the royal cemetery of Ur, excavations revealed fantastic objects fashioned from lapis-lazuli—cylinder seals, necklaces, and statuettes of animals and persons—which testify to the high degree of sophistication attained in sculpture and gem engraving. The abundance of objects of lapis-lazuli in the tombs suggests that this blue stone already possessed a ritualistic value, much as is seen today throughout Iran and the Orient. From Iraq, lapis-lazuli was exported to Egypt during the predynastic period as well as all early dynasties. In Egypt, however, objects formed from lapis-lazuli have been found only in the tombs of the wealthiest persons. Oriental people, the Hebrews, the Babylonians, and the Assyrians also used this azure stone for ornamentation in the earliest days of their civilizations.

The word *lazurium* appeared in the sixth century. It is borrowed from the Arab *lazaward,* which was taken in

Figure 1. Three-centimeter-long talisman of lazurite with gold writing that was fashioned in Afghanistan in the 19th century. Property of the Paris School of Mines, Paris, France. Photograph ©1981 Nelly Bariand.

turn from the Persian *lajevard* and from which came the word *lazul,* then *azur.* As early as the fifth century, the mineral was introduced in Europe under the name *ultramarinum,* which became *ultramarine.* Ultramarine served as the most valuable blue pigment and was used by all the great painters until the discovery by J. B. Guimet in 1826 of a method of synthesis that allowed industry to prepare enormous quantities of blue pigment at a low price.

In fact, many lapis substitutes have appeared through the years. These include glass, synthetic spinel, dyed jasper, and the mixture of pyrite fragments with plastic rich in lapis powder. Most recently, Gilson has produced imitation lapis-lazuli—with and without pyrite—that is quite attractive.

THE LAPIS-LAZULI DEPOSITS

Apart from those in Badakhshan, a few deposits have been found and occasionally exploited in the U.S.S.R. A deposit situated in the Lake Baikal region (Hogarth, 1970) produces a stone of mediocre quality, but it is too far from Mesopotamia to have been sent there. In 1930, one Russian expedition discovered some lapis-lazuli in the mountains of the Pamir, in a region of very difficult access (Webster, 1962). This deposit has been mined primarily for phlogopite, although medium-grade lapis-lazuli has been recovered as well (Hogarth, 1970).

Little lapis has been found elsewhere in the world. Deposits are known in Chile and Burma, but the quality of these materials is at best mediocre. Lapis-lazuli is also found in San Bernardino County, California, but the original beds were only a few millimeters wide (Rogers, 1938). Thicker veins have been uncovered and the material has been marketed in the U.S. recently, but the quality is such that it is of mineralogical rather than gemological interest. The reader is referred to Sinkankas (1976) for descriptions of this and other North American lapis-lazuli deposits.

The mines of Badakhshan, therefore, are not only among the oldest in the world, but they may also be the most productive and they have historically produced most of the finest-quality material. In addition, because of their location, their mode of exploitation has changed but little over the centuries.

Lapis-lazuli is usually massive and more or less impure. Rather than a single mineral, it is a rock—a mixture of minerals—that varies greatly in composition and color (figure 2). From the physico-chemical point of view, the blue constituent is the mineral lazurite. This mineral has been the object of much study, particularly with regard to its color. To resolve the questions that have arisen, one must use a sample as homogeneous as possible, such as well-formed crystals. But such crystals are rare, because the miners look only for blocks of the blue stone to be carved

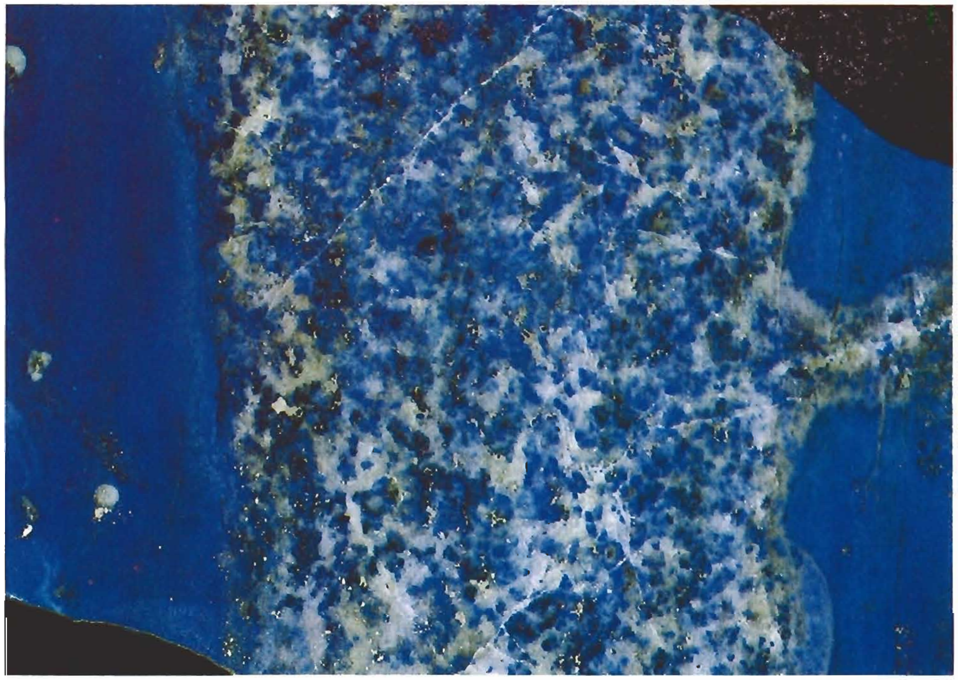

Figure 2. Lazurite slab from Sar-e-Sang, Badakhshan, Afghanistan, 14 cm. Photograph ©1981 Nelly Bariand.

and polished for jewelry or as objets d'art. It was in search of homogeneous crystals that we undertook expeditions to Badakhshan in 1964, 1967, and 1971. The results of our study of the material found are discussed below, as are the site at Sar-e-Sang, the mining methods used, and the possible origin and current economic situation of the Afghan stone.

THE CRYSTAL CHEMISTRY AND PROPERTIES OF LAZURITE

Lazurite belongs to the sodalite group, which are cubic tecto-silicates characterized by the same three-dimensional structure, with the anion $Al_6Si_6O_{24}$ as the framework motif. The unit cell is 9.0 ± 0.1 Å. The sodalite group forms a solid-solution series of which the principal end members are sodalite $(Na_8Al_6Si_6O_{24}Cl_2)$, nosean $(Na_8Al_6Si_6O_{24}SO_4)$, and haüyne $([Na,Ca]_{8-4}Al_6Si_6O_{24}[SO_4,S]_{2-1})$. Lazurite is a haüyne rich in sulfur; its ideal composition is $Na_8Al_6Si_6O_{24}S_X$, with X ranging from 1 to 4.

The atomic structure of this species was established by Jaeger (1930), and then refined by Pauling (1930), Barth (1932), Machatschki (1933 and 1934), and Saafeld (1961). The SiO_4 and AlO_4 tetrahedra are linked at their four apexes to form six rings of four tetrahedra parallel to the cube faces and eight rings of six tetrahedra parallel to the faces of the regular octahedron. This aluminosilicate structure, common to all the minerals of the group, consists of cuboctahedral frameworks ("cages") in which the large central cavities are occupied by the cations Na and Ca, and by anions such as Cl, SO_4, and S. This very open atomic structure confers on these silicates the properties of permutites (commonly called "zeolites," or compounds used as water softeners because of their ability to remove "hard" ions from water). They need only be placed in salt solutions of the cations K, Li, Rb, Cs, Ag, Tl, Mg, Ca, Sr, Ba, Zn, or Hg at 100°C for the sodium in them to be replaced by the cations named, with resultant color modification. For example, calcium or zinc replacements result in almost colorless material, while material containing lithium and thallium is very dark.

Atoms of sodium and sulfur are found in the large openings in the frameworks, and it is assumed that the atoms of sulfur move into cavities to form rather unstable radicals such as NaS_2, NaS_3, and NaS_4. The dissociation of these radicals could then liberate the active S atoms that are responsible for the coloration. Chemical analyses indicate that the greater the percentage of sulfur in the mineral, the deeper the blue. If sulfur is replaced by selenium, the color becomes blood red. Thus the blue color, which usually increases the value of the material as it becomes darker, depends above all on sulfur content as well as on the amount of calcium present.

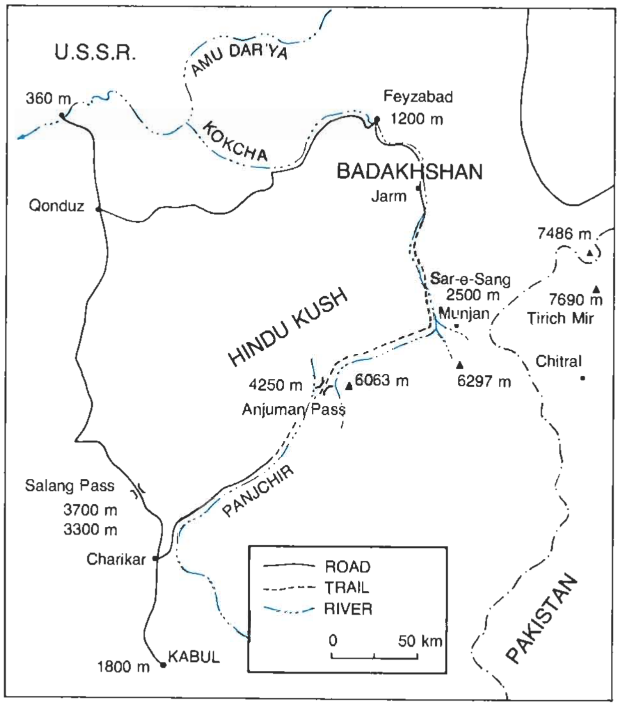

Figure 3. Map of the routes from Kabul to the lapis-lazuli deposits at Sar-e-Sang, Badakhshan, Afghanistan.

THE SITE OF SAR-E-SANG

Sar-e-Sang is located in Badakhshan, in the northeast of Afghanistan. It lies in the center of the Hindu-Kush massif, along the right bank of the Kokcha River, which cuts from north to south an anticline with summits reaching 3500 m to 5500 m. The Kokcha results from the confluence of the Anjuman and Munjan rivers, and empties into the Amu Dar'ya (the Oxus River of the ancients), which demarcates the border with the U.S.S.R. to the north.

This region in Badakhshan was mentioned in Chinese writings as early as the sixth century. From the village of Jarm, situated about 150 km north of the mines, a commercial route following the corridor of Wakhan leads to Tibet; it connects China with the valley of the Amu Dar'ya and the city of Bokhara. Thus, lapis-lazuli has been used by the Chinese since antiquity.

Marco Polo visited this region of Afghanistan in the 13th century and spoke of a "mountain where the finest azure in the world is found," although he never saw it himself. More recently, the English East India Company lieutenant John Wood (1811–1871) furnished a detailed and picturesque description of an expedition (1836–1838) to the source of the Oxus River in a book published in 1841. He was the first European to visit the mines and recounted the difficulty of access, the methods of exploitation, and the insecurity for residents and visitors alike. In 1933, French Archeologist J. Barthoux described the lapis-lazuli and "balas" rubies of the Afghan cipolins,[*] and in 1935 K. Brueckl published a study of the mines in the valleys of the Panjchir and Kokcha rivers. In recent years, several members of the French geologic mission in Afghanistan—A. F. de Lapparent, P. Bariand, and J. Blaise (1965) and P. Bordet and A. Boutière (1968)—have furnished interesting information on the region. One Russian mission of five geologists, in the course of two expeditions during the summers of 1963 and 1964, completed a detailed geologic and economic mineralogical study of the Sar-e-Sang region.

Figure 4. The small valley of Sar-e-Sang. Note the white rocks at the base of this photograph, which are the mine dumps.

Two routes connect Kabul to Sar-e-Sang (figure 3). The shorter route, from the point of view of distance, is to travel by jeep from Charikar, up the valley of the Panjchir, to Dasht-i-Rawat (around 160 km), and then to go the final 135 km to the mine on foot or by horse via Anjuman Pass (figure 4). Undoubtedly, a trail will eventually permit crossing this route entirely by jeep. Currently, the fastest route, which still takes at least four days, begins with a magnificent drive to Qonduz through Salang Pass. From this city, the traveler must follow a difficult road through Khanabad, Taloqan, Feyzabad, and Jarm that terminates

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[*] *A cipolin is a marble charged with mica, usually of the variety phlogopite and forming a transition between marbles and micas-schists, two rocks that are often associated (as defined by Kemp in C. M. Rice, 1951, pp. 75–76).*

Figure 5. The route through the Kokcha valley, 25 miles before Sar-e-Sang.

3 or 4 km beyond the village of Hazrat-Said, a distance of about 750 km from Kabul. A long journey, with horses or donkeys, is then required to climb the 40 km of narrow and rough trail that follows the gorges of the Kokcha (figure 5).

These two routes are accessible only between June and November. The climatic conditions are such that the royal mine of Sar-e-Sang is exploited at most only five months a year. The camp is located on the right bank of the Kokcha River, at an altitude of 2500 m, near the junction of the river with the stream of Sar-e-Sang. The mine workings, situated between 2700 m and 3400 m, are difficult to reach. The blocks of lapis-lazuli are brought back to the camp on the backs of men and then transported by donkey to Hazrat-Said.

DESCRIPTION OF THE DEPOSITS

The Sar-e-Sang complex consists of strongly metamorphosed rocks, with gneisses, cipolins, skarns, crystalline schists, amphibolites, veins of leucocratic granites, and dykes of pyroxenite and hornblendite which are found in enormous blocks in the streambed.

The mountain, which is nearly vertical in slope, is composed of cipolins up to 400 m thick overlying gneiss. Standing out from the white marbles of the cipolins is a gray band, about 40 m wide, consisting of skarns in which the lapis-lazuli occurs. The skarns form beds and lenses, generally 1- to 2-m—and occasionally 4-m—thick, which usually extend laterally for 20 to 100 m, rarely more than 400 m. The exploitable zones consist of calcite and dolomite associated with forsterite, diopside, and scapolite, often accompanied by phlogopite, sometimes in well-formed crystals up to 2 cm. The blue lazurite is almost always associated with pyrite.

The steep footpath that leads to the main mine (figure 6) ends at a small platform, about 2 m × 2 m, at the entrance of a vast cavern that still shows traces of black smoke from ancient mining operations and from which lead the exploited gal-

Figure 6. Access to the mine at Sar-e-Sang.

Figure 7. A block of lazurite in the mine dumps at Sar-e-Sang.

leries. The rock is very hard; to break it up, early miners used great wood fires to fracture the limestone. Now dynamite charges are used. The lenses of lapis-lazuli detached from the rock are masses of many kilograms, although they rarely exceed 100 kg. Those less than 10 kg are relatively homogeneous (figure 7). The zonal structure of the most important lenses recalls their sedimentary origins and the action of metamorphism, because the centers of the larger grains consist of a composite of plagioclase, diopside, calcite, and lazurite, which is surrounded by zones of fine, dark blue grains of lazurite, diopside, and scapolite, with a marginal zone of calcite, diopside, forsterite, and pyrite.

The blocks of rock lacking color are thrown from the platform to the dump 300 m below, in the Sar-e-Sang streambed. It is in such pieces of cipolin that one must look for well-crystallized lazurite. Single crystals may reach 5 cm in diameter (figure 8), with the dominant form being the rhombic dodecahedron {110}, sometimes accompanied by faces of {100} and {110}. A specimen of the mineral afghanite, a species of the cancrinite group, was collected from the region by P. Bariand during an earlier expedition (Bariand, Cesbron, and Giraud, 1968).

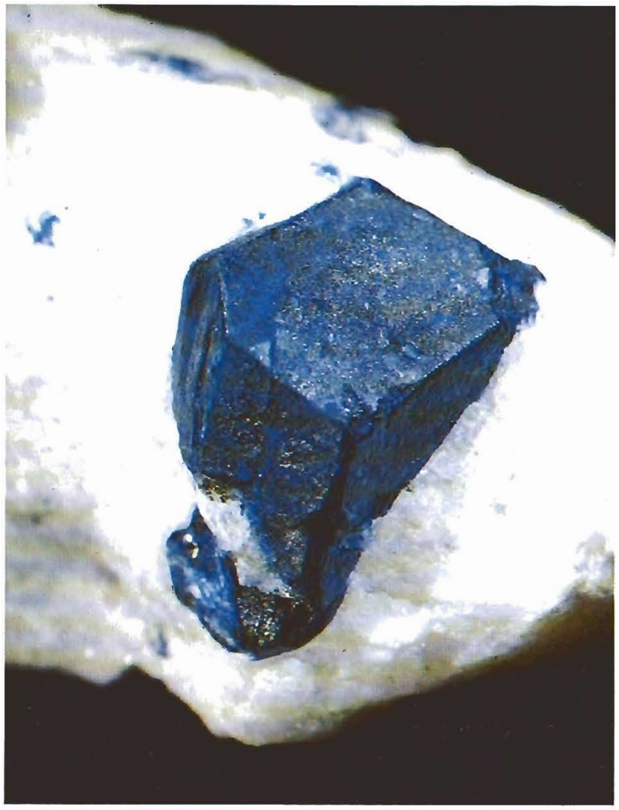
NOTES ON THE ORIGIN OF LAPIS-LAZULI

The regional petrology was described by Blaise and Cesbron in 1966. However, they relied on a detailed study made by Korzhinskij in 1947 regarding the formation of lazurite from the Pre-baikal deposits in the U.S.S.R., which present poor analogies to those of Afghanistan. The following notes are based primarily on our study of the Sar-e-Sang deposits.

The presence of almandine garnet, sillimanite, and kyanite in the schists and gneisses of Sar-e-Sang indicates a regional metamorphism involving high temperatures and pressures, a conclusion that is shared by all the geologists who have visited the region. The well-formed single crystals of lazurite, with isometric development of faces of {110}, are formed during metamorphism in a plastic environment in which fluids circulate freely. The original pelitic sediments, and thus the important bed of shale and limestone that overlies them, contained a certain amount of salt water, which with the rise in temperature and pressure during metamorphism transformed the shale into gneiss or granite (Wyart and Sabatier, 1959), and the limestone into cipolin.

Granitization liberates those solutions whose circulation is facilitated by the tectonic dislo-

Figure 8. A 5-cm lazurite crystal from Sar-e-Sang, Badakhshan, Afghanistan. Photograph ©1981 Nelly Bariand.



cations. The kaolin of the shale possesses the chemical composition $Al_4Si_4O_{10}(OH)_8$, which approaches the proportions of silica and aluminum in the minerals of the sodalite group. Solutions containing sodium chloride, which are active at relatively low temperatures (on the order of 400°C) as shown by the hydrothermal synthesis of these minerals in the laboratory, readily transform the kaolin into feldspars. However, it is only at higher temperatures that the more or less dolomitic limestones are metamorphosed into cipolins intimately associated with silicates such as diopside and forsterite. These solutions are strongly sulfurous, as is indicated by the consistent presence of pyrite and the presence, less frequently, of sulfides such as galena and molybdenite. It is the presence of sulfur that favors the crystallization of lazurite rather than sodalite, which is found only rarely in these veins. Chlorine, present in the original sediments as sodium chloride, is found in the apatite which always appears, associated with calcite.

THE COMMERCIAL EXPLOITATION OF LAPIS-LAZULI FROM SAR-E-SANG

Transport of the material from the mine at Sar-e-Sang, via Jarm and Feyzabad, to Kabul requires at least nine days. Prior to the occupation of Afghanistan by the Russians in late 1979, approximately one ton of lapis-lazuli was extracted annually. About 200 kg of this material was sold to Afghan lapidaries, and the rest was exported. Sorting by the Ministry of Mines separated the material into five categories, with the highest category priced three times that of the lowest. The first category, comprising about 2% of production, included massive blocks of deep blue color, without inclusions or fissures; the second category, or 14% of production, included smaller pieces, not more than 5 cm, with the same characteristics as the first group. These two categories were destined for jewelry. The other categories, which varied from dark blue to light blue, with veins of calcite and with varying proportions of pyrite, were used to make ornamental objects.

Reports from Afghanistan since the Russian occupation indicate that at the time of publication this mountainous area had not been taken over by the Russians and remained under the control of Afghan nationalists. However, it appears that the mines have not been worked during this period. Therefore, it is likely that current legal exports are from old stock. It should be noted that operations to smuggle the material across the border with Pakistan continue now as they have for years past.

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GEM GARNETS IN THE RED-TO-VIOLET COLOR RANGE

By D. Vincent Manson and Carol M. Stockton

The gemological classification of garnets has been thrown into question with the appearance on the market of new types of garnets that do not fit into the traditional system of description. The question of what criteria should be used to classify both old and new types of garnets is approached in this article through the study of 96 red-to-violet gem garnets. While the color of gem garnets is of paramount importance, color being both their most obvious feature as well as their principal claim to beauty, this article shows that the characteristic of color appears to have little correlation with variations in bulk (not trace) composition or physical properties. Analysis of the gemological properties, chemical composition, and CIE color coordinates of the stones studied led to the more specific definition of the widely accepted terms pyrope, almandine, *and* rhodolite *for meaningful gemological classification. This article represents the first in a series of studies aimed at developing an effective terminology for the characterization of gem garnets.*

ABOUT THE AUTHORS

Dr. Manson is director of research and Ms. Stockton is research gemologist at the Gemological Institute of America, Santa Monica, CA.

The garnet group of minerals encompasses both complex variations in chemical composition and a wide range of physical and optical properties among its members. As a result, the garnets have been subjected to various classification schemes by mineralogists and gemologists over the years. While the mineralogist usually has the instrumentation available to perform detailed chemical analyses, the gemologist is limited, for practical purposes, to a few basic tests that measure optical and physical properties of gemstones and that may or may not accurately reflect the bulk chemical composition of a complex material such as garnet. An effective gemological classification is one that enables the gemologist to employ readily available tests to reflect the differences in appearance and the chemical interrelationships that exist in a group such as garnets. For this reason, we have undertaken a review of all the gem garnets, with special attention to the needs and restrictions of the gemologist, in order to provide a viable gemological classification of this group. As the first in a series, this article looks particularly at garnets in the general hue range of red to violet (excluding those stones that are obviously orangish red), including for the most part those gem specimens whose chemical compositions consist primarily of combinations of pyrope and almandine (see figure 1). We selected this fairly familiar area in order to show that even the well-documented types of garnets still have problems that need to be addressed. In addition, this gives us an opportunity to introduce the methods of analysis that will be used throughout our ongoing study of garnets.

A representative example of a mineralogical classification of garnets is the hierarchical terminology given in Deer, Howie, and Zussman (1963), which includes group (garnet), series (pyralspite and ugrandite), and species (pyrope, almandine, etc.). Many of these terms, such as *pyralspite,* are still in use even though more recent de-

Figure 1. Examples of garnets in the red-to-violet color range used in this study.

scriptions of the compositions of garnets (Meagher, 1980) have contradicted the premises on which the terms were originally based (Winchell and Winchell, 1933). In agreement with most of the relevant literature, however, Deer, Howie, and Zussman list six species as being of major importance: pyrope, almandine, spessartine, uvarovite, grossular, and andradite. Another classification refers to these same terms as subspecies of the group garnet (Hurlbut and Switzer, 1979). To some extent, this may be due to a difference in interpretation by mineralogists of the meaning of the term *species* with regard to the members of a mineral group. Some equate species with a chemically pure end member (discussed later in this article), while for others it refers to a range of chemical variations. Hurlbut and Switzer, in fact, mention that the subspecies names are applied more loosely and cite an example in which "for convenience, gems near the end of the almandine-pyrope solid solution series are called almandine," but nowhere could we find that such a stone is specifically referred to as a member of the species almandine. Because of the influence of color on the appreciation of gemstones, an additional vital requirement of a complete gemological classification goes beyond the identification of species or bulk chemical composition to the definition of varieties. An excellent example is the invaluable distinction of ruby from pink sapphire, let alone from other corundums; all are of the same species and bulk chemical composition, but the types and quantities of trace elements present make a difference in color. Garnets do have an assortment of varietal names such as rhodolite, hessonite, and the like, but these are not rigorously defined and so lead to further confusion.

Garnets of the red-to-violet color range generally associated with the pyrope-almandine series reflect the problems associated with gem garnets in general. The importance of color in gems has led to the association by gemologists of very particular colors with the various types of garnets: any deep, pure red garnet is usually regarded as pyrope, any violetish-red garnet has been automatically assumed to be rhodolite, and so on. Such assumptions are not necessarily valid. What is a pyrope, an almandine, a rhodolite? What criteria enable us to delimit the ranges of their properties? How well do the commonly employed gemological tests (refractive index, specific gravity, and absorption spectrum) enable us to define and identify species and varieties? To what extent is the chemical composition of a garnet relevant to the gemologist? Are there natural breaks in the chemical continuum that we might use to advantage in defining these gem garnet species and varieties? What do we do with garnets that do not fit the currently defined categories? To what extent do we need definable nomenclature and how rigorous should the classifications be? How should color enter into these definitions?

THE GEMOLOGICAL PROPERTIES OF THE PYROPE-ALMANDINE SERIES

According to traditional gemological usage, this series includes three loosely defined types of garnets: pyrope, almandine, and rhodolite. Pyrope has been characterized as a dark to very dark pure red magnesium-aluminum garnet with a refractive index of approximately 1.74, a specific gravity of about 3.78, and no characteristic spectrum; almandine is described as a medium to very dark brownish-red iron-aluminum garnet with a refractive index around 1.79, a specific gravity of about 4.05, and a characteristic spectrum with bands at 4360, 4700, 5050, 5270, 5760, and 6180 Å. Rhodolite lies between pyrope and almandine and has been less well characterized. The original description by Hidden and Pratt (1898) of rhodolite from North Carolina states that "the predominant color is a pale rosy tint inclining to purple . . ." and that "the ratio of MgO to FeO is almost exactly 2:1. . . ." The refractive index and specific gravity are, respectively, about 1.76 and 3.84, but their upper and lower limits are in question. The spectrum is essentially the same as that for almandine. It should be noted that there are other pyrope-almandine garnets in the same range of chemical, optical, and physical properties as rhodolite, but they do not fit the color description for this type of garnet.

THE CHEMISTRY OF GARNETS

A garnet can be composed of four or more chemical elements, represented by the formula $X_3Y_2Z_3O_{12}$, where X, Y, and Z each signifies one or more elements. X may include one or more of the elements calcium (Ca), manganese (Mn), magnesium (Mg), or iron (Fe); Y may be aluminum (Al), iron, titanium (Ti), vanadium (V), and/or chromium (Cr); and Z may be silicon (Si), iron, titanium, and/or aluminum. Those types of garnets that contain only the minimum four elements (i.e., one element for each of X, Y, and Z, plus oxygen) are referred to as "end members."

Theoretically, then, there is a possible total of 60 end members, involving the above-mentioned elements, for the garnet group. Some of these, however, may not exist for chemical or geologic reasons that we will not go into here. Others are so rare as to be insignificant to the gemologist. In this study, nine are examined, of which only five are abundant among gem garnets (table 1). Individual garnets are composed of two or more of these end members; stones that consist of one end member only are exceedingly rare in nature, although occasional specimens do exist in which a single end member is responsible for more than 95% of the composition.

There are two essential reasons for using the concept of end members to discuss the composition of individual garnets. First, it provides a practical procedure for correlating the relationships between physical properties and chemical composition. Second, it enables us to relate results obtained in this study with similar chemical analyses that have been published previously. Our calculation of end members is based on the method formulated by Rickwood (1968), but we have changed the sequence of calculation slightly to better account for the nature of gem garnets, in particular by using as much of the Ti and the Fe^{3+} as possible. The macroanalytical techniques used for most of the analyses in Rickwood's article, principally wet chemical analysis, together with the fact that the non-gem garnets generally employed in prior studies were usually more included than the gem-quality garnets used here, required allowance for the presence of rutile, magnetite, and ilmenite as impurities. Such inclusions did not need to be considered in the chemical analysis of the gem-quality, relatively inclusion-free garnets used here, especially insofar as microprobe analysis permits selection of a microscopic inclusion-free area for testing (Dunn, 1977). In addition, we have calculated uvarovite before knorringite, in accordance with more recent findings by Sobolev et al. (1973) with regard to the existence of a pyrope-uvarovite series. In some of the calculations, Si, Al, and Fe^{2+} are present in excess of the amounts needed to satisfy the garnet formula. If there is any significance to the presence of these residuals beyond that of simple analytical error, it would not be surprising, since the geological environment and the processes involved in the formation of garnets suggest that these would be the most likely impurities present. Our scheme is further supported by the high percentage of cations accounted for by end members in the 96 stones studied: always over 97% and usually over 99% (see figure 2).

TABLE 1. Garnet end members.

Chemical formula	Name	Reference
$Ca_3Ti_2Fe_3^{3+}O_{12}$	Schorlomite	Ito and Frondel, 1967
$Ca_3Fe_2^{3+}Si_3O_{12}$	Andradite	Deer et al., 1962
$Mn_3V_2Si_3O_{12}$	(Yamatoite)[a]	Fleischer, 1965
$Ca_3Cr_2Si_3O_{12}$	Uvarovite	Deer et al., 1962
$Mg_3Cr_2Si_3O_{12}$	Knorringite	Nixon and Hornung, 1968
$Mg_3Al_2Si_3O_{12}$	Pyrope	Deer et al., 1962
$Mn_3Al_2Si_3O_{12}$	Spessartine	Deer et al., 1962
$Ca_3Al_2Si_3O_{12}$	Grossular	Deer et al., 1962
$Fe_3^{2+}Al_2Si_3O_{12}$	Almandine	Deer et al., 1962

[a] *The vanadium analog of spessartine.*

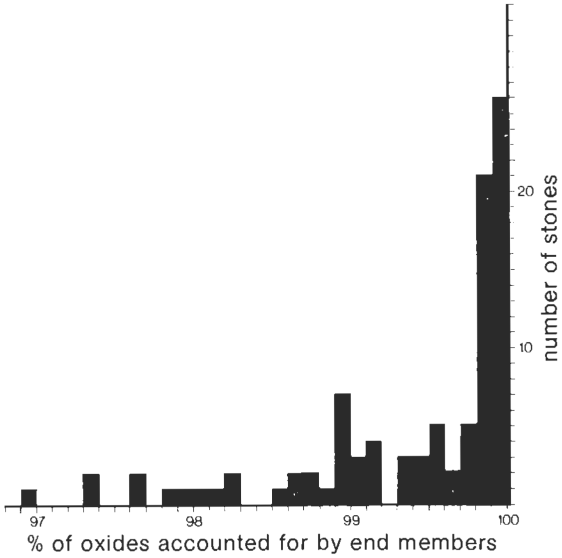


Figure 2. Histogram illustrating the percentages of oxides in the 96 garnets that are accounted for by nine end members.

It is important to remember that the garnet end member is merely a convenient theoretical concept for discussing the chemical make-up of this gem group. Garnets, even as end members, do not consist of discrete molecular units; the atoms of a garnet are combined in a continuous, three-dimensional framework (figure 3).

End members, then, were calculated for this study in the sequence shown in table 1, beginning with schorlomite. The calculation required two basic steps. Because the microprobe cannot determine to what oxidation state or states an element belongs, and because certain elements can occur in more than one oxidation state in garnet, one must first calculate the distribution of Al to the Y and Z sites, Fe to the X, Y, and Z sites, and Ti to the Y and Z sites according to the requirements of garnet stoichiometry. Any Al, Ti, and Fe allotted to the Z site are added to SiO_2 and treated as such in the absence of evidence to support preference for them by any particular end members. From the resulting oxide proportions, end members are then derived on the basis of stoichiometry. Inasmuch as Rickwood has discussed this procedure in depth, we need not go into it any further.

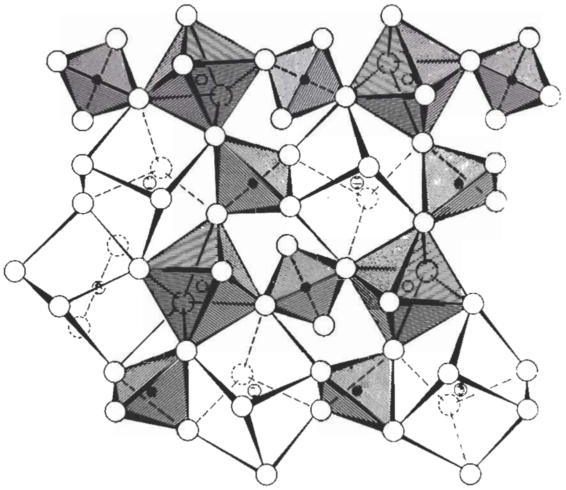


Figure 3. A portion of the garnet crystal structure. The large open circles represent oxygens, the smaller ones the Y cations, the solid circles the Z cations, and the hatched ones the X cations. (From Novak and Gibbs, 1971).

DATA COLLECTION

We selected specimen stones for the study on the basis of color, the most obvious criterion and, consciously or unconsciously, the test undoubtedly used most by gemologists in identifying variety. Thus, all the stones in the study are predominantly red to violet, but they vary widely in brightness and saturation of color.

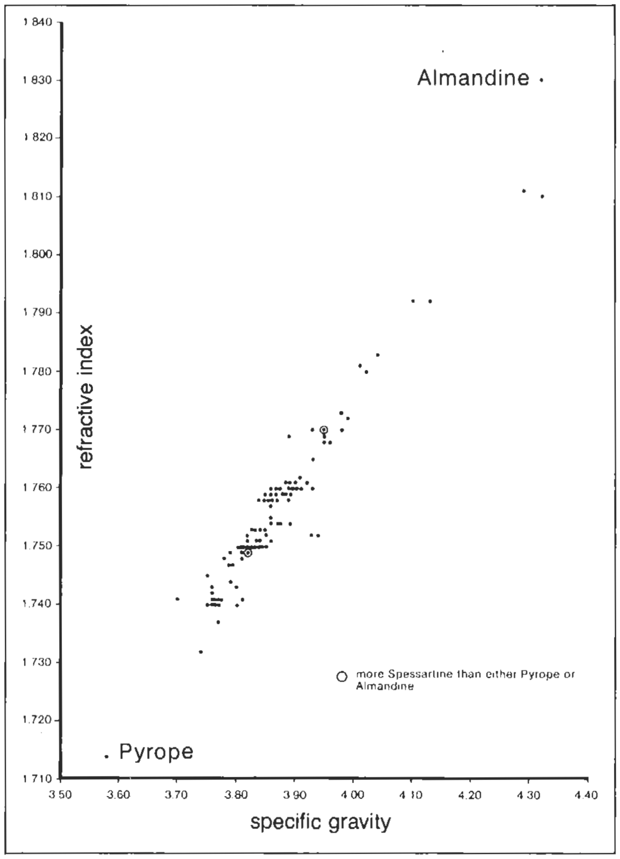
The data collected for each stone are of three types: physical and optical (specific gravity and refractive index), spectral (11 absorption bands and two color coordinates), and chemical (nine end members), totalling 24 variables for 96 garnets.

The instruments used in data collection included a GEM Duplex II refractometer and, for stones with refractive indices over 1.790, a prototype Duplex II with cubic zirconia hemisphere (Hurlbut, 1981). Specific gravities were obtained by means of the hydrostatic method with a self-taring balance. Spectra were obtained by two methods: (1) visually using a hand spectroscope, and (2) by the use of an automatic recording spectrophotometer (Hofer and Manson, 1981), which graphically displays the spectra and stores them on a magnetic disc. Color measurement was obtained using a GEM ColorMaster, and the readings were then converted to CIE (Commission Internationale de l'Eclairage) coordinates via a computer program developed by one of the authors. Garnet compositions were determined on the MAC microprobe at the California Institute of Technology using the Ultimate correction program (Chodos et al., 1973). In addition, unit-cell measurements were obtained for selected specimens by the powder diffraction method with a Philips Debye-Scherrer camera.

DISCUSSION OF DATA

Physical and Optical Data. A plot of the refractive indices versus the specific gravities for these 96 stones (figure 4) shows a more or less continuous linear relationship extending from the coordinates for the end member pyrope to those for the end member almandine. Departures from this line are probably due to the effects of end member components other than pyrope and almandine in the individual garnet specimens, as well as to a certain amount of measurement error.

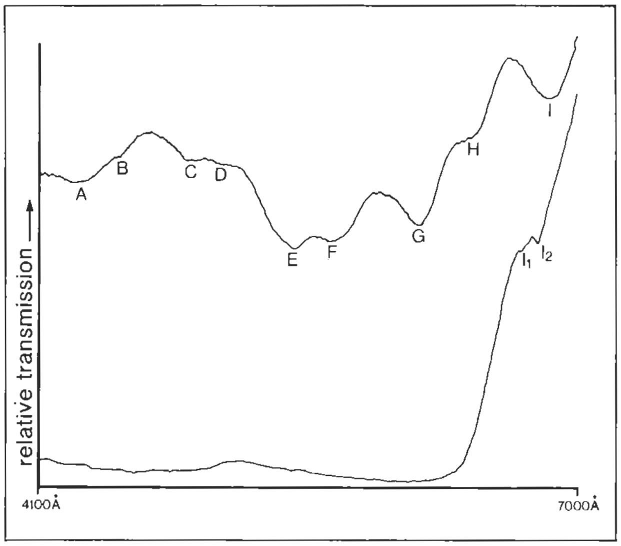
Figure 4. Refractive index plotted against specific gravity for the 96 garnets studied. Points for the ideal end members pyrope and almandine are also shown.



Unit-cell measurements were determined for about half the garnets in the study. A brief examination of their relationships with the other properties we measured revealed more complex interrelationships than we felt could be dealt with in this article alone, and so they will be discussed separately in a later article that will also include similar data for other types of garnets.

Spectral Data. The spectra obtained with the recording spectrophotometer showed 11 consistent bands (figure 5), which we refer to as A through I, I_1, and I_2 (centered approximately at wavelengths of 4270, 4380, 4610, 4730, 5035, 5230, 5710, 6090, 6920 and, within the last broad band, 6750 and 6870 Å). We devised a simplified approach to expressing the relative strengths of these bands in which we rated each band according to the spectrophotometer graphs on a scale of zero (not visible) to five (very strong). There appears to be a relationship between the darkness of a stone and the number of bands visible, as might be expected based on the ability to transmit light: the darker the stone, the fewer bands visible, especially in the shorter wavelengths. With few exceptions, bands E through I were always visible

Figure 5. Representative spectral curves showing the absorption bands as observed in the 96 garnets with the spectrophotometer. Approximate wavelength equivalents are: A = 4270, B = 4380, C = 4610, D = 4730, E = 5035, F = 5230, G = 5710, H = 6090, I = 6920 and, within the last broad band, I_1 = 6750 and I_2 = 6870 Å.



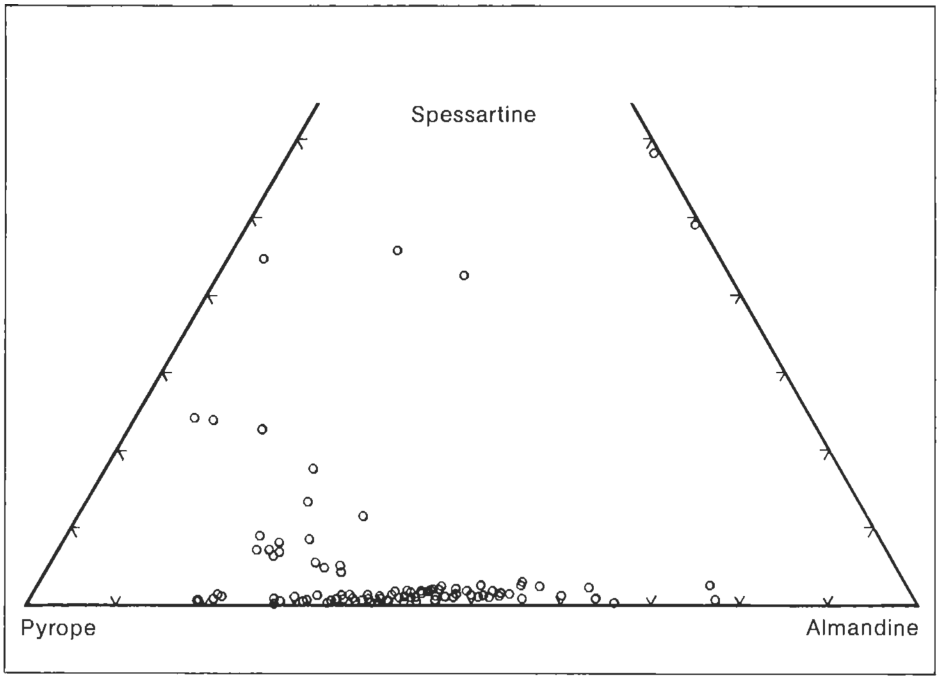


Figure 6. Points for the 96 garnets plotted on the pyrope versus almandine versus spessartine ternary diagram.

with the spectrophotometer; bands E through G could always be seen with the hand spectroscope as well. Bands B and D always appeared to be very weak, even with the more sensitive spectrophotometer. The former never appeared in the hand spectroscope, and the latter was seen only rarely, even though the spectrophotometer indicated that one or both bands were present.

A distinctly different curve was visible with both the spectrophotometer and the spectroscope for four very dark red stones. All four clearly showed the I_1 and I_2 bands, in three cases to the exclusion of all other absorption bands while the fourth did exhibit a very faint E band.

Chemical Composition. The interrelationships among end members can be portrayed, three end members at a time, by means of ternary diagrams. (An explanation of ternary diagrams is provided in the Appendix.) We plotted diagrams for various combinations of the five major end members and selected two that best exhibited the general patterns that appeared (the first illustrated in figures 6 and 7, the second in figure 8). The first ternary involves pyrope, almandine, and spessartine, as these three end members together comprise the largest portion of the composition of most of the garnets in the study. The second ternary was selected from a number of other diagrams illustrating various combinations of end members because it showed the most distinctive pattern. The end members included are pyrope (on an average, the single most abundant end member), spessartine, and the sum of grossular and andradite.

Figure 6 (pyrope, almandine, and spessartine) displays a distinct trend among those garnets that contain 34% to 72%* pyrope, 28% to 66% almandine, and 0% to 4% spessartine. The trend illustrates a tendency for spessartine to increase slightly as the amount of almandine increases, probably because Mn easily substitutes for Fe^{2+} due to their similarity in atomic size and structure. It is this group that contains the greatest number of garnets in the study. Two garnets, both containing approximately 78% almandine and 22% pyrope, also may belong to this group, but they are notably higher in almandine content than the main group. Also in line with the principal trend are four garnets that are considerably higher in pyrope (around 80%) but that, in terms of oxide percentages, exhibit 1.7% to 2.0% Cr_2O_3 which translates to about 6.0% uvarovite. These are the same garnets previously noted as showing only the I_1 and I_2 absorption bands; this apparently reflects the large quantities of chromium they contain, since these stones are also the only

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**These values as well as the other percentages in this paragraph refer to the amounts recalculated for plotting of the end members on the ternary diagram in figure 6.*

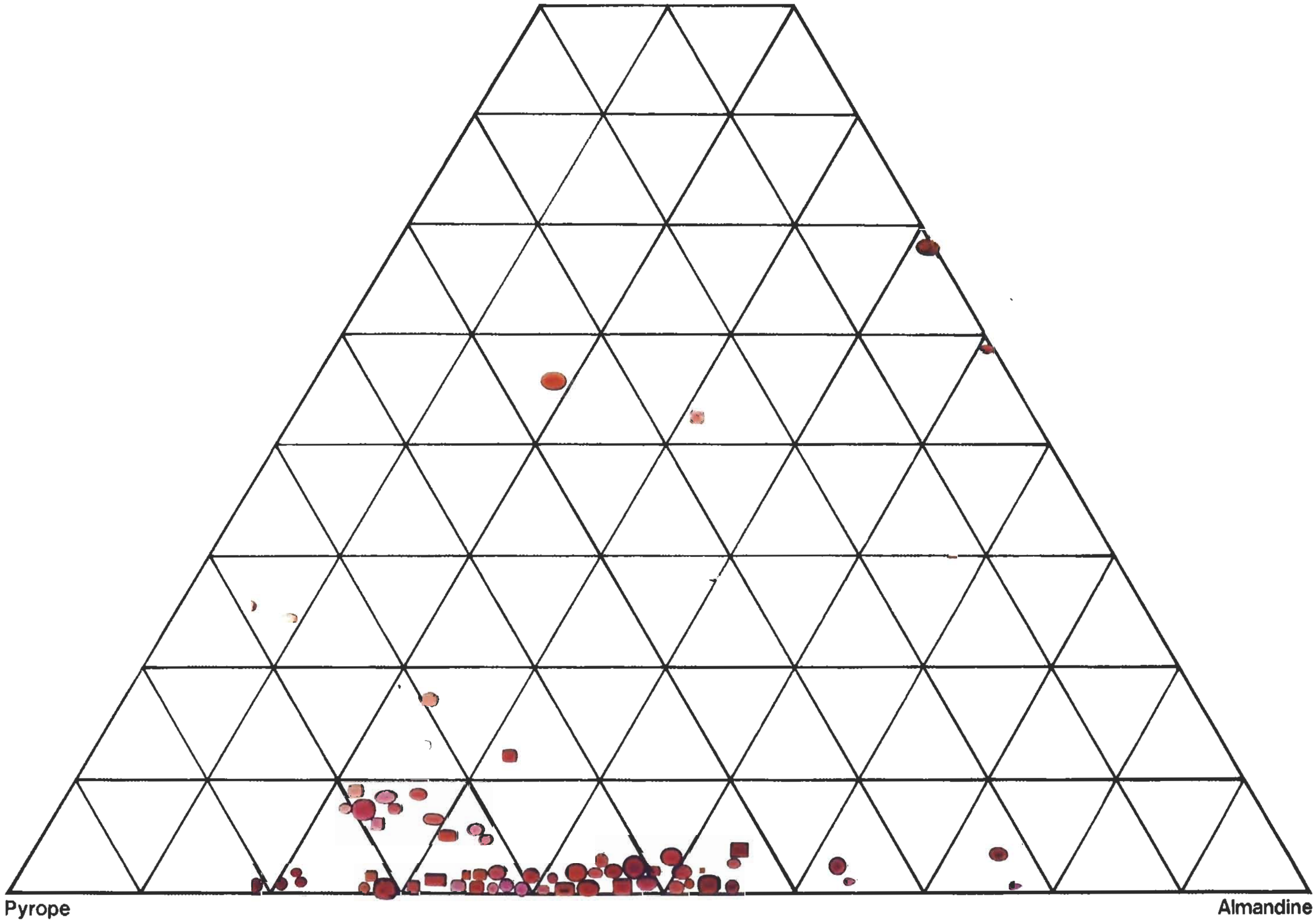

Figure 7. Pyrope versus almandine versus spessartine ternary diagram with garnets placed on their respective coordinates. It is obvious that color is not a function of chemistry with regard to these three end members.

garnets in the study that contain more than 1.0% of this oxide.

Another group of 11 garnets may be distinguished by the greater amounts of spessartine present, from 4% to 10%. Two other stones continue this trend toward even higher spessartine content. They are composed of (respectively): pyrope, 62% and 55.5%; almandine, 25% and 32%; and spessartine, 13% and 12.5%. In addition, seven garnets that each contain more than 17% spessartine do not belong to any group identifiable in this study. However, the colors of these stones and, in most cases, their readily observable physical and optical properties might otherwise place them among the group of gemstones traditionally recognized by gemologists as the pyrope-almandine garnets. Figure 7 displays 63 of the 96 stones in the study, a representative sample of the colors of these garnets, placed table down on the pyrope-almandine-spessartine ternary in their respective positions and photographed to illustrate the distribution of color. This dramatically shows the apparently random variation in hue associated with these major chemical components of the red-to-violet garnets.

The most obvious feature of the second ternary (figure 8: pyrope, spessartine, and grossular + andradite) is that the stones that fall along the line between pyrope and grossular + andradite clearly fall into two groups: (1) 2% to 12%** gros-

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**Values expressed in this paragraph refer to amounts recalculated for plotting in figure 8.*

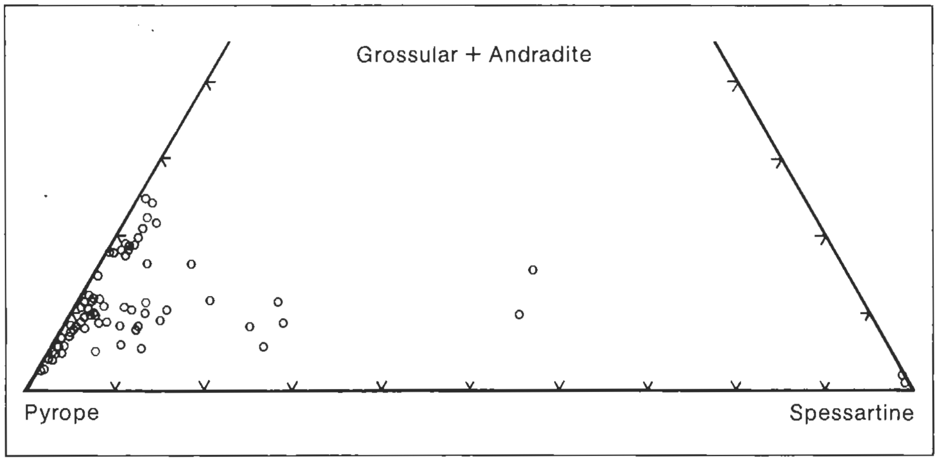


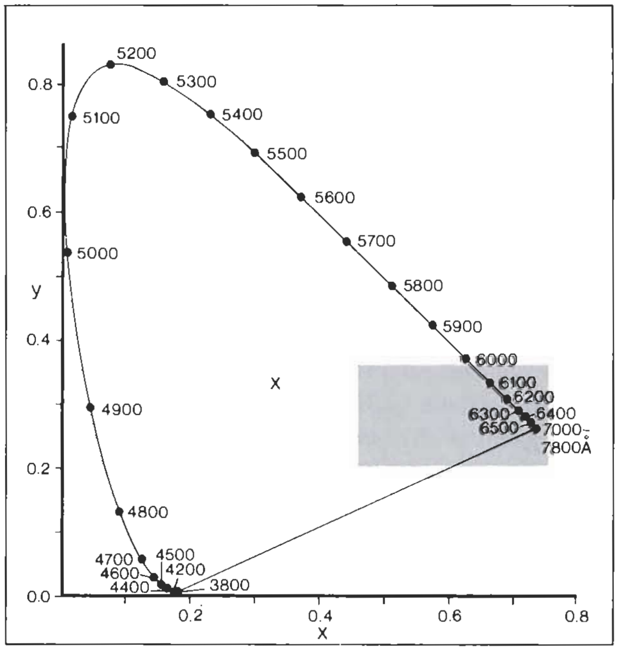
Figure 8. The 96 garnets plotted on the pyrope versus spessartine versus grossular + andradite ternary diagram.

sular + andradite, and 86% to 98% pyrope; and (2) 17% to 25% grossular + andradite, and 74% to 82% pyrope. Stones in both groups have roughly less than 4% spessartine. One stone that has 15% grossular + andradite lies between the two groups and suggests that the gap may simply be due to sampling bias. On this diagram, the higher-spessartine-content stones appear to have about 4.5% to 25% spessartine. Two of these contain more than 15% grossular + andradite, as in the second group mentioned above, while the rest have less than 12% grossular + andradite, as in the first group above. However, there are not enough stones in this region to draw any conclusions about the significance of such a split among the higher-spessartine-content stones. There are two stones with a still higher spessartine content of about 49.5% and 51% and with, respectively, 35% and 39.5% pyrope and 15.5% and 9.5% grossular + andradite. The two stones containing no pyrope appear here as containing 98% and 99% spessartine since almandine has been excluded.

Color. The color of each garnet in the study was described in terms of GEM ColorMaster notations that were then converted to the CIE system of color measurement, so called after the Commission Internationale de l'Eclairage, an international committee devoted to the study of the behavior of light and color. CIE is supported by many organizations and is the most widely recognized authority in the field, attempting to consolidate the immense quantity of research done in the area of light and color into standardized and internationally acceptable systems of description.

While the CIE system is described fully elsewhere (Wright, 1969), as well as with particular reference to gemology and the GEM ColorMaster (Manson, in preparation), a brief explanation of the chromaticity diagram integral to this system is warranted here. A set of coordinates was developed to express the relationship among all colors from the most saturated hues to white light (or neutral gray) on the basis of a "standard observer's" response to various color stimuli (the average of observations of a large number of people). The chromatic portions of these measurements were plotted on an x-y coordinate graph to produce the chromaticity diagram (figure 9), standardized in 1931. This diagram consists of a

Figure 9. The CIE chromaticity diagram, with points for white light (X) and selected wavelengths. The shaded area indicates the portion of the diagram reproduced in figure 10.



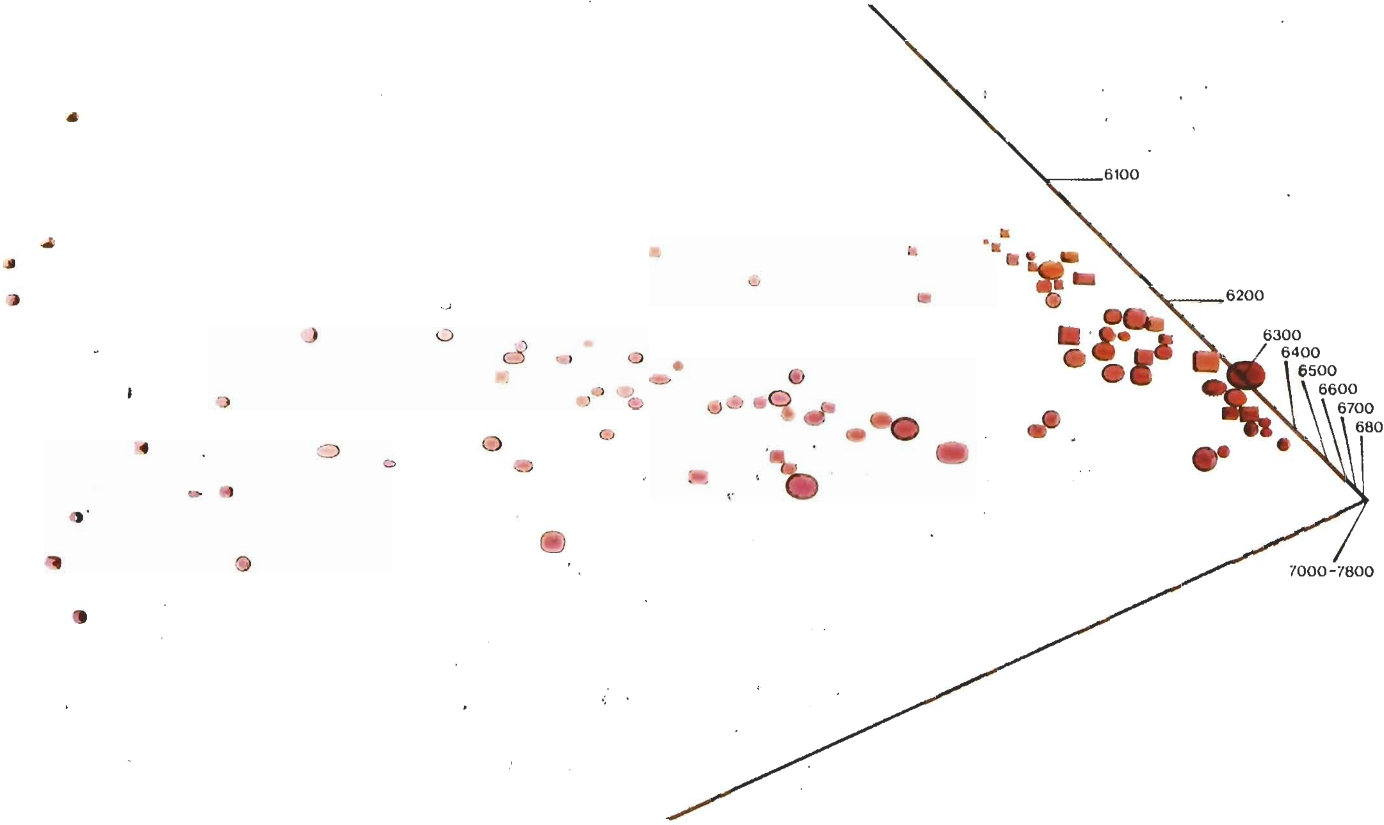


Figure 10. The red-to-violet region of the CIE chromaticity diagram with the 96 garnets positioned according to their x-y coordinates. Hues range from violet at the lower left, through red at the lower right, into orangish red at the upper right. Pale colors appear in the upper left, near the coordinates for white light.

skewed parabolic curve along which lie the saturated hues and in the approximate center of which is the location of the white light coordinates.

Thus, any hue and saturation can be represented by a set of x-y coordinates and plotted as a point along or within the chromaticity curve—going from violet and blue at the extreme lower left, through green at the top of the curve, to red at the extreme lower right. In the region defined by the straight line that connects the two ends of the curve lie the nonspectral hues, from violet through purple to red. Spectrophotometric measurements have enabled us to correlate the coordinates of the saturated hues with their respective dominant wavelengths, as shown in the diagram in figure 9. Along any radial line drawn between white light and a saturated hue lie colors of increasing saturation as one approaches the curve, but that are of the same hue and dominant wavelength. For example, on such a line between white light and the coordinate point for red at 7000 Å, the color near white light would be pale pink, increasing to deep red as the line approached the chromaticity curve, but any point along the line would have the dominant wavelength 7000 Å.

Color notations for the garnet specimens were obtained with a GEM ColorMaster and were then converted mathematically to x and y CIE coordinates. The color notations used represent averages of readings obtained on the ColorMaster by three trained observers. The ColorMaster proved to be extremely useful as a simple and efficient means of obtaining measurements that could be converted to CIE coordinates, of which there is only one set for any given color. Once converted, the CIE coordinates were plotted on a chromaticity diagram (figure 10), as well as employed in the factor analysis described later in this article.

DISCUSSION OF ERROR

While we feel confident that the results obtained in this study are significant, we must also point out that no scientific research is without uncertainties. Sources of error do exist in the operation, function, and mathematics of microprobe analysis; in the possible chemical inhomogeneity of some of the stones tested; in the coating and mounting of gem specimens for chemical analysis; and in simple human error in measuring the physical and optical properties. However, we feel that the error factors in this study are minor and do not significantly affect our conclusions.

As a measure of the error associated with the microprobe, we examined the extent to which sample compositions expressed by microprobe chemical analyses deviate from the actual composition of a given stone. This variability is caused by slight irregularities in operating conditions such as the preparation of the specimen, the position of the specimen relative to the electron beam, electronic fluctuations in the microprobe, mathematical and statistical error in the interpretation of microprobe data, and the like. A sample of the McGetchin standard garnet (McGetchin, 1968) at the California Institute of Technology was analyzed at intervals over the same span of time that the 96 garnet specimen analyses were performed for this study, and 27 control analyses with total weight percentages between 99% and 101% were obtained. To provide an idea of the amount of error that could exist in our microprobe analyses, we compared the various results for the control garnet, which produced the averages and standard deviations from the original weight percentages shown in table 2.

Deviation from the average varies from case to case depending on the amount of any given oxide present in a specimen; the greater the amount of an oxide present, the smaller the relative variability due to the greater sensitivity of the microprobe as the amount of any element present increases.

TABLE 2. Measurement of error.

Oxide	Average weight %	Range	Standard deviation
SiO_2	41.93	40.73–42.80	0.54
TiO_2	0.16	0.10– 0.20	0.03
Al_2O_3	22.41	21.67–22.92	0.34
V_2O_3	0.03	0– 0.09	0.03
Cr_2O_3	1.37	1.28– 1.45	0.04
MgO	20.00	19.49–20.39	0.26
CaO	4.58	4.42– 4.77	0.18
MnO	0.37	0.27– 0.44	0.05
FeO	9.18	8.56–10.23	0.32

STATISTICAL ANALYSIS

The final analytical method used was a mathematical procedure known as factor analysis (explained in Manson, 1967). This is a sophisticated method of data reduction designed to look simultaneously at the interrelationships among large numbers of variables measured on many samples. The nature of physical space limits us graphically to three or, by means of models, four dimensions in dealing with variables. Factor analysis, especially with the aid of a computer, enables us to handle as many dimensions at once as we wish, in this case 24. However, routinely describing any given garnet by 24 properties would be entirely too cumbersome and might involve some variables that were completely or partly redundant. For example, if refractive index and specific gravity were so perfectly correlated that knowing one would allow you to exactly predict the other, then there would be no need to obtain both of these properties in testing for the identity of a stone. Essentially, the factor analysis checks for such correlations, though the relationships are usually more subtle than in the above example.

This procedure provides us with a set of new variables, or "factors," that are composites of the relevant original data variables. The factor analysis tells us how much of the variability among the specimens can be accounted for by each factor and rates the factors accordingly. Thus, the first five factors might account for 85% of this variability, the first eight for 90%, the first 10 for 92%, and so on. It is up to the investigator at this point to decide what amount of variability adequately describes the situation at hand, extract the minimum number of factors that provide this optimum amount of information about the samples, and then interpret the factors in terms of the original variables.

In this case, the factor analysis provided us with seven factors, as described below, which account for more than 90% of the overall variability in the garnets examined. The original 24 variables are represented by, or "load" onto, the factors as shown in table 3, in which the factors are arranged from the most variability accounted for (factor 1) to the least (factor 7). The factor analysis also describes the percentage of variability in each stone as accounted for by each individual factor.

Factors 1 and 2 generally describe the collection of 97 garnets as a whole, that is, by the end members pyrope and almandine and, to a lesser extent, by andradite and grossular. Factor 3 accounts for stones that are high in uvarovite content. The fourth factor represents garnets that contain yamatoite, which correlates positively with pyrope and negatively with almandine. (It must be noted, however, that the quantities of yamatoite on which this correlation is based are very small, less than 0.85%.) Similarly, schorlomite forms the basis for factor 5, correlating with grossular. Factor 6 represents spessartine, which correlates negatively with andradite and pyrope; the negative correlation with pyrope was already evident in the trend seen in figure 6. The final factor correlates knorringite positively with andradite and negatively with grossular, but again it must be kept in mind that the knorringite only occurs in small quantities.

TABLE 3. Factor loadings.

	Factors						
Variables	1	2	3	4	5	6	7
End Member							
Almandine	+++			−−			
Pyrope	+++	+	+	++	+	−−	
Spessartine						+++	
Grossular	++	−			++	+	−−
Andradite	++	−		+	−	−−	++
Schorlomite					+++		
Uvarovite			+++				
Knorringite							+++
Yamatoite				+++			
Physical Properties							
R.I.	+++						
S.G.	++			−−−			−
Color	+++						
Spectral Bands							
A		+++					
B	−	+++		−−	++		
C		+++				+	
D		+++				−−	−
E	+	+++		++	−		
F	+	+++		++	−		
G	++	++		++	−		
H	++	+++			−−		
I	+++	+			−−		
I_1			+++				
I_2			+++				

+++	*strong positive correlation*
++	*moderate positive correlation*
+	*weak positive correlation*
−−−	*strong negative correlation*
−−	*moderate negative correlation*
−	*weak negative correlation*

Table 3 also illustrates how the physical, optical, and spectral properties relate to the various end members. However, caution must be used in interpreting these relationships, since differing scales of measurement that were used have varying effects on the mathematics of factor analysis. Generally, the patterns that emerged from this statistical analysis confirm the ideas we had formed along the course of the project, but subtle interrelationships also appeared that might prove more important as further detailed investigation is conducted in the future.

Because of the strong relationship indicated by the factor analysis between refractive index, specific gravity, and the pyrope and almandine constituents of the red-to-violet garnets, we reexamined the graph of refractive index versus specific gravity (figure 4) and at the same time distinguished between high pyrope content, high almandine content, and approximately equal content of pyrope and almandine for each stone in the study (figure 11). It can be seen that, for the most part, a refractive index of less than 1.752 in conjunction with a specific gravity of less than 3.86 represents garnets that contain more pyrope than almandine. A refractive index of more than 1.779 with a specific gravity over 4.00 indicates garnets that have more almandine than pyrope. Approximately equal portions of pyrope and almandine (1.5:1 to 1:1.5) yield a range of refractive index over 1.751 and up to 1.774, with a range of specific gravity of more than 3.81 and up to 3.99. There is a continuation from the range of the high pyrope properties to that of properties for the stones having approximately a 1:1 ratio of pyrope to almandine; in fact, a small area of overlap can be seen in figure 11. Other exceptions to the ranges described with respect to composition are also visible in figure 11. Three high-pyrope stones lie well within the range for those stones usually having a 1:1 ratio of pyrope to almandine, and another stone with a 1:1 ratio lies within the range for high-pyrope garnets. Two of these stones contain more spessartine than either pyrope or almandine, which might explain this anomaly, but the other two garnets are definitely members of the pyrope-almandine series that contain more pyrope than almandine. Thus far we have been unable to determine what causes their properties to be so high.

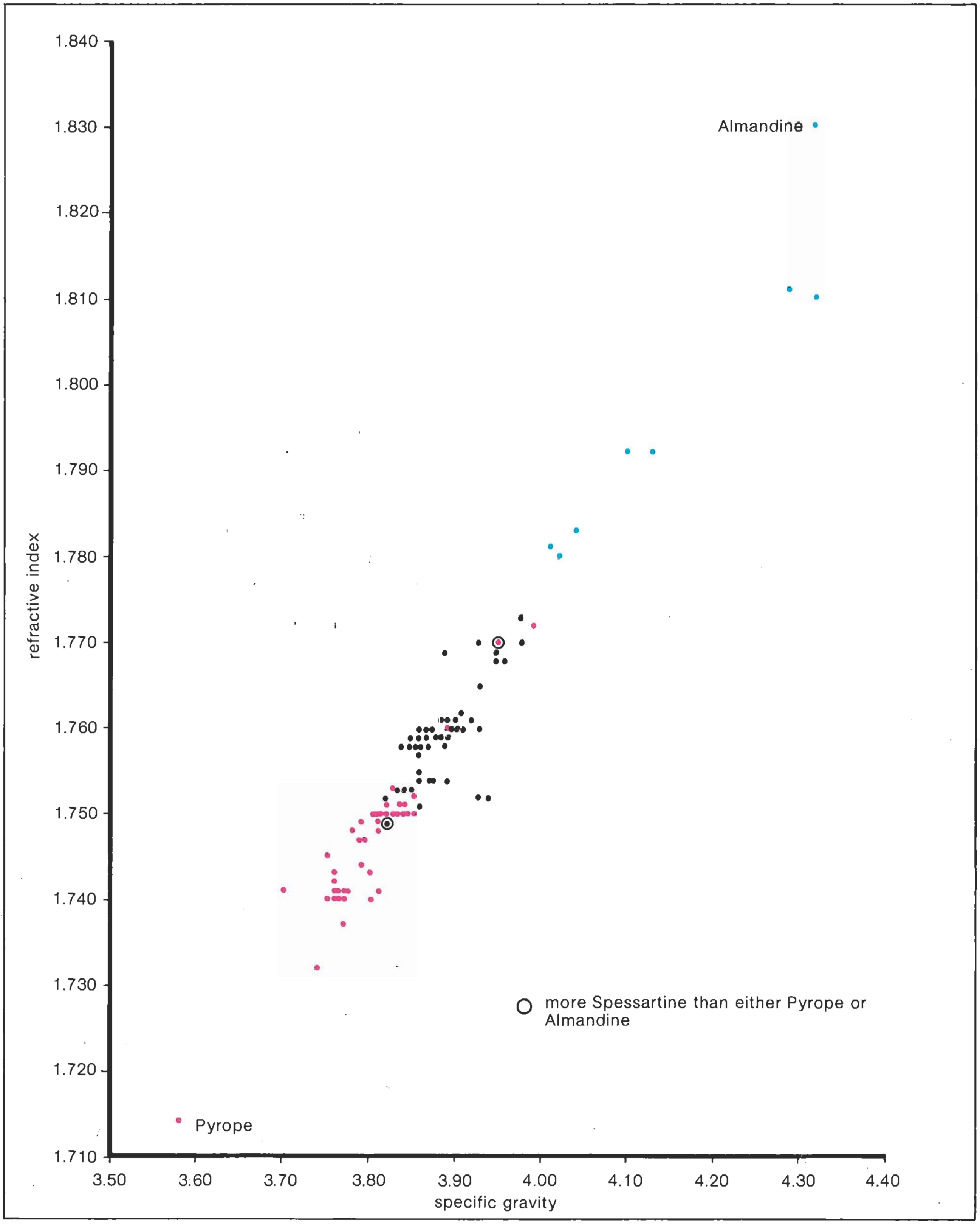


Figure 11. The graph of refractive index versus specific gravity, color coded to indicate the ratio of pyrope to almandine for each of the 96 garnets. Red indicates a pyrope:almandine ratio of greater than 1.5:1, black indicates an approximately 1:1 ratio (1.5:1 to 1:1.5), and blue denotes a ratio of less than 1:1.5.

CONCLUSIONS

In practical terms, the gemologist is essentially limited to the use of three tests in the identification of garnets: refractive index, specific gravity, and absorption spectrum. For the red-to-violet garnets, this study shows that these three determinations do provide certain indications of the composition of the stones studied. In one case, that of chrome pyrope, we can use the spectroscope to observe obsorption bands that are characteristic of the high Cr_2O_3 content of these garnets. In addition, refractive index and specific gravity together give us a reasonably reliable indication of the ratio of pyrope to almandine for any specific stone. Anomalies between the two properties may indicate the presence of significant amounts of end members other than pyrope and almandine, especially spessartine. More often, though, stones that contain large amounts of other end members have a relationship between refractive index and specific gravity that still falls within the trend shown by the pyrope-almandine series, as one can see in figure 11. Generally, however, we can define ranges of refractive index and specific gravity that, taken together, indicate whether pyrope or almandine predominates in any given specimen.

To avoid proliferation of names, and for convenience, we support using the name of the end member that predominates. In the less rigorous application of these terms, we can label stones in the red-to-violet color range as being *pyrope* if the refractive index and specific gravity indicate that there is more pyrope than almandine present (R.I. below 1.752 and S.G. less than 3.86), or as *almandine* if these properties indicate that this end member predominates (R.I. above 1.799 and S.G. more than 4.00). In the case of red-to-violet stones having approximately a 1:1 ratio of these two end members (R.I. between 1.751 and 1.774 and S.G. between 3.81 and 3.99), we recommend that the term *pyrope-almandine* be applied. Rhodolite, according to the original definition of the variety, falls within the region to which we would also apply the term *pyrope.*

The spectral data support the existence of a general absorption spectrum associated with garnets in this color range, but there is no clear association between a particular spectrum and any individual end member, including almandine. With the exception of the chrome bands I_1 and I_2, the variations that can be observed are of questionable usefulness within this color range. Some bands appear to be affected by various end members, as indicated by the factor analysis (see table 3), but combinations of such end members may cancel out or enhance these effects in such a way as to conceal any correlations. In addition, the general absorption of light associated with stones of deeper color masks many of the bands in the shorter wavelengths.

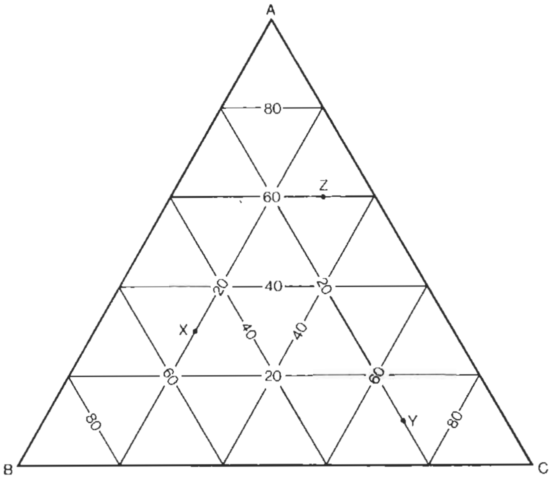
The relationship between color and bulk chemistry for the garnets in this color range seems to be, as can be seen from figure 7, entirely random. This is not surprising, as garnet has long been recognized as allochromatic. The presence of trace elements or ions not readily measurable by the microprobe is undoubtedly responsible for some or all of these variations in color. The quantities in which these trace elements are present, however, apparently are not sufficient to affect refractive index or specific gravity (both of which reflect bulk chemical composition). Thus, the common gemological tendency to associate color with a particular type of garnet such as pyrope or almandine is likely to be misleading if one is interested in an indication of chemical composition within the red-to-violet color range of garnets. Because of the importance of color in the appreciation of gem garnets and based on the results of this study, however, the color criterion must be an important consideration in any gemological classification of garnets. The precise role of color in the classification of all gem garnets, as well as the roles of the other properties examined in this study, must remain unresolved until we have completed the examination of garnets in the other ranges of color and chemical composition.

Acknowledgments: The authors wish to thank all the personnel of the GIA and the Gem Trade Laboratory, Inc., who assisted in the gathering of data. Special thanks go to Chuck Fryer for his valuable contributions and expert assistance and to Shane McClure for the considerable time and effort he expended in furthering the study. Thanks also go to Arthur A. Chodos and the California Institute of Technology for their assistance with equipment, instruction, and advice in microprobe chemical analysis. Thanks also to Peter Johnston for the line drawings in figures 2, 4, 5, 6, 7, and 11; to Tino Hammid for the photograph in figure 1; and to Mike Havstad for the photographs in figures 7 and 10.

The data gathered on the 96 garnets used for this article will be published at a later date, upon the completion of the entire GIA garnet project. Until that time, the authors will provide these data on specific request.

APPENDIX: TERNARY DIAGRAMS

The graphic illustration of the relationship between three components is complicated by the difficulty of visualizing three dimensions on paper (which is two-dimensional). A ternary diagram achieves this illustration by the use of an equilateral triangle scaled from 0% to 100% in each of its three directions (see diagram at right). Each point of the triangle represents 100% of its respective component (e.g., A, B, or C in this diagram), while the side opposite represents 0% of that component (e.g., the line between points B and C represents 0% of A). In order for a specimen to be represented as a single point on this diagram, A + B + C must total 100%. If a specimen is made up 80% of components A, B, and C, and 20% of other components, but one only wishes to examine the relationships between A, B, and C, this can be done by recalculating A, B, and C to add up to 100%. For example, sample X contains 24% A, 40% B, and 16% C. Dividing A, B, and C each by their total (80%) and multiplying by 100% yields recalculated amounts for A, B, and C equalling, respectively, 30%, 50%, and 20%, which now total 100% and can be plotted on a ternary diagram. So, to locate the point for X, read the percentage scale for each component in the appropriate direction (bottom to top for A, upper right side to lower left corner for B, and upper left side to lower right corner for C). Likewise, the percentages of components represented by points Y and Z can also be read: Y consists of 10% A, 20% B, and 70% C; while Z has 60% A, 10% B, and 30% C.



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SAN CARLOS PERIDOT

By John I. Koivula

Each year basalt-topped Peridot Mesa, on the San Carlos Apache Reservation, is a major source for thousands of carats of gem-quality peridot in sizes suitable for use in modern jewelry. Marketed throughout the world, San Carlos material is often confused with, and sold as, peridot from localities that are better known and documented. Peridot Mesa resulted from a single volcanic eruption and basalt flow over an already existing conglomerate base; it is thought to be of late Tertiary or Quartenary age. The peridot is found in irregularly shaped nodules within the basalt. The gemological properties and color range of these Arizona gems suggest an olivine that is rich in the magnesium forsterite end member. Inclusions documented are chromite, chromian spinel, negative crystals, "lily pad" cleavages, glass blebs, chrome diopside, biotite, and smoke-like veiling.

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Acknowledgments: The author wishes to thank Mr. Udell T. Brown, planning director for the San Carlos Apache Tribe; Ms. Caroline Bread, community planner and community development specialist; and Ms. Ramona Noline, executive secretary of the planning commission, for allowing a study of the Peridot Mesa to be made. Thanks also go to Tino Hammid of GIA's Gem Media Department for the photographs in figures 9 and 10, and to Susan Kingsbury, also of Gem Media, for preparing the maps.

For over a century, the San Carlos Apache Reservation in Gila County, Arizona, has been a major source of gem-quality olivine (peridot) in sizes that are very suitable for jewelry (figure 1). Yet very little has been published about the principal gem locality on the reservation, Peridot Mesa, or the peridot that is mined there by the Apache Indians, who have exclusive rights to the deposit. Through the kind permission of the Apache Nation Tribal Council, however, the author was permitted to examine the deposit and collect the specimens that served as the basis for this report. The observations about the area and the results of gemological tests reported in this article were derived from a series of experiments performed by the author on gem-quality olivine collected at Peridot Mesa.

HISTORY OF THE DEPOSIT

Many years before the Peridot Mesa deposit was recognized by the international trade as a gem source (Kunz, 1904), the area was mined by the Apache Indians and the stones were used exclusively among tribal members (Kunz, 1882, 1892). From 1904 to 1909, however, mining was carried out at an almost feverish pace, and soon the market was choked with an excess of available gems. This tended to reduce prices and hold them down, while decreasing buyer interest in the stone (Sterrett, 1909).

Consequently, mining activity declined rapidly and for many years was almost nonexistent. Gems continued to trickle from the reservation to a worldwide market, but much of this material had been extracted some years previously. In spite of its tremendous potential, the deposit has been worked only sporadically by the Indian residents during the last 72 years. Even today, mining of the peridot is done only intermittently by any of a number of Apache families who claim sections of the mesa as their own, although by Indian law all members of the tribe are al-

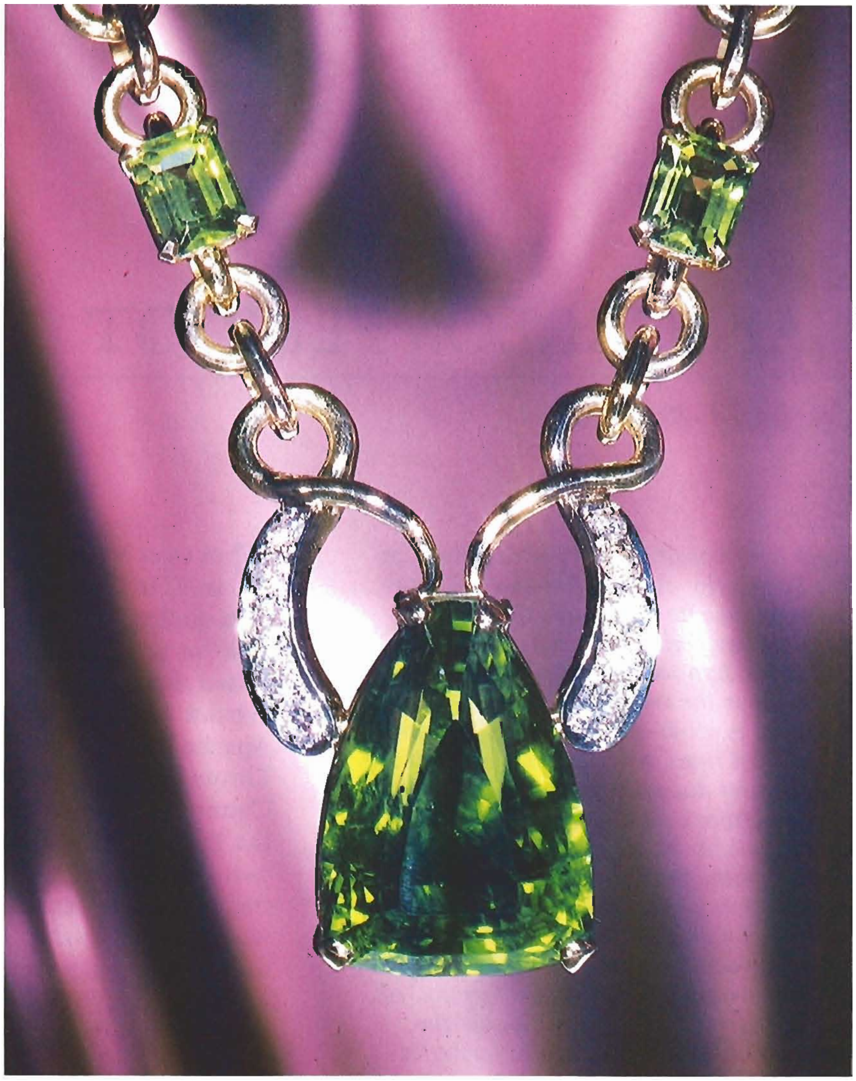


Figure 1. This 34.65-ct. peridot is one of the largest fine Arizona stones in existence. It is complimented by two 3.74-ct. peridots that are more typical in size of the stones found on the San Carlos Apache Reservation. This necklace, which was designed by Aldo Cipullo, is part of the American Gemstone Jewelry Collection of the American Gem Society. Photograph © 1978 Harold and Erica Van Pelt — Photographers, Los Angeles, CA.

lowed to mine. Only when the weather is suitable and the single access road to and from the mesa is passable will one or more of these families be found working their mines.

No records of any kind are kept concerning the amount of peridot mined each year from Peridot Mesa. The majority of the material is sold through the Apache Nations Peridot Enterprise, the Peridot Trading Post on the reservation, and another trading post just off the reservation between Globe and San Carlos. The material is sold directly to private individuals, wholesalers, and retailers alike. Little is known about any other peridot deposits in the area, and Peridot Mesa is the only one that is worked.

THE LOCATION

The San Carlos Apache Reservation is located in east central Arizona (see figure 2; Bromfield and Shride, 1956). Globe, the nearest major city off the reservation, lies approximately 18 miles (28.8 km) due west of Peridot Mesa. San Carlos, the main reservation town and local Bureau of Indian Affairs headquarters, lies 2.5 miles (4 km) northeast of the mesa.

Peridot Mesa and its surroundings are in a desert environment that supports various cacti and low-growing bushes and shrubs. The mesa rises above the lower desert by as much as 90 m and, like other mesas on the reservation, is easily visible, breaking the horizon of the otherwise flat terrain.

The two-lane road from San Carlos to the base of the mesa is paved blacktop. From the base, a bulldozed dirt road snakes up the side of the mesa. There is only one main dirt road across the surface of the mesa, with many forks branching from it to the various mining sites.

MINING METHODS

Peridot Mesa is dotted with numerous small open pit mines that break the uniformity of the essentially level mesa surface like so many small craters. Although the basalt is tough and does not yield readily to hand tools, blasting is done sparingly and only when absolutely necessary because explosive shocks can easily shatter the rocks and scatter the friable peridot in the nodules. A light bulldozer is sometimes used to work freshly blasted areas, remove top soil, and maintain or build roads; otherwise, no heavy equipment is employed and the vast majority of the mining is done almost entirely by hand. The most commonly used hand tools are large, long, heavy-stock picks and pry bars, smaller splitting chisels and wedges, various heavy-weight hammers (like the large-head Nevada-type long striking hammers), long- and short-handled shovels, hand rakes, and a variety of sizing sieves.

In working the basalt, the miners take advantage of any naturally occurring fractures or pits in the rock. Chisels and sledge hammers are used first to widen any existing separations in the rock or to create new ones (figure 3). Once a fracture or series of fractures is started in the basalt, wedges and long, heavy-weight pry bars are used (figure 4) together with the chisels and hammers to break the basalt into small chunks. In this way, the peridot nodules are freed from the host rock.

Figure 2. San Carlos location map. (Adopted from Basso, 1977.)

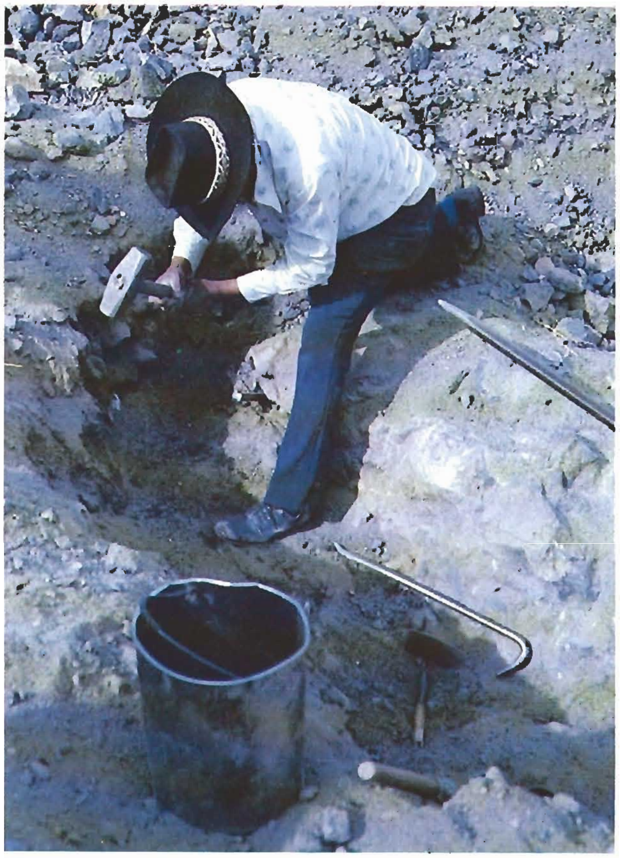


Figure 3. An Apache miner uses a chisel and sledge hammer to work a hand-dug peridot pit in the hard basalt.

Once the rock is broken down and the peridot nodules are freed, the chunks of peridot with their rock matrix are shoveled into first a one-half-inch and then a one-fourth-inch mesh sizing sieve (figure 5). The material left in the sieve is then hand-sorted and the loose matrix and undesirable minerals are quickly discarded. Exceptionally large or fine peridot grains are put aside to be sold individually. Once sieved for size, the mine-run peridot is stored in some type of sturdy container, usually a bucket or small tin can (figure 6).

Some of the rock faces being worked for peridot appeared dangerous inasmuch as the basalt was loose and broken and certain faces had been undercut with shallow tunnels. None of the workers in these areas was wearing any head pro-

Figure 4. Tools used to break the fractured basalt into small chunks.

Figure 5. The freed chunks of peridot on matrix are shoveled into a sizing seive.

tection. In addition, very few of the miners observed on the mesa were wearing any type of eye protection, which is extremely important when hammering rock with chisels. Nevertheless, anyone who has ever worked basalt can surely appreciate the efforts of the Apache peridot miner.

GEOLOGY OF PERIDOT MESA

The basalt capping the mesa is a vesicular, fine-grained, hard rock that is dark gray to black on fresh surfaces. It appears to have been extruded as the result of a single volcanic event. It extends approximately three and one-half miles (5.6 km) in a northeast direction and about two and three-fourths miles (4.4 km) along a northwest-southeast axis. The cone that produced the flow lies at the far southwestern end of the mesa (Lausen, 1927; see figure 7). The basalt ranges in thickness from 3 m near the cone vent to over 30 m where the flow filled natural depressions in the underlying Gila conglomerate, a flat horizontal to slightly folded sedimentary structure of early Pleistocene age. Thicker portions of the flow show rudimentary columnar structure, while thinner areas nearer the cone display a somewhat platy and/or concentric structure that developed in the flow during cooling and consolidation. The basalt is thought to be of late Tertiary or Quarternary age (Bromfield and Shride, 1956). Exposed contacts between the basalt and underlying sedimentary rocks show a definite baked or heat-altered zone.

Figure 6. Mine-run San Carlos peridot.

Two theories have been proposed for the origins of the vesicles in the basalt: (1) gas (carbon dioxide?) expansion caused by heat and diminishing pressure as the lava rose in the cone throat and poured out on the ground, and/or (2) water vapor expansion if the surface of the ground was wet when the flow emplaced.

The vesicles range in size from microscopic (the most common) to several centimeters in their longest dimension; they are spherical to subspherical or ovoid in shape, with some stretched into elongated tubes by the flow of the fluid lava. In general, the vesicles are larger as they near the surface of the flow.

Under the petrographic microscope, the rock proved to be a typical olivine basalt (Lausen, 1927). Plagioclase feldspar (labradorite) is present as

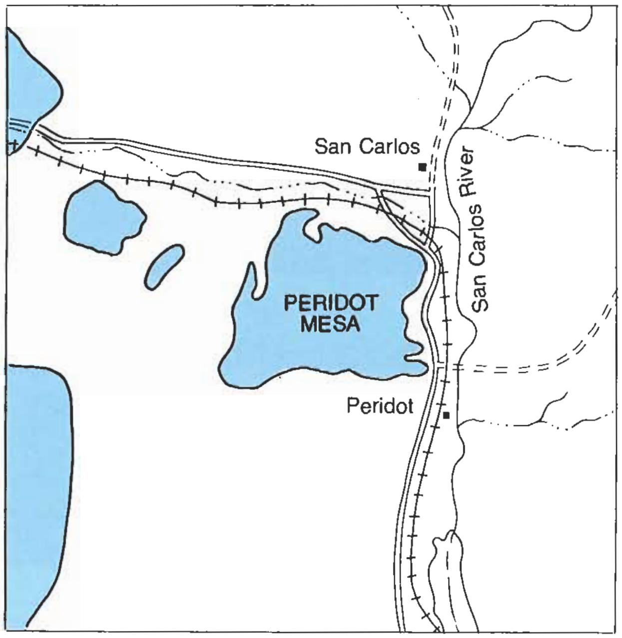


Figure 7. Generalized geological map of Peridot Mesa and vicinity, including the location of the basalt outcrops. (Adopted from Lausen, 1972.)

slender laths, along with olivine and augite in subhedral to anhedral grains. In addition, magnetite, apatite, analcime, diopside, chromite, biotite, and hornblende have been identified as accessories. Small blebs of volcanic glass of a dark brown to black translucent to nearly opaque transparency also occur in the basalt.

OCCURRENCE OF THE PERIDOT NODULES AND THEIR ORIGIN

Peridot occurs as spherical, ovoid, semi-angular included masses in the vesicular basalt (see figure 8). Such masses range in size from 1 cm or less to 30 cm or more in longest dimension. In the richest mining areas, the nodules may be found within a few centimeters of one another throughout large volumes of the basalt (again, see figure 8); elsewhere they may occur as isolated units, separated from one another by a meter or more of barren rock. The masses are composed chiefly of granular olivine with most of the peridot crystals no larger than a grain of sand; even the largest are scarcely over a few cubic centimeters in volume (see figure 9). The nodules closely resemble peridotite in composition and texture and, therefore, may represent fragments torn at depth from a peridotite rock mass through which the basaltic lava was forced. The random distribution of the nodules in the basalt tends to support this theory (Sterrett, 1909; Lausen, 1927). A thin shell of spongy basalt containing hornblende and augite envelopes each of the peridot nodules; this may represent a thermal reaction zone that formed as a result of limited magmatic differentiation, chemical alteration, and fractional crystallization within the boundaries of the alteration zone.

Figure 8. Basalt face showing typical olivine nodules. The largest is over 25 cm in longest dimension.

DESCRIPTION AND GEMOLOGICAL PROPERTIES OF SAN CARLOS PERIDOT

The mode of formation of the olivine nodules precludes the existence of extremely large single crystals and solid masses such as those from Burma and the classic locality of St. John's Island (Zabargad) in the Red Sea. Faceted San Carlos gems typically are small in size; the average weight is between one-half and three carats. Gems over three carats are somewhat rare, and stones over five carats should be considered collectors' pieces.

In color, the peridot ranges from a very dark brown to brownish green to a very pleasing bright lime green from which lively, attractive gems are cut (figure 10). The darker gems are higher in iron content than their lighter counterparts. A chemical analysis of San Carlos peridot (Anthony, Williams, and Bideaux, 1977) by S.S. Goldich (USNM 86128) showed 49.78% MgO, 40.90% SiO_2, 8.24% FeO, 0.59% Fe_2O_3, 0.30% NiO, 0.22% Al_2O_3, 0.12% MnO, and minor traces of TiO_2, CaO, Cr_2O_3, and H_2O. John Sinkankas (1976) reported analytical percentage ranges of 48.34 to 49.49 MgO, 41.11 to 41.96 SiO_2, 8.67 to 10.37 FeO, 0.09 to 0.18 MnO, 0.09 to 0.16 CaO, 0.03 to 0.06 Cr_2O_3, and 0.01 to 0.02 TiO_2. The 0.30% NiO reported by Anthony, Williams, and Bideaux, as compared to the absence of this chemical in the Sinkankas analysis, suggests that in some cases nickel might play a part in the coloration of peridot.

Tests performed by the author on the 12 sam-

Figure 9. San Carlos peridot in vesicular basalt matrix, 18 cm in longest dimension.

ple stones pictured in figure 10 indicate that both refractive index and specific gravity vary slightly with color depending on the percentage of iron present. Refractive indices of the test gems were obtained using a GEM Duplex II refractometer and a sodium light source. The lightest colored gem was biaxial positive with a refractive index of 1.649 alpha, 1.665 beta, and 1.686 gamma, and a corresponding birefringence of 0.037. The darkest specimen was biaxial positive with a refractive index of 1.653 alpha, 1.671 beta, and 1.691 gamma, and a birefringence of 0.038.

From these numbers, it is apparent that not only does the refractive index increase with a darkening of color and a rising iron content, but the beta (intermediate) index also shifts numerically away from the alpha index toward the gamma index. This movement of the beta index suggests that if enough iron substitutes for magnesium in the structure, not only will the refractive index increase substantially, but the material will also become biaxial negative in optic character, as the iron-rich end member fayalite proves.

Specific gravity, as well, varied with color. Through the use of a specially modified Arbor 306 electronic balance, a specific gravity range of 3.28 to 3.38 was established for the test stones, with lighter colored gems tending to cluster toward the lower numerical value while darker stones showed higher specific gravities. However, chromite, with a specific gravity of approximately 4.80 (and possibly magnesiochromite, with a specific gravity of 4.20), is commonly present as an inclusion in peridot, frequently in abundance. Its presence as an inclusion in any significant amount will produce a higher than normal specific gravity for the stone. In fact, the highest reading, 3.38, was obtained from a light green gem that contained numerous chromite octahedra.

On the GEM spectroscope unit, the visible light absorption spectrum observed in both the light and dark San Carlos gems was determined to be typical of peridots in general and to match lines already observed and recorded in the gemological literature, namely, at 4520, 4730, 4880, 4960, and 6400 Å. The 4880 Å and 4960 Å lines together usually appear as a single broad band. Using GIA's Zeiss PMQ$_3$ spectrophotometer, Stephen C. Hofer of GIA's Research Laboratory confirmed the spectrum and showed that the 4880 Å and 4960 Å lines were in fact separate absorption points in the spectrum. A weak, smudged line at 5200 Å seen in the darkest gems did not appear in the spectrophotometric scan.

INCLUSIONS IN SAN CARLOS PERIDOT

The inclusions found in San Carlos peridot are limited in variety. When present, though, they are usually quite interesting and often gemologically diagnostic. Thus far, the following inclusions have been identified: chromite and chromian spinel, negative crystals, "lily pad" cleavages, glass blebs, chrome diopside, biotite, and smoke-like veiling.

Chromite and Chromian Spinel. The most common inclusions are dark reddish-brown to black euhedral to subhedral octahedrons of chromite ($FeCr_2O_4$) or chromian spinel [$(Mg,Fe)(Cr,Al)_2O_4$].

Figure 10. This selection of 12 cut gems, averaging 2.5 cts. each, illustrates the color range common to San Carlos peridot. The rough that produced these cut stones was collected from the road bed on the mesa in less than 30 minutes.

Carol Stockton of GIA's Research Laboratory used the scanning electron microscope–energy dispersive spectrometer to perform chemical analyses on two randomly selected inclusions and found both to be chrome-rich spinel phases, possibly chromite (and referred to in this article as chromite). Dunn (1974) identified other similar inclusions as a close cousin to chromite: chromian spinel (magnesiochromite). Although no chromian spinels were identified in this study, it seems chemically possible for chromite and chromian spinel both to be present as inclusions in a single Peridot Mesa peridot. In the stones examined for this study, the chromites were randomly distributed as single crystals or as small groups of crystals and were almost always associated with tension fractures that resulted from the expansion of the chromite crystals against their host (see figure 11).

Negative Crystals. Negative crystals, as described by Eppler (1966), were very abundant in the San Carlos peridots (see figure 12). Under magnification, with liquid nitrogen used as a cooling agent, condensation and freezing of the fluid gas components in the negative crystals were observed by the author. Although no actual analyses were performed on the contents of the negative crystals,

Figure 11. A grouping of octahedral chromite inclusions. Dark-field illumination, magnified 40×.

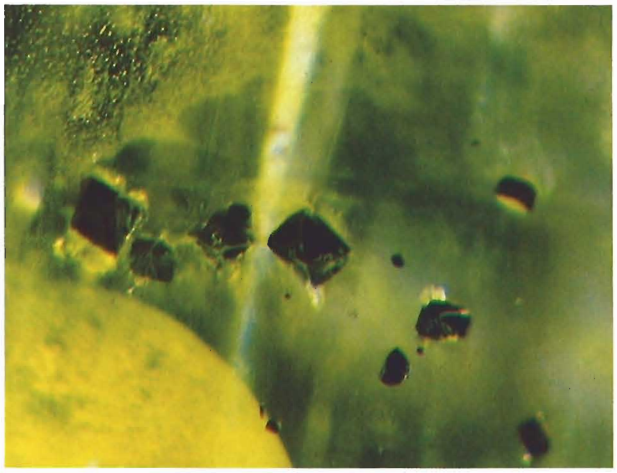
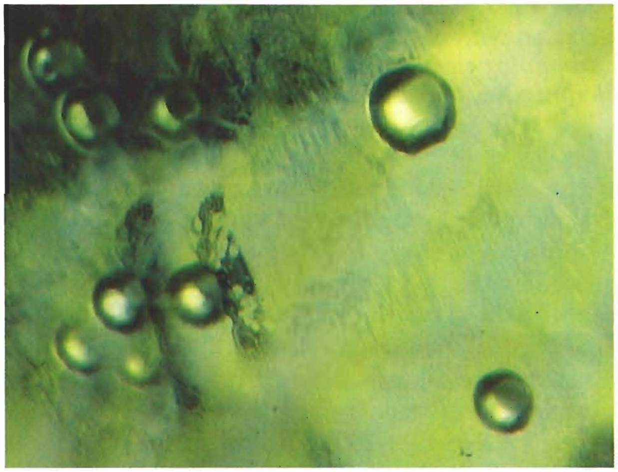


Figure 12. Negative crystals in San Carlos peridot. Oblique and transmitted light, magnified 100×.



the author theorizes that the primary component might be carbon dioxide (CO_2), as identified in similar negative crystals by Roedder (1965,1976) in experiments that he performed on peridots from a number of localities.

"Lily Pad" Cleavages. The lily pad–like, disc-shaped inclusions commonly associated with peridot are abundant in Peridot Mesa gems (see figure 13). "Lily pads" in San Carlos peridots are all oriented along one of two directions of imperfect cleavage: the planes designated [010], the most common orientation for the lily pads, and [100]. These cleavages result from the rupturing of a negative crystal and appear as circular to oval-shaped discs surrounding a transparent to whitish negative crystal that may appear dark or even black under certain lighting conditions. It is hypothesized that rupturing of the negative crystals is the result of heat and diminishing pressure as the peridot is brought to the surface by the basalt. As pressure falls off and the peridot is continually heated by the molten basalt, fluids (possibly CO_2) that filled the negative crystals at a much greater pressure push outwardly against their peridot host until the pressure is released through the formation of a cleavage around the negative crystal. When viewed in reflected light, as in figure 14, the details of the cleavage surface and any subsequent healing that may have taken place are easily studied.

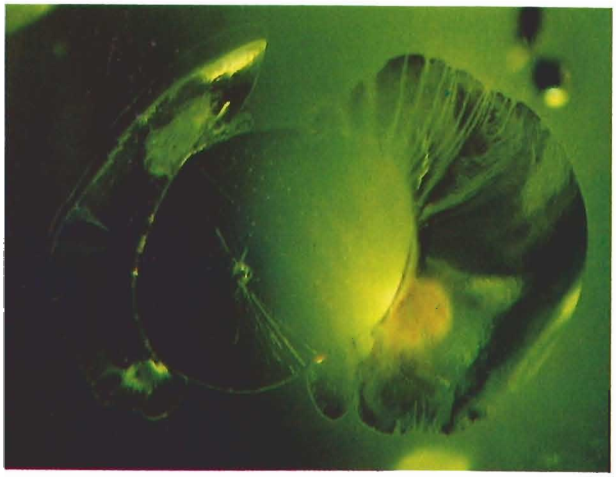


Figure 13. Typical San Carlos "lily-pad" inclusion with central negative crystal and surrounding cleavage disc. Dark-field illumination, magnified 45×.

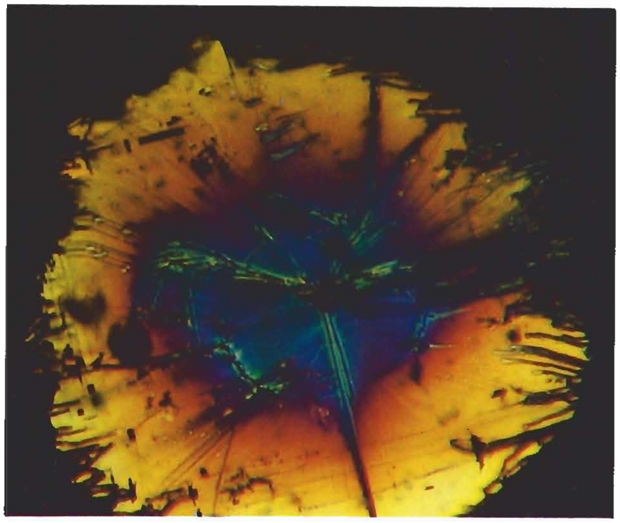
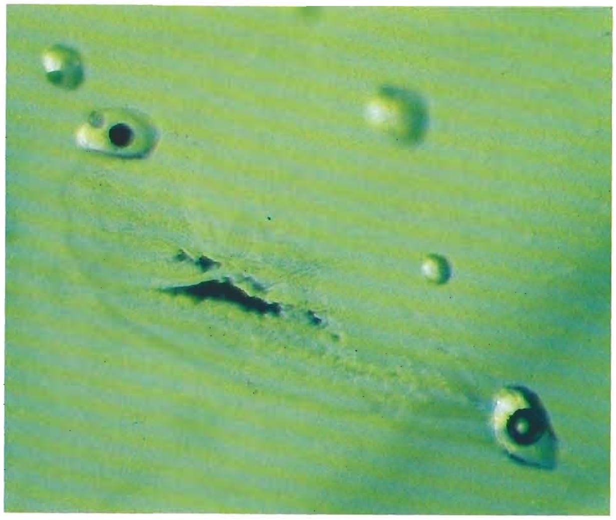


Figure 14. "Lily-pad" inclusion as viewed under reflected light, "thin film" conditions. Oblique illumination, magnified 70×.

Glass Blebs. The peridots from Peridot Mesa contain numerous tiny glass blebs that are very similar in appearance to those described by Roedder (1965, 1976) and Gübelin (1974, pp. 168–169) in Hawaiian peridots. Microscopic examination of the glass inclusions shows that they often contain one or more shrinkage gas bubbles (see figure 15).

Figure 15. Blebs of natural glass in San Carlos peridot often contain one or more gas bubbles. Transmitted light, magnified 150×.



Movement of the gas bubbles in the glass beads was brought about by carefully heating the peridot host to a temperature between 800° and 900° C. At these temperatures, the glass beads melt and the gas bubbles are free to move. Such heating, however, often results in the explosive rupturing of these fluid inclusions. Cooling experiments performed on the gas bubbles, with liquid nitrogen as the cooling agent, indicate that the gas filling the bubbles may be carbon dioxide. When cut through during lapidary treatment, some of the glass inclusions show themselves to be underdeveloped negative crystals lined with only a very thin shell of glass.

Chrome Diopside. Included crystals of chrome diopside can easily pass unnoticed in a microscopic examination of San Carlos peridot unless they are somewhat large, because they show virtually no interfacing and their color (see figure 16) and refractive index are very near those of peridot (Koivula, 1980). In polarized light, however, they are readily revealed as rounded subhedral to anhedral protogenetic included crystals. Thus far these crystals have not been reported in peridot from any other locality and may, therefore, be diagnostic of the San Carlos material.

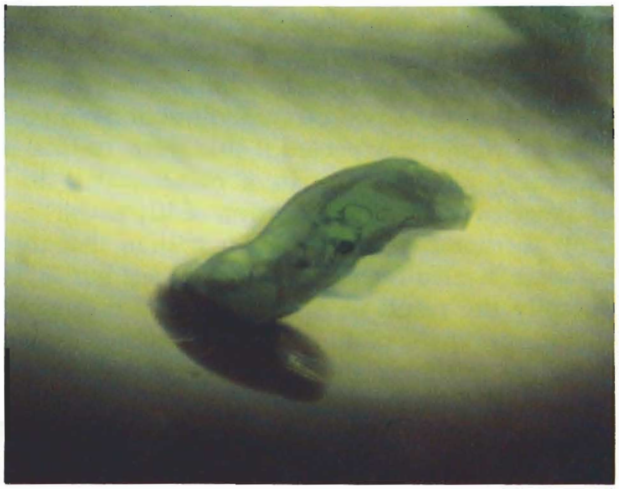


Figure 16. The deep green of this protogenetic crystal of chrome diopside contrasts with the lighter green of its peridot host. Transmitted light, magnified 50×.

Biotite. As described by Gübelin (1974), biotite mica is a rare inclusion in San Carlos peridot. Only one small, euhedral, flat, brown, translucent, tabular crystal was noted by the author during this study.

Smoke-Like Veiling. Never before described or photographed, and yet very common in San Carlos peridot, the smoke-like veiling shown in figure 17 at first appears to be a simple form of healing fracture. However, it should be noted that no individual healing tubes or the tiny negative crys-

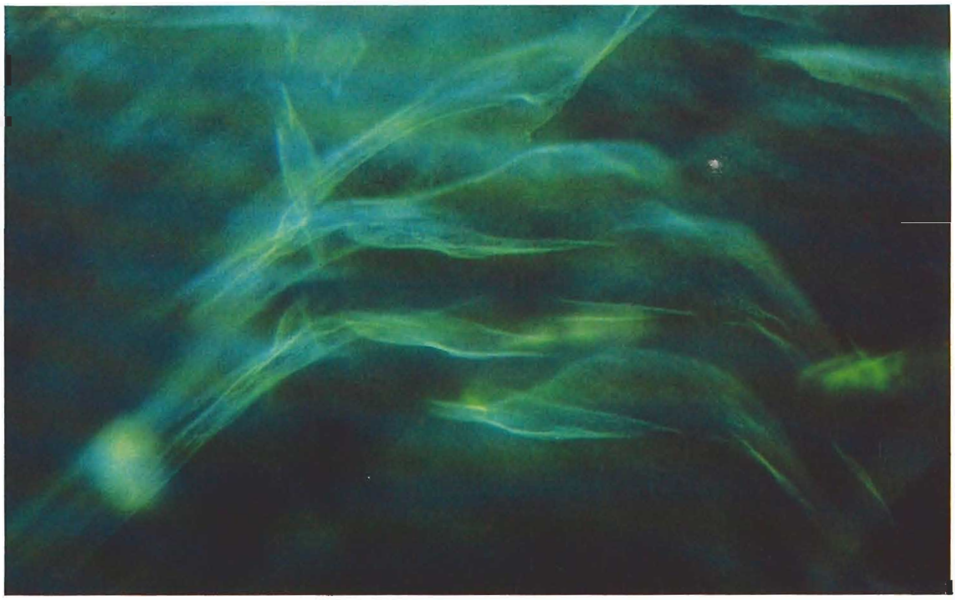


Figure 17. Characteristic of peridot from the San Carlos locality, this smoke-like veiling is possibly the result of solid-solution unmixing or decorated dislocations. Dark-field illumination, magnified 60×.

tals that are commonly associated with healing fractures can be microscopically resolved in any of the smoke-like wisps. In addition, the veiling never follows the two cleavage directions in peridot, as would be expected if this were, in fact, a fracturing phenomenon in a mineral that had cleavage (witness the formation of lily pads).

It is, therefore, this author's opinon that this is not a healed-fracture phenomenon, but it is possibly the result of a solid-solution unmixing that occurs as the peridot is brought to the surface and cools in the basalt. Other possibilities would be olivine dislocation decoration as described by Kohlstedt et al. (1976), who picture inclusions somewhat similar to that shown in figure 17, or a combination of solid-solution unmixing and decorated dislocations.

It should be noted that the image in figure 17, which was selected because it is so highly photogenic, is an exceptionally sharp example of smoke-like veiling in peridot. In general, the effect is much more ghost-like, with the wisps so fine and sometimes so concentrated as to fill the entire host peridot completely, rendering it slightly milky.

CONCLUSIONS

Peridot mining on the San Carlos Apache Reservation is an erratic affair, with most of the work done by hand by the Indians who hold the rights to the deposits. Once the peridot is freed from its basalt host, it is sorted and marketed locally to wholesale and retail customers alike. While few, if any, formal production records have been kept, the author viewed thousands of carats of gem-quality material during his visit.

The gemological properties obtained from 12 test gemstones of San Carlos peridot are almost classic textbook values. With the exception of chrome diopside, which seems to be a diagnostic inclusion in San Carlos material, and the smoke-like veiling shown in figure 17, all other inclusions noted in this paper have been documented in peridot from other localities. This suggests a very similar paragenesis between peridot from San Carlos and that from other mining areas.

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NOTES
·AND·
NEW TECHNIQUES

IRRADIATED TOPAZ AND RADIOACTIVITY

By Robert Crowningshield

A parcel of 100 stones of deep blue irradiated topaz, imported from Brazil, was found to be radioactive at a level somewhat higher than typical background activity. Analysis indicates that the material had been treated by neutrons in a nuclear reactor. Most irradiated topaz in the trade is not *radioactive. Nevertheless, routine testing for radioactivity in topaz, beryl, green diamonds, red tourmaline, and possibly all gemstones may be advisable for the protection of the jeweler.*

Large quantities of colorless topaz are currently being treated by gamma irradiation to turn them blue, a process that does not produce radioactivity in the stone (Nassau, 1980). The resulting color is a medium deep blue that is significantly darker than that of most natural blue topaz. A considerably darker color does result in rare instances (M. Welt, personal communication, 1981); this blue color is produced by a treatment (nature unknown) that is purportedly used on colorless topaz that will not turn blue with gamma rays (M. Welt, personal communication, 1981).

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Mr. Crowningshield is Vice President–Director of the Gem Identification Department of the Gem Trade Laboratory, Inc., New York.

Acknowledgments: The author wishes to thank Dr. K. Nassau and Dr. M. Welt for experimental results and helpful discussions.

Dr. M. Welt of Radiation Technology, Rockaway Township, NJ, was shown a parcel of about 100 unusually deep blue topaz gemstones that had recently been imported from Brazil. Upon testing, he found them to be radioactive. Two of these stones were further examined by the author and Dr. K. Nassau of Bernardsville, NJ, and are described below. Subsequently, Dr. Welt tested lighter blue topaz that also proved to be radioactive. Representative samples of light and dark irradiated stones and a larger, even lighter natural blue topaz are shown in figure 1.

EXAMINATION

The two stones, 8 cts. and 10 cts. in size, were exceptionally dark, fine-quality blue topaz. Gemological testing revealed a typical natural topaz: with two-phase inclusions typical of topaz, refractive index of 1.61–1.62, birefringence about 0.009, biaxial—doubly refractive, specific gravity of 3.57, no features observed in the spectroscope, and greenish fluorescence (long-wave, very faint; short-wave, barely detectable).

The 10-ct. stone showed about 0.2 milliroentgens per hour (mr/hr)* when tested in contact with a Geiger counter survey meter, while the parcel of about 100 stones shown to Dr. Welt

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**The Roentgen, rad, rem, and rep are units used for radiation dose and differ only slightly in value. Microcuries (μc) are units that measure the quantity of radioactive material.*

Figure 1. Three representative samples of blue topaz. The two smaller stones on the left have both been irradiated to enhance color. The larger, lighter blue stone on the right has not been treated. Photograph by Tino Hammid.

measured at 12 mr/hr. Gamma-ray spectroscopic examination (K. Nassau, personal observation, 1981) showed the presence of the following amounts of radioactive elements:

scandium-46:	0.1 μcuries (half-life 84 days)
tantalum-182:	0.002 μcuries (115 days)
manganese-54:	0.002 μcuries (303 days)
iron-59:	0.001 μcuries (45 days)

These radioactive elements were probably produced from neutron exposure in a nuclear reactor by neutron reactions with scandium, tantalum, iron, and cobalt, respectively. It should be noted that the radioactivity from the major emitter, scandium-46, is quite penetrating, consisting of gamma rays with the relatively high energy of 889,000 and 1,120,000 electron volts.

DISCUSSION

A number of important points arise from these findings.

First, the nature of the radioactivity indicates that the stones were exposed to neutrons in a nuclear reactor. The importer stated that he had obtained several hundred of these stones some months previously in Brazil. Given the half-lives of the radioactive elements involved, it is obvious that the stones had been even more radioactive then; the dealer may have received an undesirable dose of radioactivity himself while carrying them about for some weeks. It is also evident that the stones were imported without the required radioactive materials import license (issued by the Nuclear Regulatory Agency).

Second, a spokesperson for the Nuclear Regulatory Agency stated that, for relatively low levels of activity such as might be associated with a single stone, there are no appropriate standards. This person added, however, the personal observation that the 0.2 mr/hr intensity of the 10-ct. stone definitely would be "not desirable" for extended personal wear.

Third, a survey conducted by Dr. M. Welt, Dr. K. Nassau, Mr. S. Church (of Church & Company, Bloomfield, NJ), and others of a wide variety of blue topaz, including several lots of the dark blue material, indicates that none of these others contained detectable radioactivity above the usual background reading of 0.02–0.05 mr/hr. Accordingly, it is not at present possible to determine the extent of the problem.

Fourth, radioactivity has been reported in a number of other gemstones, such as some of the Maxixe-type blue beryls (Nassau, 1973) and the occasional old radium-exposed green diamonds (Liddicoat, 1981). Testing in the Gem Trade Laboratory has shown that some of the latter are extremely high in radiation emission, darkening photographic film in just a few minutes. In addition, people are experimenting with irradiation on a wide variety of gem materials, for example, to turn pale tourmaline dark red (Nassau, 1974). Tests show that some of these materials may also be radioactive. It should be noted that even if the color fades or is removed by heat treatment, the radioactivity still remains.

The specific type and intensity of the radioactivity will depend on impurities present in the gemstone as well as on the time of exposure in the nuclear reactor. All radioactive material slowly loses its activity, the time being dependent on the half-lives of the active elements involved.

Fifth, for the protection of his staff and himself personally, as well as for liability protection with respect to his customers, the jeweler (particularly one who handles large parcels of any particular type of gemstone) may wish to obtain a Geiger counter survey meter and check all parcels of stones. A similar test should probably be performed routinely on all stones examined in testing laboratories.

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NONFADING MAXIXE-TYPE BERYL?

By K. Nassau and B. E. Prescott

It is sometimes stated that there exists some Maxixe-type deep blue beryl (occasionally misnamed "aquamarine") that does not fade. All specimens ever reported in the literature did fade, typically to almost colorless in one to two weeks in bright sunlight or over a somewhat longer period under less intense illumination. A "nonfading" specimen recently examined proved to be typical fading Maxixe-type beryl. A possible reason why such a stone might give the impression that it is nonfading is discussed. With the exception of some brown topaz and some kunzite, no significant gemstone material fades on the same time scale as does Maxixe-type beryl.

Several years ago there appeared on the gemology scene a deep blue beryl that had unusual properties. Specifically, the material was at first designated aquamarine; but the dichroism of the stone differed from that of aquamarine. It was soon shown that the color faded upon exposure of the material to heat or to light. A detailed study (Nassau and Wood, 1973a and 1973b; Nassau et al., 1976) demonstrated that an irradiation-induced color center produced the color and that this material was closely related to, but not identical with, the naturally occurring deep blue beryl found in 1917 in the Maxixe mine in the Piaui area of northeastern Minas Gerais, Brazil, which also faded. The new material was designated "Maxixe-type beryl" to distinguish it from the original, natural "Maxixe beryl." Although the stones appear to fade at the same rate, the color centers in these two materials have been shown to be slightly different (Anderson, 1979).

Statements are occasionally made that specific specimens of Maxixe-type beryl do not fade. All such material studied in detail and reported in the literature has been found to fade (e.g., Nassau and Wood, 1973a and 1973b; Crowningshield, 1973; Schmetzer et al., 1974; Nassau et al., 1976; and Anderson, 1979). One such purportedly nonfading specimen recently became available to the authors; it was examined to establish if it did fade

ABOUT THE AUTHORS

Dr. Nassau and Dr. Prescott are research scientists residing in Bernardsville and Murray Hill, New Jersey, respectively.

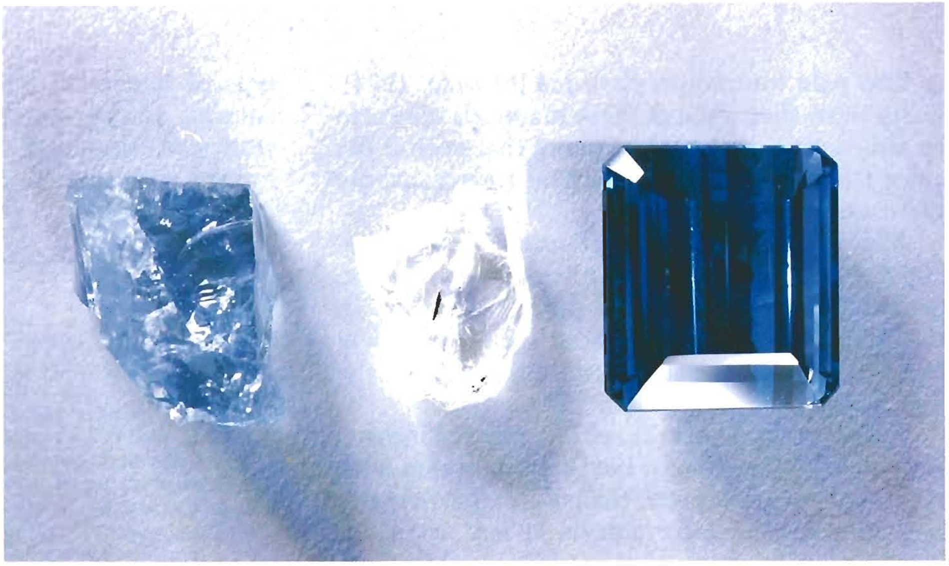

Figure 1. Three Maxixe-type beryls: left—the subject specimen as received; center—the specimen after being subject to light and heat (corresponding to curve C of figure 2); right—a typical, near-saturated dark blue specimen.

and, if so, why the claim that it did not would have been made.

THE EXPERIMENT

A 2-cm fragment of blue beryl was obtained with the kind cooperation of Dr. J. Keane of KMC Inc. (Bedford, MA). The specimen was reported to originate from a New England locality, although the exact site was unknown. It had been irradiated some years ago and purportedly had maintained its color during this time while lying on a desk.

Examination showed a typical Maxixe-type beryl, but of a much paler blue than the intense color that usually results from irradiation to saturation, as seen in figure 1. A slice cut from the specimen was polished and the polarized spectra were measured in a Cary Model 14 spectrophotometer at room temperature. The result was an absorption spectrum typical of a Maxixe-type beryl, with the blue-causing absorption bands in the ordinary ray (Nassau and Wood, 1973a and 1973b; Nassau et al., 1976), as at A in figure 2.

This specimen was exposed for 100 hours (at a distance of 10 cm) to the focused light from a 25-watt microscope lamp equipped with a blue filter in an environment that was air-conditioned in such a way that no heat was experienced by the beryl. As can be seen from the much-reduced absorption in curve B of figure 2, this treatment produced a drastic bleaching. Heating in an oven at 200°C overnight removed all the remaining color, as shown in curve C of figure 2 and also in figure 1.

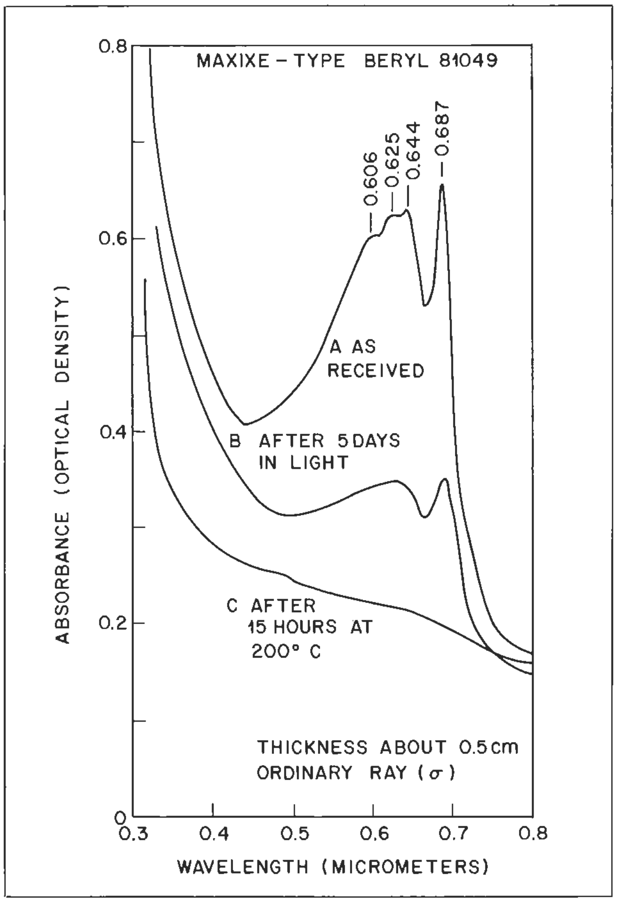

Figure 2. Absorption spectra plotted for the Maxixe-type beryl studied: curve A—as received; curve B—after 100 hours under a 25-watt microscope lamp; curve C—after heating at 200°C overnight (ordinary ray spectrum only shown here).

DISCUSSION

The specimen proved to be an "ordinary," fading Maxixe-type beryl and had undoubtedly faded significantly since it was irradiated. The question remained, though, why it had been thought to be nonfading.

A possible answer was obtained by means of some light-intensity observations taken with a photographic exposure meter. From a series of measurements recorded during a sunny day (late June in New Jersey) and from a sampling of desks, ranging from brightly lit by a large window to the more usual interior desks lit by incandescent or fluorescent lamps, it was found that the average desk illumination was about one hundredth the average outdoor illumination. Accordingly, a Maxixe-type beryl that faded in one week in the sun to less than one half its original color would reach the equivalent stage in 100 times as long a period on a typical desk, that is, in two years.

A series of factors may slow the fading even more: the illumination at some desks is lower than at others; the stone may lie face down, so that what light there is does not enter as effectively as occurred in a purposely face-up positioned fade test; papers can inadvertently cover the specimen part of the time; and there is some small variability among Maxixe-type beryls that otherwise appear to be identical, as has been reported (Nassau et al., 1976).

The "nonfading" specimen examined in this report had not lost all of its color over several years on a desk. Clearly, though, it had lost some color, but the loss had been so slow and gradual that it was not evident to the eye in the absence of a color reference sample.

A survey was made among various gem authorities for other gemstone materials that might fall into a similar fading category. Only three were candidates. Of these, amethyst was eliminated since reports of fading could not be substantiated where a high probability of exposure to heat was not also present. There remained brown topaz from a few localities (such as some in Mexico and in Utah) which fades rapidly, and also some kunzite. Apart from these, all other acceptable gemstones do not fade even after many decades under bright spotlights in museum and store displays.

It may be concluded that no authentic instance of nonfading Maxixe-type beryl has been proved. Although fading may be delayed by exposure to only low levels of light and can be halted completely in the absence of light, there is a major qualitative difference between this material and nonfading gemstones acceptable to the trade.

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THE CUTTING PROPERTIES OF KUNZITE

By John L. Ramsey

In the process of cutting kunzite, a lapidary comes face-to-face with problem properties that sometimes remain hidden from the jeweler. By way of examining these problems, we present the example of a one-kilo kunzite crystal being cut. The cutting problems shown give ample warning to the jeweler to take care in working with kunzite and demonstrate the necessity of cautioning customers to avoid shocking the stone when they wear it in jewelry.

The difficulties inherent in faceting kunzite are legendary to the lapidary. Yet the special cutting problems of this stone also provide an important perspective for the jeweler. The cutting process reveals all of the stone's intrinsic mineralogical problems to anyone who works with it, whether cutter or jeweler. Knowledge of these problems also aids the person marketing the stone, both in conveying the specialness of the faceted gem and in advising customers of the proper care that it requires.

To explain the various problems presented by kunzite, this article describes the cutting of an extremely large kunzite crystal. In some ways, the size of the crystal magnifies the problems and renders them examinable in a manner that allows us to generalize to all kunzites.

It should first be mentioned that the availability of a one-kilo, essentially clean kunzite crystal from Brazil in today's marketplace is in itself a phenomenon. Certainly, a number of fine crystals from Brazil were available in the late 1950s and early 1960s, but these disappeared from the market some time ago. Afghanistan produces kunzite, but nothing of the size and quality of the crystal described. This particular crystal, which was virtually unflawed and of superb color (figure 1), had been held in a European collection for 25 years before its release to the author.

THE PROBLEMS OF PERFECT CLEAVAGE AND RESISTANCE TO ABRASION

Kunzite is a variety of spodumene, a lithium aluminum silicate (see box). Those readers who are familiar with either cutting or mounting stones in jewelry are aware of the problems that spodumene, in this case kunzite, invariably poses. For those unfamiliar, it is important to note that kunzite has two distinct cleavages. Perfect cleavage in a stone means that splitting, when it occurs, tends to produce plane surfaces. Cleavage in two directions means that the splitting can occur in a plane along either of two directions in the crystal. The property of cleavage, while not desirable in a gemstone, does not in and of itself mean trouble. For instance, diamond tends to cleave but splits with such difficulty that diamonds are cut, mounted, and worn with little trepidation. In contrast, the abrasive process used in sawing and faceting represents a danger with kunzite. The separation in kunzite happens very easily, especially if the stone is ground against the direction of cleavage, and it may simply fall apart during faceting.

To compound the problem, kunzite has an unusual resistance to abrasion. While the hardness of spodumene is 6½ to 7, it grinds with more difficulty than corundum which, at 9, is exceeded in hardness only by diamond. The resistance no doubt comes from the crystal structure, which is also responsible for the problems with cleavage. The combination of these two problems in one gem material forces the cutter to delicately balance two factors: (1) a stone that resists abrasion

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Mr. Ramsey is president of Ramsey Gem Import, Inc., Escondido, CA.

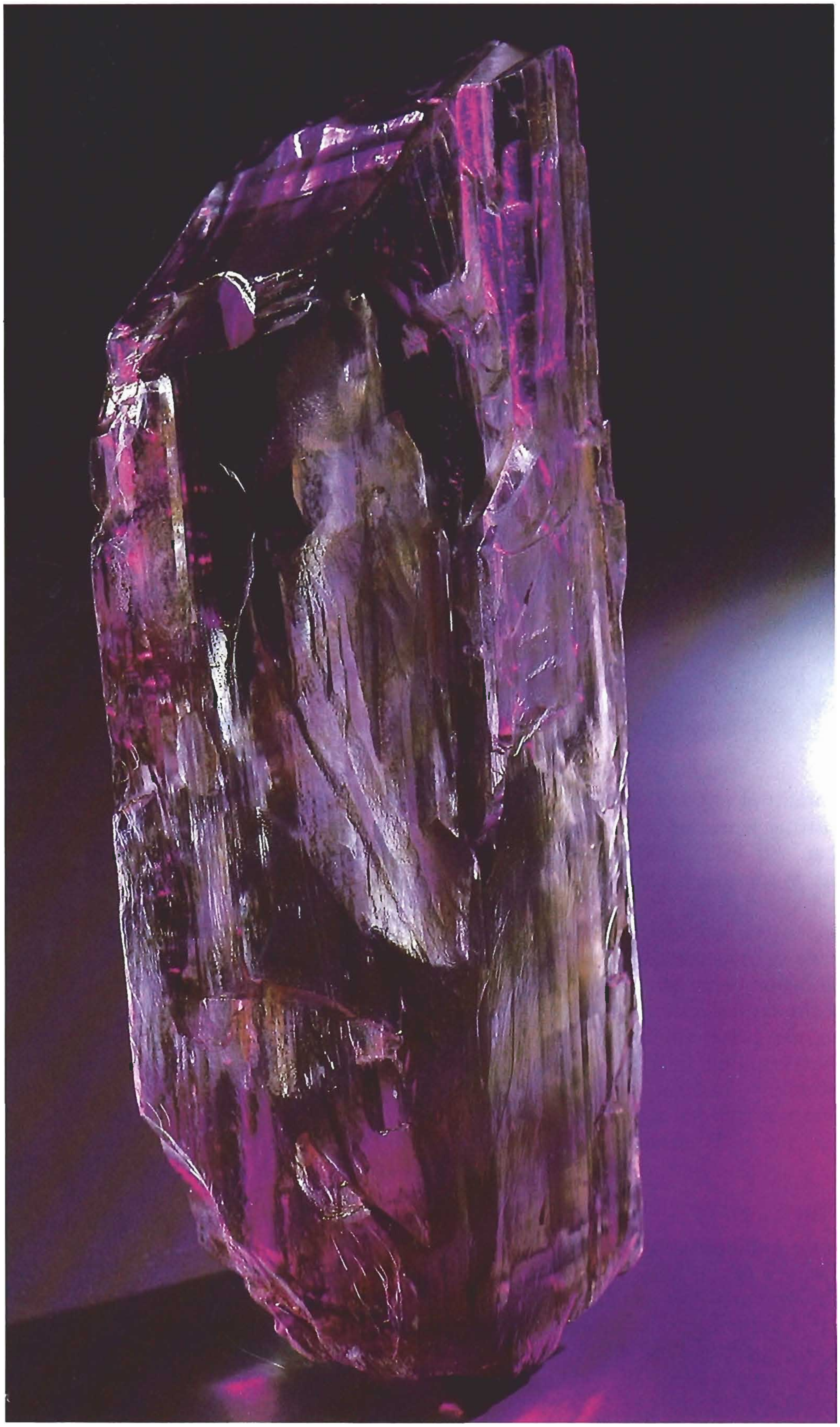

Figure 1. The one-kilo kunzite before cutting. The dimensions were 150 cm × 5.1 cm × 4.9 cm. Photograph ©1981 Laura Ramsey.

PROPERTIES OF SPODUMENE

SPECIES: spodumene (lithium aluminum silicate)
Varieties: kunzite (lavender, pink, amethystine purple)
hiddenite (green)
triphane (colorless to yellow)
Problem inclusions: tubular inclusions
rutile
open cleavages

JEWELRY PROPERTIES
Hardness: 6½–7
Cleavage: perfect, two directions
Fractures: subconchoidal, frays easily
Steam cleaning: extremely sensitive; use other method

OPTICAL PROPERTIES
Refractive index: 1.660 (±0.005) to 1.676 (±0.005)
Birefringence: 0.016, medium
Pleochroism: trichroic—light to deep colors
Dispersion: 0.017, medium
Specific gravity: 3.18 (±0.03)

must be given a fair amount of physical pressure against the diamond cutting wheel or it will not cut, and (2) a stone that will split easily in two directions may separate if too much pressure is placed against the lap.

In addition, the propensity of kunzite to fall apart during cutting tends to be aggravated by the fact that resistance to abrasion varies with respect to the different axes of the crystal. Since dopping is not an exact process, the cutter cannot determine precisely whether grinding will be only mildly difficult or extremely difficult. Kunzite never grinds easily. One positive point, though, is that kunzite is perhaps one of the easiest stones to polish.

HOW LARGE A STONE TO CUT?

With these factors in mind, the next step was to determine the optimum size of the finished material. The rule of thumb in cutting is usually to produce the largest gem possible from each piece of rough regardless of the species. This is done because large stones are relatively rare. For every one-carat diamond there are hundreds or thousands of 10 pointers, and so on through most of the known gem species.

Upon evaluating this kunzite, we saw that we had three cutting options: (1) one 1,500-ct. stone, (2) many smaller gems, or (3) several extremely large gems.

Cutting a 1,500-ct. stone was a temptation, since at that size it would have been one of the largest spodumenes ever faceted (see Sinkankas, 1959, for a description of the cutting of an 1,800-ct. green spodumene). Kunzite is distinctly trichroic, however, and the best color is seen parallel to the c-axis of the crystal, which is invariably also the narrow axis. While trichroism in kunzite varies from crystal to crystal, in this case the exceptionally high trichroism of the stone virtually dictated the cutting orientation: the table(s) had to lay perpendicular to the c-axis. The choice of cutting a single 1,500-ct. stone was, therefore, ruled out because of the poor color orientation that would have resulted.

Following the premise that in any gem the size/quality ratio is of paramount importance, we also ruled out the second alternative, that of cutting the crystal into many small stones (although we were assured by many gem dealers that there is a ready market for these smaller gems). Instead, we chose as our model the 800-plus-carat kunzite housed in the Smithsonian Institution, Washington, DC, which is one of the few large spodumenes of the variety kunzite with exceptional color and clarity.

From the point of view of aesthetics, there was only one choice. Not only did the trichroism of this crystal dictate the cutting preference, but the opportunity to cut some genuinely fine, large kunzite gems, and thus add to the other large stones already in existence, also prompted the selection of the third option.

CUTTING THE CRYSTAL

Tom Carleton, of Menasha, Wisconsin, agreed to do the cutting under the author's supervision. At this point, we looked to the existing literature for tips on cutting spodumene, but found little helpful information. The article by Sinkankas referred to earlier discusses some basic techniques, but new technology has contributed much to the field in the two decades since that article appeared. For example, whereas Sinkankas had to charge his own cutting laps, we had precharged, bonded and plated diamond laps. Then, too, there is some published information with which we disagree on the basis of previous experience cutting smaller spodumenes. In their book, *Faceting for Amateurs,* Glenn and Marth Vargas state that "the table should be oriented 80 or 100 degrees away from [the long axis of the crystal]." Although we have the utmost respect for the Vargas's and their book, use the book continually as a reference, and recommend it to every faceter we train, practical experience has shown this particular prescription to be unnecessary. For cutting procedures we had to rely primarily on our own experience and knowledge.

The next step was to calculate the largest fine-quality stone that could be realized from this crystal. In this case, the goal was to exceed the 560-ct. kunzite the author had cut the previous year. Given the dimensions and the weight of this first stone, we felt that we could predict the probable weight of a second stone of the same species. The two stones would be different in shape and the new stone was to be cut with different angles, so an exact comparison was impossible; yet the possible length × width × depth of the new stone correlated to the dimensions of the first such that a 700-ct. stone was deemed possible. Using these crude mathematical calculations, we marked a line on the crystal with a diamond scribe. That line was the place to begin sawing.

The initial sawing was done by the author (figure 2) because of his greater experience with kunzite. A Raytech saw was used, with Johnson Brothers blades. As a precaution against shocking the stone, the decision was made to change the saw blades at an extremely high frequency, two per cut. Because kunzite resists abrasion, it ruins any diamond tool, including saws. It seemed logical that a dull blade would generate a great deal of heat and possibly ruin the crystal (subsequent experiments with inferior material proved this point). The first saw cut was made starting at 3:00 p.m. (figure 3). Two hours and thirty-three minutes later we had a crystal section that weighed 1,298 cts. Nearly 40 minutes of this time was devoted to cooling down either the cutting oil or the crystal. We changed saw blades twice during that period.

Two and one-half hours to make a single saw cut is a very long time and demonstrates the amount of care required for this material. Sawing a quartz crystal of equivalent dimensions would take about five minutes.

Figure 2. The author examines the crystal during the sawing process.

The next step in the process was to dop the 1,298-ct. piece for faceting. Dopping involves attaching a stone for cutting to a dop stick—a metal rod that is inserted into the faceting machine. In this way the faceting machine holds the stone during cutting and permits very accurate grinding (abrading). In most faceting, the material holding the stone to the dop stick is a type of sealing wax, heated along with the stone to form the bond. In the case of extremely large stones, however, the danger of thermal (heat) shock is great because of the temperature difference between the outside of the stone, where heat is applied, and the interior of the stone, which starts out at room temperature. This is why steam cleaning is not recommended for jewelry containing kunzite. The

Figure 3. The crystal as it appeared moments after the first cut.

greater the size of a stone, the greater the problem. To avoid heat shock, epoxy was used to bond the rough stone to the dop stick.

One of the main concerns was whether or not the 1,298-ct. piece of rough would yield a finished stone of 700 cts. We calculated that our recovery rate had to be 54%, a little on the high side. Yet both the shape and cleanliness of the rough crystal were good, and the cutter had already proved that he was capable of a good recovery rate.

Another concern was the ability to maintain cutter concentration on the project (see figure 4). The demands of this kunzite—the slow grinding process when working across the end of the crystal, the possibility of splitting, and the high value of the stone—made the job very tedious. Yet a slow, tedious procedure must be observed to avoid fracturing or cleaving the stone. Jewelers face similar problems with kunzite during the mounting of a finished stone.

The grinding process that the cutter started with is called rough cutting, which is done with a coarse-grit diamond wheel. Normally a stone of this size would be ground with a grit of 180. Given the delicate nature of kunzite, however, a grit half that coarse, 360, was used. The rough cutting of the pavilion took three days. By way of contrast, the entire faceting process for a 20-ct. tourmaline, aquamarine, or garnet would normally take only a few hours. The faceting machine used for the kunzite was a second-generation design by Bryant Harris of Fallbrook, California.

Fortunately, the grinding process, which was potentially the most dangerous portion of the work (i.e., when splitting was most likely to occur), went well. The next steps, fine grinding and polishing, were unlikely to cause cleavage problems and went faster than the rough grinding. When the rough grinding was completed, we felt confident that the stone would hold together for the entire process, and it did. After 14 days, Carleton finished the first stone—703.5 cts. (see figure 5). We had reached our goal and were accurate in our calculations to within 0.49% or 49/1,000. More realistically, we were lucky within 99.999%.

The remaining stones went smoothly and more quickly. These stones weighed 725 cts., 514 cts., and 145 cts. respectively (see figure 6). The one-kilo Brazilian crystal had yielded four beautiful stones totaling 2,087 cts. Not only were the finished gems large but, as can be seen from the photographs, they were also of the finest possible color for kunzite.

Figure 4. Carleton faceting the kunzite. This custom-made faceting machine, a second-generation design by Bryant Harris of Fallbrook, California, is big enough to cut the world's largest faceted stone.

Figure 5. The first gem faceted from the crystal, 703.5 cts. The second stone is in progress, and the third still shows its crystalline origins. Photograph ©1981 Laura Ramsey.

Figure 6. The final three kunzites: 725, 514, and 145 cts., respectively. Photograph ©1981 Laura Ramsey.

CONCLUSION

The care shown in working this crystal into finished gems emphasizes the need for care that everyone must show kunzite. The jeweler must exercise caution in the choice of a protective mounting and in the mounting process. Proper admonition to purchasers to avoid shock to the stone is also advised. Only when jewelers and their customers are adequately educated in the properties of all colored stones will the market be able to fully utilize and appreciate these gems.

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Gem Trade
LAB NOTES

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A CORAL SUBSTITUTE, DYED MARBLE

The Santa Monica laboratory recently encountered some loose drilled beads that looked like reddish-orange coral to the unaided eye. A micro-spot hydrochloric acid test revealed effervescence, a typical carbonate reaction. High birefringence by the spot method was also indicative of a carbonate. Under the microscope, however, the structure associated with coral was not seen. Instead, the material had the somewhat granular, almost sugary, texture indicative of marble. In addition, surface fractures could be seen to contain concentrations of a reddish-orange dye (see figure 1).

If a gemologist were to examine this type of material without checking structure and allow the color and birefringence to influence his judgment, he could easily mistake these dyed marble beads for true reddish-orange coral.

Figure 1. Concentrations of dye in a marble bead. Magnified 6×.

DIAMOND

Angular Grooves on Diamond

While visiting Japan, a New York dealer acquired a diamond that showed very unusual features. As can be seen in figure 2, small marks extend from the girdle up across two upper girdle facets into a bezel facet. They outline the shape of an angle. This same outline was found in different places in the crown area. The Santa Monica laboratory had not previously seen a diamond with these characteristics. We still have no explanation for how these grooves might have occurred. Perhaps one of our readers can solve this mystery.

Figure 2. Unusual marks on a diamond. Magnified 16×.

Burned Diamond

Burned diamonds are occasionally submitted to the laboratory for the purpose of estimating fire damage and the approximate weight loss to be anticipated in recutting. Sometimes these stones have suffered no permanent damage. Most diamonds that are mounted in jewelry and worn frequently accumulate foreign substances such as oils and soaps, particularly on pavilion surfaces. When they are placed in contact with high heat, such as that which would be encountered in a fire or in retipping a prong, the foreign substances often become charred. While this charred residue is usually difficult to remove, in many cases boiling the stone in an acid bath will clean the offensive coating.

Other diamonds may be damaged more severely and may have suffered surface erosion as a result of oxidation. These stones require repolishing to repair the damage. Recently submitted to the Los Angeles laboratory was a yellow pear-shaped diamond that was reportedly burned in a house fire (see figure 3). This stone was burned so severely that none of the facets remained and large cavities appeared on both the

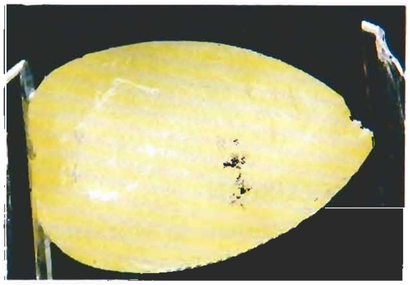


Figure 3. Badly burned diamond. Magnified 18×.

crown and pavilion surfaces. Since the color of this diamond proved to have resulted from artificial irradiation, the client decided not to have the stone recut.

"Chameleon" Diamond

Some of the rarest fancy color diamonds are the medium dark, yellowish- to grayish-green stones known as "chameleon" diamonds because they will temporarily change color and become yellow after a period in darkness. They will also turn yellow when heated mildly. Most return to their green color after only a short exposure to light. All such stones that we have encountered may be recognized by the strong yellow fluorescence and phosphorescence. Diamond polishers recognize them by the intense red glow they emit while on the wheel.

Recently, in our New York laboratory, we encountered two very pale grayish-green stones that we were about to dismiss with the statement, "Color origin undetermined," when the yellow phosphorescence was noted. On a hunch, we checked the color before and after mild heating in an alcohol flame. As we suspected, when the stone was heated all traces of green disappeared, leaving a pleasant light yellow color. The green returned after about five minutes in the Diamondlite.

By coincidence, the next day we received two slightly darker grayish-green "chameleons." According to the cutter, both came from the same rough and glowed red while on the wheel.

The greatest coincidence occurred later that day when we received a pear-shaped, typical dark gray-green stone that turned to an intense orange-yellow when heated. It too returned to green after about five minutes in the Diamondlite. A faint absorption line at about 4190 Å could be seen in the hand spectroscope—one of two absorption peaks in the area that were observed more readily with the recording spectrophotometer.

Green Diamonds

Occasionally, we encounter other pale green diamonds with green or brown spots on their naturals or faceted girdles (figure 4). This suggests—but does not prove—that the stones have been exposed to natural irradiation, which often produces green-skinned and brown-skinned rough crystals (see figure 5).

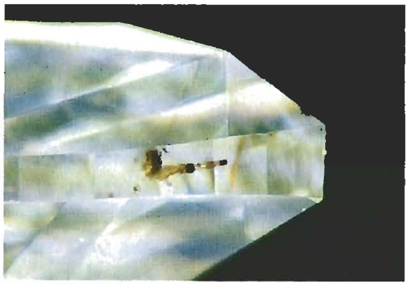


Figure 4. Brown spots on the faceted girdle of a diamond. Magnified 20×.

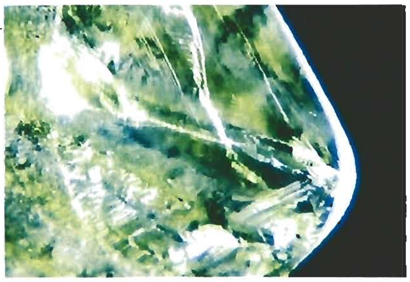
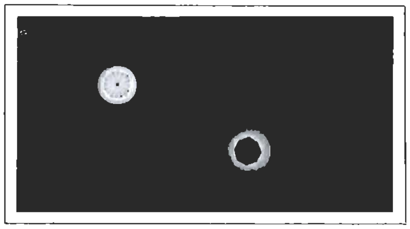


Figure 5. Green skin on a naturally irradiated rough diamond crystal. Magnified 15×.

Figure 6. Short-wave ultraviolet transparency test of type II_A (left) and type I (right) diamonds.



Other pale bluish-green diamonds seen recently in the New York laboratory were determined to be type II_A stones, which are transparent to short-wave ultraviolet light. The dark-centered stone on the left in figure 6, a short-wave transparency test photo, is type II_A; the other stone is type I. Although the color could be due to irradiation, type II_A crystals that have this color naturally have been recorded. The questions arise: Can the color green in diamonds ever be due to factors other than irradiation, either natural or man induced? What caused the color of such famous green diamonds as The Dresden Green?

Figure 7 illustrates a dark green round brilliant with mossy color patches over the entire surface. Such an appearance immediately suggests radium treatment. However, the stone neither reacted to the scintillometer (Geiger counter) nor "took its own picture" from radioactivity when placed on a film overnight. Every indication points to a treated stone, but we do not know what treatment method was used.

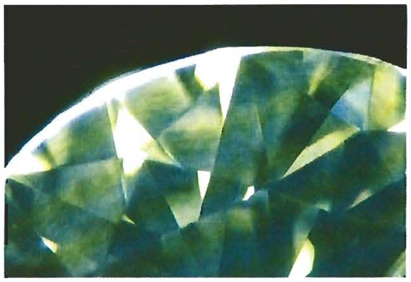


Figure 7. Mossy color patches on what appears to be a treated green diamond. Magnified 15×.

EMERALD

Emerald Substitute, Dyed Beryl

A cabochon set in a yellow metal mounting was recently submitted to the Santa Monica laboratory for identification. Testing proved it to

Figure 8. Dyed beryl cabochon in a ring. Magnified 6×.

be a whitish beryl that had been partially dyed green to resemble an emerald (see figure 8). We often see pale emeralds dyed to improve their appearance, but this stone was an example of complete color alteration from white to green through dying.

A similar situation occurred when a lot, consisting of transparent green emerald-cut stones ranging in size from one to two carats, was brought to the Los Angeles laboratory. The client explained that these stones had been stored in a gem paper for several years and had lost a significant amount of their green color. Three of the stones were selected from the lot for identification. Two of these proved to be emeralds oiled in the manner that seems to be typical. These two stones apparently lost some oil over the years so that the color subsequently appeared lighter.

When the third stone was viewed with the unaided eye in overhead lighting, it appeared to be a medium-dark green with just a few near-colorless areas. Figure 9 shows how this stone appeared in dark-field illumination. When the stone was placed on translucent white plastic over transmitted light, however, it proved to be a near-colorless beryl with green and minor amounts of yellow dye present in numerous surface fractures (see figure 10). The client stated that this stone had lost more color than the rest of the stones in the lot.

The use of translucent white plastic over an intense light source, as in this case, and examination of the stone under a microscope using transmitted light are the easiest ways of detecting this type of treatment. The former technique, in particular, is an excellent, simple alternative to immersing the stone in a heavy liquid, which carries the risk of removing dye, oil, cement, and the like.

Figure 9. Dyed beryl as seen with normal, dark-field illumination. Magnified 10×.

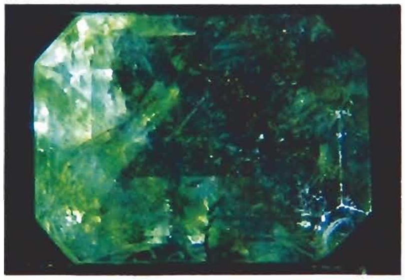


Figure 10. Dye concentration visible in the stone shown in figure 9 when viewed over diffused transmitted light. Magnified 10×.

A Remarkable Three-Phase Inclusion

The Santa Monica laboratory had the welcome opportunity to examine a Colombian emerald crystal that played host to one of the largest three-phase inclusions ever encountered. The crystal measured approximately 22.8 mm in length by 11.3 mm in largest diameter and weighed 24.07 cts.

The fluid inclusion in the crystal was easily visible to the unaided eye. The gas bubble measured approximately 5.0 mm in its longest dimension, and as the crystal was tilted it moved back and forth quite readily in its liquid-filled chamber. Note the position change of the gas bubble in figures 11 and 12. Also trapped within the inclusion, suspended in the liquid phase and adhering to the surface of the gas bubbles, were a countless number of tiny white crystals that appeared to be calcite. A black opaque material thought to be shale and metallic, brass-colored crystals of pyrite were also present.

Figure 11. Large bubble in a three-phase inclusion in emerald. Magnified 6×.

Figure 12. Movement of the bubble in emerald from the position shown in figure 11. Magnified 6×.

PEARLS

Natural Pearls Worn Out

The natural pearl necklace in figure 13 was more worn than any previously seen in the New York laboratory. Many of the small pearls that undoubtedly touched the wearer's

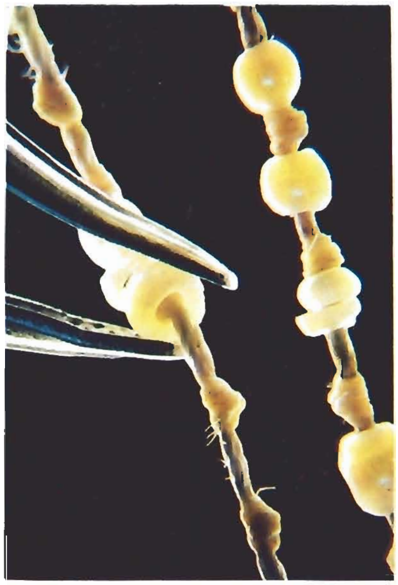


Figure 13. A pearl necklace showing extreme wear. Magnified 10×.

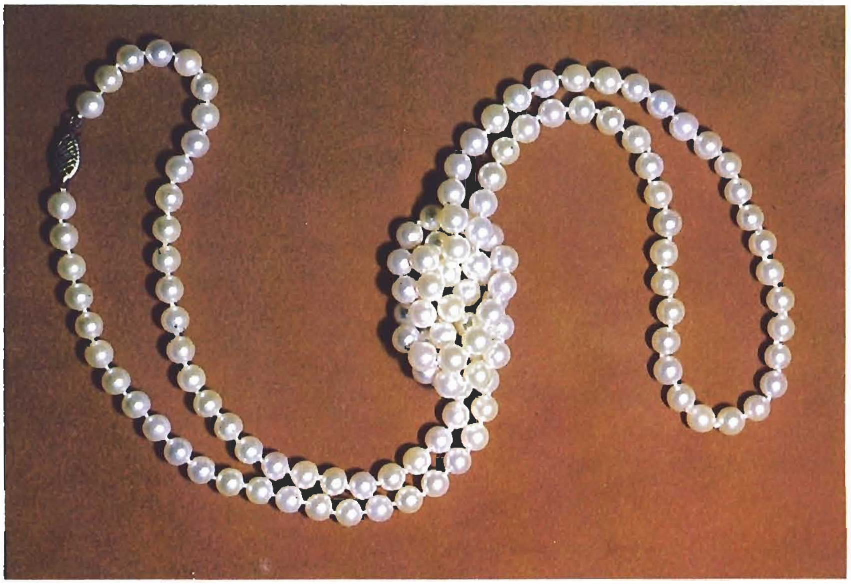


Figure 14. A rope necklace of 7½-mm mother-of-pearl beads.

neck were either gone entirely or reduced to fragments. The one held by the stoneholder in this photo could be passed over all the knots in its area. The mystery is that the string still appeared to be relatively strong. Although such damage is not a common occurrence, people with an acid skin condition should be cautioned not to wear pearls constantly against the skin or should be advised to rinse them in water after wearing.

Pearl Simulant

Figure 14 illustrates a not-unattractive rope necklace of mother-of-pearl beads with a lacquer coating that was seen in New York. We could not substantiate the client's claim that these are very thin-nacre ("immature") cultured pearls with a nearly clear lacquer as a protective coating. When a commercial fingernail polish remover dissolved the lacquer on a small spot near the drill hole of one bead, we could see no evidence of nacre.

Figure 15. Dyed "crackled" green quartz, 0.96 ct.

QUARTZ

Dyed "Crackled" Quartz

The Los Angeles laboratory recently received for identification one intense green, emerald-cut stone and one bright red, oval, modified-brilliant-cut stone. To the unaided eye, these stones had an obvious "crackled" appearance (figure 15). Magnification revealed dense concentrations of dye in intertwined surface fractures that extended deep into the stone (figure 16). When examined in the polariscope, in conjunction with a condensing lens, both stones exhibited bull's-eye uniaxial interference figures, thus proving that they are quartz. The "crackling" (by heating) and subsequent dying of colorless and near-colorless quartz

Figure 16. Dyed "crackled" red quartz. Magnified 38×.

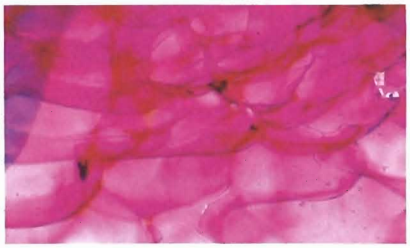


Figure 17. An 8.70-ct. bluish-gray star quartz cabochon.

has been practiced for many years and is usually intended to imitate gemstones other than quartz. In the early 1940s, dyed green "crackled" quartz was represented on the market as "Indian emerald."

It has been quite a while since dyed "crackled" quartz was last seen in this laboratory. These two stones serve as a reminder of the many treatments and imitations that have been known for many years, but may seldom be encountered today.

Star Quartz

The 8.70-ct. light bluish-gray star quartz seen in figure 17 was recently sent to the Los Angeles laboratory. The phenomenon of asterism in quartz is usually associated with rose quartz. Asteriated rose quartz often exhibits a weak star and is frequently backed with a foil mirror to improve and accentuate the asterism. Colored foil backings are also used to imitate star corundum. Some star quartz, and particularly the very light gray and bluish-gray quartz from Brazil, exhibits a fairly strong asterism when cut *en cabochon*, like the stone illustrated here which is presumably from Brazil.

Asterism in star quartz appears to be confined almost entirely to the surface of the stone, rather than emanating from the interior as is the case with star rubies and sapphires. Most star quartz contains microscopic needles of rutile oriented in definite crystal directions. These rutile needles produce asterism when the cabochon is viewed with the light coming through the optic axis direction, called diasterism, or with a strong overhead reflected light, called epiasterism.

SAPPHIRE

Heat-Treated Yellow-Orange Sapphires

The latest suspect encountered in New York in the ongoing battle to detect corundum treatment methods is a lot of unusually bright, yellow-orange natural sapphires that show no iron absorption in the hand spectroscope and only a weak red fluorescence in long-wave ultraviolet light, both clues that indicate unnatural color. Inspection of more than 50 stones that were almost identical in color showed evidence of high-temperature treatment. Several had internal stress fractures, and many showed surfaces that had not been completely repolished. Most showed multiplane girdles (figure 18).

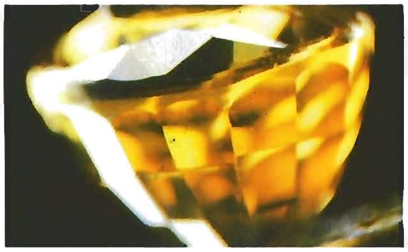


Figure 18. Multiplane girdle, thought to be typical of treated sapphire. Magnified 12×.

ACKNOWLEDGMENTS

The photos that appear in figures 1, 2, 8, 11, and 12 were taken by John Koivula in the Santa Monica laboratory. Bob Kane of the Los Angeles laboratory is responsible for figures 3, 9, and 10. Shane McClure, also associated with the Los Angeles laboratory, photographed the stone in figure 16. All of the photographs that originated from the New York laboratory—figures 4, 5, 6, 7, 13, 14, and 18—were taken by Rene Moore. Tino Hammid, of the Gem Media Department at GIA, photographed the stones in figures 15 and 17.

Editorial Forum

AN AUSTRALIAN COLLEAGUE CLARIFIES OUR REPORT ON AUSTRALIAN SAPPHIRE

I congratulate you on your new editions of *Gems & Gemology.* It is a fine, well-presented journal. I was, however, amazed at comments contained in the column, Gem News—Sapphire, Volume 17, Summer 1981.

It appears that the information received in the States concerning Australian sapphire is very sketchy, and I would like to draw your attention to a few facts.

Queensland sapphire fields were first started in 1892. During the last fifteen years there have been at least 40 mining operations being carried out, some of which have processed up to one thousand cubic yards a day.

The main product is blue sapphire, not yellow, gold or green. However, due to the fact that particularly fine stones in these [latter] colours are produced there, Queensland has gained a reputation for them. Almost all the production of blue stone is exported in the rough state to Thailand for treatment and cutting.

The sapphire fields in New South Wales, some 500 miles to the south of the Queensland fields, have also been producing sapphire from large-scale alluvial mining for the past fifteen years. The stone is similar to Queensland material but generally considered to be of an overall better quality.

Thailand, up until the advent of large-volume sales of Ceylon stone there during the last three years, was selling Australian sapphire as Thai, and Australian sapphire made up about 80% by volume of all stone exported from Thailand. Even now it accounts for the greater majority of stone exported from that country, certainly in terms of carats and possibly total value.

I feel it is about time Australia is recognized in gemmological circles for what it is, i.e., one of the biggest producers of sapphire in the world. Also I would like to destroy the common misconception that Australia only produces dark greeny-blue stone of inferior quality, or green or yellow stone.

T. S. Coldham, B.A., F.G.A.A.
Sapphex Pty. Ltd.
Sydney, Australia

We thank Mr. Coldham for his comments and are pleased to report that he has agreed to prepare a more extensive article on this subject for a future issue of the journal.—Editor

A TRIBUTE TO LEW KUHN, THE TEACHER

Your tribute to Lewis Kuhn in the Summer 1981 issue of *Gems & Gemology* was indeed fitting and appropriate. I only regret its necessity.

I was one of the GIA resident students that Lew invited to his office and shared his time and knowledge with. One could not escape his concern and devotion to the industry and its students. His ability to speak and teach has touched many a gemologist. I'm glad I was one.

William C. Sites
Sites Jewelers
Clarksville, TN

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Amber mining in the Dominican Republic. P. C. Rice, *Rocks & Minerals,* Vol. 56, No. 4, 1981, pp. 145–152.

Over the last 30 years, amber from the Dominican Republic has become increasingly known and sought after. This relatively new source now rivals the traditional mining localities of the Baltic region.

The current Dominican production comes from secondary deposits that do not allow us to formulate an accurate date of origin, although the Lower Miocene age has been suggested, as has the Cretaceous age. These deposits are yielding several colors of amber, including red, yellow, and a unique blue fluorescent variety from various sites. Using picks and shovels, the miners dig small holes and tunnels in the soft sedimentary rock to reach the amber-bearing strata.

Like the author's book *Amber: The Golden Gem of the Ages,* this article is articulate and well illustrated. An in-depth geological study, personal communications with knowledgeable people, and visits to the actual mines have nicely augmented Ms. Rice's research on amber. *Frederick L. Gray*

Garnets from Umba Valley, Tanzania—members of the solid solution series pyrope-spessartine. K. Schmetzer and H. Bank, *Neues Jahrbuch für Mineralogie Monatshefte,* No. 8, 1981, pp. 349–354.

Drs. Schmetzer and Bank describe six garnets represented to be "Malaya" garnets from the Umba Valley in Tanzania. Complete chemical and physical data are provided for the stones studied, which are also described in terms of four end members: grossular, pyrope, spessartine, and almandine. The described color range of the six specimens ranges through rose, rose-red, wine red, and reddish brown. In addition, the authors present a fairly comprehensive review of the existing literature on this type of East African garnet.

This section is designed to provide as complete a record as possible of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and her reviewers, and space limitations may require that we include only those articles that will be of greatest interest to our readership.

Inquiries for reprints of articles abstracted must be addressed to the author or publisher of the original material.

The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names.

The conclusion drawn is that, as the six garnets examined support the idea of solid solutions existing among the end members pyrope, spessartine, and almandine, these stones need no new name and, in the authors' opinion, can be referred to by the subgroup term *pyralspite.* They also conclude that only chemical and/or spectroscopic investigation can reveal whether any single specimen belongs to the pyrope-almandine or pyrope-spessartine series. *CMS*

Golden yellow tourmaline of gem quality from Kenya. H. Hänni, E. Frank, G. Bosshart, *Journal of Gemmology,* Vol. 17, No. 7, 1981, pp. 437–442.

The authors investigated the chemical composition and optical characteristics of golden-yellow tourmalines from the Voi-Taveta area of Kenya. Previous articles have focused on stones from Brazil, Burma, and Sri Lanka; with attractive stones coming out of East Africa, however, this research is very timely.

The microprobe was used on four stones to determine chemical composition. The results are presented in a table that includes several point analyses for each crystal, indicating the variation that can exist within one crystal. The authors conclude that these compositions fall within the range of the ideal formula and that the stones are magnesium-aluminum tourmalines of the dravite-uvite series. They note a tendency toward deficiency of Mg(Na,Ca), with a corresponding excess of aluminum that suggests additional substitution of aluminum for these elements. Since the microprobe recorded the presence of only one transition element, titanium, the authors argue that the intensity of the yellow color is due to different percentages of titanium oxide. When the authors analyzed the thin rim of green that occurs in some of these crystals, a greater concentration of iron was observed. The absence of tsilaisite or elbaite components corroborates previous reports which concluded that no solid solution exists between dravite and elbaite.

The X-ray powder diffraction diagrams also substantiate previous research, and testing on a Topcon refractometer produced the acceptable refractive index values. The inclusions cited were negative crystals parallel to the c-axis, flat healing fractures of long and short drops of residual liquid, and curved growth tubes or trichites.

The authors conclude with a short discussion of results observed from a spectrophotometer, noting in particular that a wide absorption band occurs at 4400 Å on the spectrum. This is probably caused by titanium and thus confirms the microprobe data. *DMD*

Growth structure in Ceylon zircon. T. G. Sahama, *Bulletin de Minéralogie,* Vol. 104, No. 2–3, 1981, pp. 89–94.

This report describes a detailed study of the growth structure of alluvial zircon crystals from the Ratnapura area of Sri Lanka. The 15 crystals examined ranged from the strongly metamict, which are frequently brown, to the nearly ordered ones, which are often yellow. Although the concentric structure evident in many of these stones has been described in the literature, it had not been studied previously. The author argues that evidence does not exist to call this structure zoning, rather it should be termed *banding.* He then classifies the bands as being of three types: (1) fine, (2) coarse, and (3) high birefringent or high density. The fine, microscopic banding may originate from rhythmic fluctuations in the rate of crystallization. The coarse banding is visible to the unaided eye and may be homogeneous or may consist of a group of fine bands.

The density of some of the crystals tested tended to decrease from the core to the outer edges, while other crystals showed a directly opposite trend. Chemical analysis showed that the uranium content varied regularly with the degree of density, giving rise to the conclusion that variations in the degree of radiation damage caused by the uranium are mainly responsible for the visible growth banding. *SFM*

New data for jeremejevite. E. Foord, R. Erd, G. Hunt, *Canadian Mineralogist,* Vol. 19, No. 2, 1981, pp. 303–310.

Jeremejevite ($Al_6B_5O_{15}[F,OH]_3$) is an extremely rare gem material found only on Mt. Soktuj, Transbaikal, East Siberia, U.S.S.R., and at Cape Cross, Swakopmund, Namibia (South West Africa). Foord et al. have studied material from both localities and compared these stones with a synthetic (OH)-jeremejevite. Natural material from both localities shows anomalous optical properties related to growth-sector zoning. The Mt. Soktuj crystals have a core of biaxial material with a uniaxial rim; the Cape Cross jeremejevite exhibits the opposite, having a small uniaxial core and a biaxial rim. The Mt. Soktuj crystals are colorless, while the Cape Cross material is cornflower blue in varying intensities depending on its composition.

The electron microprobe revealed minor amounts of OH (hydroxyl) and major amounts of F (fluorine) in the natural samples. The presence of fluorine has not been previously recorded; its recognition here is fundamental to establishing a standard chemical composition for jeremejevite.

The authors' interpretations of mid-infra-red spectra support the presence of aluminum, boron, hydroxyl, and fluorine in the natural jeremejevite. Unit-cell data and optical constants are tabulated for Mt. Soktuj, Cape Cross, and synthetic (OH)-end member jeremejevite along with calculated densities for the respective samples.

The authors state that the widely disputed optical properties concerning variation in 2V angle, the relationship of optical properties to growth features, and the origin of anomalous optics will be treated in a subsequent paper. *Stephen C. Hofer*

An unusual pleochroism in Zambian emeralds. K. Schmetzer and H. Bank, *Journal of Gemmology,* Vol. 17, No. 7, 1981, pp. 443–446.

African gemstones are generating much interest as research topics because the properties they exhibit are different from those of stones from more traditional localities. One such case is that of Zambian emeralds. Although the Miku and Kafubu emerald deposits of Zambia have been known since 1931, they have been commercially important only since 1977. Not only do these stones have unusually high refractive indices of n_o 1.589–1.590 and n_e 1.580–1.581, but some also look blue to bluish green and have a blue pleochroic color when viewed parallel to the c-axis and a yellowish green when viewed perpendicular to the c-axis. To determine the causes of this unique coloration and distinctive pleochroism, the authors performed electron microprobe analyses and plotted absorption spectra on emeralds from the Kwale District of Kenya and the Lake Manyara area of Tanzania, as well as from the Miku deposits of Zambia.

The microprobe analyses of the samples studied revealed that in addition to chromium and vanadium as trace elements, they also contained iron. While the samples from Kenya and Tanzania had less than 0.50% iron, the Zambian emeralds had 0.73%. The Zambian samples also had unique absorption spectra: they exhibited not only the expected chromium bands of emerald, but also the iron bands found in aquamarine. The authors conclude that the bluish-green pleochroic emeralds from Zambia owe their unusual color and spectra to the combination of an emerald component and an aquamarine component in the same crystal. Since the aquamarine component is most influential parallel to the c-axis and the emerald component is most influential perpendicular to the c-axis, the stones appear blue when viewed parallel to the c-axis and yellow-green when viewed perpendicular to the c-axis.

Peter C. Keller

DIAMONDS

Diamond production in Guyana. R. J. Lee, *Journal of Gemmology,* Vol. 17, No. 7, 1981, pp. 465–479.

This article covers the major aspects of diamond mining and gives a brief overview of the history of the diamond industry in the tiny South American country of Guyana.

No primary deposits have ever been discovered in Guyana, although one or two academic geologists continue to search for diamondiferous pipes. The author discusses Guyana's alluvial deposits, dividing them into four groups: (1) the high alluvials or hill deposits, (2) terrace deposits between the hill deposits and river channels, (3) river-flat deposits, and (4) deposits in a plateau that is located to the west of Guyana about 1,000 m above sea level.

Since gold and diamond mining are often linked together, they are both discussed in the section on history of production. In the 1880s, as a result of a crisis in the sugar industry, many laborers packed what they owned and moved into the bush in search of diamonds and gold. Since they arrived at the deposits without food or equipment and had to obtain credit, or 'knock', for the salt port that is the basis of a bush diet, the name *pork-knocker* was coined and is still used today for "Those small bands of men with little money and much faith." Even today miners must obtain credit from bush traders who supply food, liquor, and equipment in exchange for diamonds.

Lee also discusses the methods used to work the deposits, and provides photographs and diagrams of the sites and equipment.

This is an interesting and informative article about an industry that is unfortunately in decline in this country. The author cites one hope when he describes finding six pieces of deep-blue sapphire in one sieve. He closes with the suggestion that perhaps soon we will see Guyana sapphires on the market as well as the occasional Guyana diamond. *ET*

Étude de la coloration de quelques diamants du muséum national d'histoire naturelle (Study of the coloration of some diamonds from the National Museum of Natural History). J. F. Cottrant and G. Calas, *Revue de Gemmologie,* a.f.g., No. 67, June, 1981.

Messrs. Cottrant and Calas obtained an unspecified number of colored diamonds from the French National Museum of Natural History and performed spectrophotometry on them using a Cary 17D spectrophotometer. The diamonds were rough octahedra of the colors yellow, orange, green, and pink.

The authors provide a graph of the spectra for these stones, using both wavelength and energy parameters. The spectra are labeled and broken down into "systems," which are shown to be consistent with and diagnostic of not only the color of the diamonds but also the diamonds themselves.

Cottrant and Calas conclude that spectra are valuable in determining the nature of impurities and color in diamonds. They state that further tests into the fluorescence and electromagnetic properties of diamonds are progressing. *Michel Roussel-Dupré*

First diamond finds in Alpine-type ultramafic rocks of the northeastern USSR. N. A. Shilo, F. V. Kaminskiy, S. A. Palandzhyan, S. M. Til'man, L. A. Tkachenko, L. D. Lavrova, K. A. Shepeleva. *Doklady Akademii Nauk SSSR,* Vol. 241, No. 1, 1980, pp. 179–182.

On the basis of recent thermodynamic research, scientists have argued that the pressures and temperatures at which Alpine-type ultramafic rocks crystallized were very high, with some approaching the range necessary to form diamond. In particular, such conditions were calculated by Kaminskiy and V. I. Vaganov for some ultramafic plutons in the Koryak Mountains of the U.S.S.R.

Peridotite samples from various plutons in this area were analyzed by a thermochemical decomposition method, whereby the samples are fused with alkalies and decomposed in acids. Diamonds were found in two samples, confirming earlier predictions. The diamonds recovered were small, colorless fragments measuring 0.375 mm × 0.15 mm and 0.2 mm × 0.125 mm, respectively. X-ray diffraction analysis verified the identification. Both stones showed a yellow-green ultraviolet fluorescence, which would be unusual for kimberlite diamonds. The photoluminescence spectrum showed lines at 415.2 nm, 496 nm, and 503 nm.

The authors conclude that the discovery of diamonds in the Alpine-type ultramafic rocks is of great scientific importance, and that detailed study of different types of these rocks will result in new diamond finds. *SFM*

The ice layer in Uranus and Neptune—diamonds in the sky? M. Ross, *Nature,* Vol. 292, No. 5822, 1981, pp. 435–436.

Current U.S. space exploration efforts have led to some startling speculations. Marvin Ross, of the University of California, Lawrence Livermore National Laboratory in Livermore, California, conjectures from recent shock-wave experiments that there may be diamonds on the planets Uranus and Neptune. He theorizes that between the inner rocky core and an outer hydrogen-helium layer of each planet is a layer of "ice" composed in part of methane. Shock heating would cause the separation of the hydrogen and carbon atoms of which methane is composed, thereby freeing the carbon which under tremendous heat and pressure could form diamond.

The author illustrates this theory with two diagrams. The first is a plot of temperature and pressure data for water, ammonia, and methane as predicted for the ice layer of Uranus and Neptune. The second is the Grover phase diagram for diamond, with the first plot superimposed. This short article, although thought provoking, lacks the background material needed for it to be meaningful to the average reader.

Frederick L. Gray

Scientist forecast Siberian diamond finds. N. Y. Sobolev, *Diamond News and S.A. Jeweller,* Vol. 44, No. 8, 1981, pp. 51, 53, 55, 57.

In 1829 the first diamonds on Russian territory were found in alluvial deposits in the Urals. Although additional alluvial deposits have been located since then, no kimberlite sources for these deposits have been found. In 1954 Geologist Larisa Popugayeva discovered the first kimberlite pipe, not in the Urals but in the Yakutia area of Siberia. Interestingly, the discovery of this and subsequent pipes was predicted by Vladimir Sobolev in the late 1930s.

Sobolev stated that diamond-bearing pipes would be found not in the Urals but in the northern part of the Siberian platform. He based that prediction on information gleaned from laboratory and on-site geological studies performed in the harsh Siberian environment, and from published information on South African diamond deposits. His prediction held. The 1954 discovery, named Zarnitsa, was followed in 1955 by the location of the "Mir" pipe, largest of all the Russian pipes, and then others. Author Sobolev provides a rare and fascinating glimpse into Soviet scientific history. *Frederick L. Gray*

GEM INSTRUMENTS AND TECHNIQUES

Defectos reticulares y color en las gemas (Structural defects and color in gems). J. Solans Huguet and M. V. Domenech, *Gemología,* Vol. 13, No. 47–48, 1980 , pp. 9–22.

In an earlier work in *Gemología* (J. Solans Huguet, 1974), studies investigating the causes of color in gemological materials were discussed. The causes determined fell into two large groups: those related to the chemical composition of the crystals themselves; and those linked to defects in the crystalline structure. In this article, the authors maintain that in two thirds of gemological materials, color is caused by three types of defects: (1) holes in the atomic structure caused by missing anions or cations, (2) interstitial atoms occupying positions where normally there are no atoms, and (3) substitutional atoms—that is, atoms in the lattice that differ from those that form the structure. Minerals with this last type of defect exist in solid-solution series, where gradual replacement can occur between distinct end members. Occasionally, substitutional atoms belong to the same chemical species as those that form the structure, but are in valences distinct from the usual number.

One can determine if the color in a given gemstone is due to structural defects by observing whether heat treatment causes change in color; if such is the case, the color of the material in question must have been due to a color center. Excepted are cases involving substitutional atoms with electrons of the sublevels *d* or *f*.

Amazonite, topaz, diamond, fluorite, quartz, lapis-lazuli, sodalite, tugtupite, and hackmanite are discussed. The authors point to the need to use not only spectroscopy, but spectrophotometry as well, to derive conclusions. A short bibliography is provided. *SLD*

Demise of the Beilby-Bowden theory of polishing. P. J. Crowcroft, *Journal of Gemmology,* Vol. 17, No. 7, 1981, pp. 459–465.

In this article, Dr. Crowcroft lays to rest a favorite piece of gemological esoterica: the Beilby-Bowden theory of polishing. First proposed by G. T. Beilby in 1901, the theory held that a polish can be produced on a material if enough heat is generated to melt a thin layer of the material and create an amorphous, glass-like shiny surface. Crowcroft states that the theory received some apparent support from experiments in the 1930s; by the 1950s, however, it had been "completely superseded." Despite this (Crowcroft continues), modern gemological literature contains no mention of the debunking, but stops with discussion of the experiments done in the 1930s.

Crowcroft reports that in the 1950s Dr. L. E. Samuels repeated Beilby's experiments with metals, supplementing them with electron diffraction studies. Samuels concluded that in metal polishing the abrasive particles act "in a similar manner to a planing tool. Material is removed and scratches are produced, the better the polish/the finer the scratches." In the early 1960s, Dr. D. C. Cornish and coworkers studied glass polishing under various conditions. They found that polishing was actually a process of removing material from a strain layer created during initial cutting and grinding operations: "To achieve a good finish it is imperative that the surface be lowered beyond this strain region." Cornish et al. concluded that the rate of material removal depended on the pressure used, the speed of the machine, the chemical activity of the polishing compound, and the chemical composition of the glass, stating: "A chemical mechanism of polishing was proposed which involved the absorption of hydrated silica from the glass by the polishing powder following the disruption of the surface Si-O-Si bonds." The rate of removal was found to be "temperature-independent."

Crowcroft also makes passing mention of some factors that would affect an alternative interpretation of the experimental evidence originally cited in support of the Beilby-Bowden theory. About modern research, Crowcroft says: "The use of glass and ceramics for heat shields, missiles, and electronics has ensured continuing research into the nature of non-metallic surfaces after abrasion and polishing." He then recommends *The Science of Ceramic Machining and Surface Grinding II* (which can be obtained from the U.S. Government Printing Office) as a good survey of present research; among other topics, it covers the polishing of sapphire by superheated steam. While admitting the lack of a comprehensive theory of gem polishing—one that includes techniques such as tumbling and polishing cabochons with leather—Crowcroft concludes that: "Polishing . . . involves the removal of material to below the damaged and deformed layers of material resulting from the prior pre-polishing operations." The article is complemented by a 22-entry bibliography which traces the evolution of the discussion. R.I.P.

MLR

A fibre-optic reflectivity meter. P. Read, *Journal of Gemmology,* Vol. 17, No. 7, 1981, pp. 454–458.

Mr. Read discusses the operating principals and capabilities of a new reflectivity meter developed by U. A. Aldinger of Stuttgart, West Germany. The instrument sends a pulse of infrared radiation along a fiber-optic light guide that is tipped with a test probe 1 mm in diameter. At the tip, a tiny lens 1 mm in focal length concentrates the beam. When the tip is brought at right angles to the gem's surface, the reflected radiation is collected by the detector portion of the probe. As the reflected energy reaches a maximum, a memory circuit in the unit latches onto the value and feeds the corresponding electrical impulse to a needle scale.

The smallness of the tip allegedly permits the testing of cabochons and deeply recessed set stones. However, closely set small stones may give anomolous high readings as a consequence of the high reflectivity of the surrounding metal. The main precautions to be taken in using this instrument are a clean, relatively scratch-free stone surface and a perpendicular contact between the probe and the surface. Also, the instrument's scale shows general ranges for various gemstones (names in German); the numbers on the scale that do not correspond to the refractive indices of the respective gemstones are evidently arbitrary units. The cost of the unit was not stated. *BFE*

Some fallacies of gemmology. R. K. Mitchell, *Journal of Gemmology,* Vol. 17, No. 7, 1981, pp. 446–450.

Keith Mitchell attempts to debunk some misconceptions in gemology. He reviews information on the diamond pen, breath test, dichroscope, and Chelsea filter. Unfortunately, he is inconsistent about citing references and evidence.

He begins with the diamond pen test, pointing out that the term *surface tension* is a property of liquids and not of solid crystals, and thus it cannot be used to explain the diamond pen test. He suggests that the test is founded instead on diamond's affinity for hydrocarbons, since the ink used is based on a glycol.

Mitchell goes on to discuss problems with the breath test. When he attempted a controlled experiment, standardizing the initial temperature of a number of stones by placing them in a refrigerator before testing and then controlling the environmental temperature during testing as closely as possible, he found that either the stones demisted at roughly the same rate or in those cases where there were differences they were not necessarily repeatable. He concludes that the breath test is valuable as a way of masking the internal characteristics of a diamond so that its color can be assessed, but that as a separation technique it is "at best hit or miss and at worst a bit of gemmological flummery we can well do without."

He next comments on the dismissal by some authors (he doesn't say who) of the dichroscope and the Chelsea filter. His defense of the dichroscope is strong, but his discussion of the Chelsea filter amounts to an unsupported assertion that "the Chelsea filter is still a powerful tool in gem identification and should not be dismissed out of hand."

In his conclusion, Mitchell refutes the notion that the dichroism of tourmaline consists of only light and dark of one color. In looking at more than 80 tourmalines, he discovered a stone that showed yellow-brown in one direction and bright green at right angles to it. Another stone appeared almost black when examined normally but showed dichroic colors of "deep tourmaline green" and "deep garnet red" when viewed under the dichroscope. He describes the stones, but offers no explanation for their unusual dichroism. *ET*

GEM LOCALITIES

Colourless grossular and green vesuvianite gems from the Jeffrey Mine, Asbestos, Québec. W. Wight, and J. D. Grice, *Canadian Gemmologist,* Vol. 3, No. 2, pp. 2-6.

The authors, who are both connected with the National Museum of Natural Sciences in Ottawa, Ontario, Canada, describe the first faceted specimens of colorless grossular and green vesuvianite from the Jeffrey Mine at Asbestos, Québec. The properties that they report for these stones fit well with those observed in similar stones from other locations. Although the authors do not provide quantitative analyses for the stones examined with the article, they do refer to the compositions of the materials.

The authors also give a very useful review of the other color varieties of grossular and vesuvianite from the Jeffrey Mine. However, the brevity of this article provides just enough information to whet one's appetite. Given the quality and increasing quantities of the gem materials, especially grossular, coming from this locality, it is hoped that the authors will publish a more in-depth study of the museum's collection of Jeffrey gems in the near future. *CMS*

How to find mineral and gemstone deposits. J. R. Mitchell, *Gems and Minerals,* No. 522, 1981, pp. 32–39.

This article provides general information that is helpful in the search for mineral deposits. The collector should begin by noting the geologic setting of known collecting sites, since minerals tend to occur in similar settings worldwide. Also, searching near known sites and downstream from such sites in rivers and washes may turn up specimens or new deposits. After reviewing the three types of rocks (igneous, sedimentary, and metamorphic), the author discusses pegmatites in detail, describing their origin and keys to their identification.

In the field, the reader is advised to observe differences in the terrain, because highly mineralized zones in igneous rocks are subject to rapid decomposition. Such decomposition often shows itself as rounded hills with a reddish soil that can support plant life more easily than the surrounding terrain.

Openings formed as a result of folding and uplifting or along planes in sedimentary rocks are good places to look for hydrothermal deposits. Since hot water will dissolve limestone, this environment also offers good possibilities for mineralized zones.

Contact metamorphic deposits are usually easy to see since two distinct rock types are adjacent to one another. Marbles and schists are also metamorphic rocks that often contain interesting minerals and gems.

In his conclusion, Mitchell reviews the formation of some specific minerals and notes localities where they might be found. *GSH*

JEWELRY ARTS

African gold—extravaganza with a message. *Jewelers' Circular Keystone,* Vol. 152, No. 6, 1981, pp. 148–152.

Africa—the very name of this beautiful continent inspires new and different ideas in jewelry. Many of these ideas were revealed by Intergold at the New York Jewelers of America show in July, in a presentation entitled "African Gold."

The designs are flamboyant works of art that mix gold with porcupine quills, giraffe and elephant hair, wildebeest tails, shells, ivory, wood, and beads. The jewelry pieces have been coordinated with costumes that reflect ethnic African traditions. Flamboyant as the costuming may be, Intergold seeks to inspire designers with new ideas rather than set new fashion trends.

Don MacKay-Coghill, who is chief executive of Intergold's worldwide offices, states that the marriage of gold and these other natural materials will offer the consumer a less-expensive alternative in jewelry. In these inflationary times, this concept is important. As the article states, however, the public's reaction will be the true test of whether the ideas are a success.

Lillian C. Hensel

Gilding through the ages. A. Oddy, *Gold Bulletin,* Vol. 14, No. 2, 1981, pp. 75–79.

The art of gilding, or applying a layer of gold to the surface of another metal, goes back at least as far as 3000 B.C., as documented by the discovery in Syria of silver nails with gilded heads. Andrew Oddy takes us through the ages with an account of the different methods used in the gilding process, beginning with mechanical gilding where the foil was folded over the edges of the object. Around 2000 B.C., when methods for purifying gold developed, it became possible to hammer gold thin enough to produce leaf. Since gold leaf is not strong enough to support its own mass, new techniques then had to be devised for attaching the leaf.

This description of a fascinating process is rich with information gleaned from artifacts as well as from historical writings. As in his previous articles, Oddy includes an extensive bibliography. *NPK*

The long history of lost wax casting. L. Hunt, *Gold Bulletin,* Vol. 13, No. 2, 1980, pp. 63–79.

Hunt traces the history of lost wax and investment casting from its earliest appearance sometime around 4,000 B.C. in the Middle East up to the present day. As one would expect, a subject this vast has to be somewhat abbreviated, but the article is amply footnoted and an extensive bibliography is included for further reference.

The author touches upon the various techniques exhibited by each culture and speculates about the possible influence each had on the others. Hollow casting, indirect casting, and carved molds for wax models are also discussed, as is the more recent development of rubber molds for mass production. *EBM*

Okimono and netsuke: made in Hong Kong! S. Markbreiter, *Arts of Asia,* Vol. 11, No. 1, 1981, pp. 137–141.

Ironically, Hong Kong has a thriving Japanese netsuke carving industry. The demand in Hong Kong for netsuke began about 10 years ago. In recent years the industry has grown, gearing itself to the tourist trade. This article describes the background and business of one master carver, Mr. Suen. He was trained as a Chinese carver in the northern or Peking style, and for years he carved traditional Chinese ivories. In 1976, he started his netsuke factory. It was difficult to learn the Japanese style of carving; he had few opportunities to examine fine true netsuke and had to rely on illustrations in books and magazines. When he and his wife visited Japan, the Japanese carvers, aware that he was a Chinese carver from Hong Kong, were careful to preserve their own secrets.

Today Mr. Suen has 10 young craftsmen-apprentices in his shop. The first part of netsuke making, the initial blocking of the piece, is done by his inexperienced apprentices. He and his most experienced workers do the more detailed second part. The article explains, with the use of photographs, the 15-part process Mr. Suen uses to produce his netsuke; however, to preserve Mr. Suen's trade secrets, the author does not discuss or photograph the second stage of the work, which Suen calls the "making of the rough." The author does, however, illustrate the other stages, including polishing, painting, and aging (in a smoke box). *ET*

Opportunities ahead for platinum. *Executive Jeweler,* Vol. 1, No. 4, 1981, pp. 163–164.

Many people are not aware of the advantages of using platinum for jewelry. For example, platinum is a very hard and durable metal; jewelry craftspeople do not have to worry that it will bend or break as easily as gold does. It is also more desirable for use in expensive jewelry because platinum will hold large stones more securely than other metals.

In this article, a few jewelers recount their sales experiences with platinum. Now that platinum is competitive with gold in price, it may be more viable to the prospective customer.

Johnson Matthey, Inc., a worldwide fabricator and distributor of platinum metals, has just announced their Fifth Annual Platinum Jewelry Design Competition for rings, jewelry with gemstones, and jewelry without gemstones. In addition, Johnson Matthey, Inc., has implemented a one-million-dollar promotional campaign to educate the public about the desirable aspects of platinum. *Lillian C. Hensel*

Rhinebeck: jewelry artists at work. E. Lauré, *Jewelers' Circular Keystone,* Vol. 152, No. 9, 1981, pp. 94–97.

Each year one of the fall issues of *Jewelers' Circular-Keystone* features the Northeast Craft Fair, held in June in Rhinebeck, New York. As one of the major craft shows of the country, it is limited to about 500 artists who must compete for the honor of participating.

While 1980 was the year of cloissoné, this year's show will be remembered for the use of titanium and tantalum, space-age metals that produce vibrant colored pieces when heat treated. Lauré characterizes the show as containing many well-designed, well-crafted items of jewelry fashioned by a variety of new artists. She goes on to discuss a number of the artisans, describing their backgrounds and their work. The eight color photographs of jewelry that accompany the article illustrate why this is considered such a significant craft event. *DMD*

She designs jewelry that may save a life! *Executive Jeweler,* Vol. 1. No. 4, 1981, p. 81.

Mary Ann Scherr, chairperson of the Metals, Fibers, Clay, and Glass Department at Parsons School of Design in New York City, has developed a unique concept in jewelry design. She creates jewelry to assist with certain medical problems. Her designs include a post-tracheotomy necklace to aid the emotional recovery of tracheotomy patients, pulse-monitoring bracelets, and necklaces that carry a hearing aid battery. After her own thumb was severed, she designed a "thumble:" a protective device made of gold or silver that slips over the finger to protect it following surgery. In collaboration with a doctor, she has designed a posture belt that signals the wearer to hold in his/her stomach and a no-nod alarm monitor that warns a driver when his/her head nods. She also makes metal whiplash collars that resemble African jewelry. The possibilities seem endless. *Lillian C. Hensel*

Stone flower blossoms. L. Butorina, *Australian Lapidary Journal,* Vol. 17, No. 9, 1981, pp. 19–24.

The stone carvings from the Soviet Union are famous worldwide. The name of one carving factory, Yekaterinburg, is often associated with major museum pieces as well as with items sold in the trade. Butorina gives us a glimpse into the history of this 254-year-old factory. Now called Russkiye Samotsvety, it is located in Sverdlovsky in the Ural Mountains, where carving material is abundant. Two hundred different types of jasper alone have been found in this region. Five photographs illustrate carvings made from jasper as well as those fashioned from other materials such as rhodonite, obsidian, and corundum.

Originally, the primary function of the factory was to fill orders for the imperial court under strict specifications of design and material. One of the key differences for the carvers today is that they have flexibility in designing and making their pieces. Another key difference is that machines augment that hand work; for example, diamond saws may be used to preform the pieces. However, the tradition of beautiful hand work continues, as each piece is carved and finished individually. *DMD*

Tibetan jewelry: a lost art. V. Reynolds, *American Craft,* Vol. 41, No. 5, 1981, pp. 30–35.

This article describes in detail the clothes and jewelry worn by Tibetans, examples of which were recently exhibited at the Newark Museum in New Jersey. Tibetan men and women traditionally wore clothing that identified their specific region as well as their social and financial status. These customs of adornment have been documented as early as the seventh century, A.D., and may date back even further.

The jewelry described is primarily composed of gold, silver, copper, and brass set with turquoise, coral, pearls, amber, and agate—as well as beads made of glass or plastic. In fact, there have been periods in the 19th and 20th centuries when glass and plastic were considered valuable in their own right both because they are substances that were technically unknown to the Tibetans and because of their flawless appearance and their colors, which may be brighter than natural stones. In fact, gold and silver were often coated with an orange lacquer wash to satisfy the vivid sense of color of the Tibetans.

The jewelry worn by Tibetan men usually included heavy cast gold or silver earrings set with turquoise, finger rings, charm boxes on bead necklaces, medallions, and hat finials. Rank was often denoted by the amount of jewelry and whether gold, silver, or copper was used.

Women wore large, elaborate headdresses that incorporated their own hair and that were adorned with coins and ornaments representing their wealth and rank. They also wore ear ornaments, charm boxes, and milk-pail hooks. These elaborate headdresses and other pieces of jewelry were part of everyday dress, judging from photos showing women milking, riding, and harvesting while wearing such items.

Since the abolishment of traditional Tibetan society and religion following the takeover of Tibet by China in the 1950s, these modes of dress and ornamentation have virtually disappeared. *EBM*

Totally tantalizing: new jewelry of titanium or tantalum. *Executive Jeweler,* Vol. 1, No. 4, 1981, p. 65.

Titanium and tantalum, metals that have heretofore been used primarily in the aircraft and space industries, are becoming popular materials for jewelry. Both are extremely hard and light. The key attraction, however, is that they can be changed from their natural drab gray to intense iridescent colors. Heating different areas of either metal with a torch or with high voltage will produce different colors and combinations of colors depending on the temperature used. Although these vibrant colors affect the surface of the material only and can be scratched off with a sharp point, they will last if the jewelry is worn carefully.

Because both metals cost about the same as silver, the finished pieces are unique and inexpensive, creating a new, futuristic look in jewelry.

Lillian C. Hensel

RETAILING

Brilliant company: New York's resplendent jewelers. N. T. Gardiner, *Town and Country,* Vol. 135, No. 5017, 1981, pp. 188–199.

The "who's who" in fashionable jewelers are photographed displaying some of today's finest jewelry creations. Diamond to tanzanite, emerald to amethyst, and ruby to pearl are all shown off in elaborate suites of jewelry on some of the major jewelry people in New York. Included are M. Claude Arpels, president of Van Cleef and Arpels in New York; Ralph Destino, president of Cartier, U.S.A.; Henry Platt, vice-chairperson of Tiffany & Co.; Designer David Webb; Dominique Gérard, president of the M. Gérard Joalliers store in New York; Nicola Bulgari, director of the Bulgari store in New York; Count Enrico Carimati di Carimate, president and chief designer of Carimati Jewelers; and Ronald Winston, president and chairperson of the board of directors of Harry Winston, Inc.

Gardiner comments on the influence that these jewelers have on the culture of the city as well as on jewelry. The article is both interesting and well presented. *NPK*

SYNTHETICS AND SIMULANTS

Natural and synthetic gem materials, a comparison. I. Sunagawa, *Bulletin de Minéralogie,* Vol. 104, No. 2-3, 1981, pp. 128–132.

Emphasizing that the solid-liquid interface is the only place where crystal growth occurs, Ichiro Sunagawa compares natural and synthetic crystals, specifically their growth conditions and how their properties are affected by differences in growth mechanisms. Synthetic and natural diamond and emerald crystals are used to illustrate the discussion.

Natural crystallization can be regarded as growth from solution phases exclusively; this is in contrast to synthetic growth, which can be accomplished from either melt or solution phases. Melt products should be easily identifiable because of their rough solid-liquid interface growth and the resulting characteristics, such as curved growth or curved color banding. Solution-phase crystals may not be detected as easily. The differences in the chemistry of solutions in solution phases, however, result in differences that can be reflected on surface microtopographs; the article provides comparison photographs of both natural and synthetic emerald and diamond crystal faces. Internal morphology, revealed by X-ray studies, can also reveal differences but only for the properties affected by crystal growth.

ALS

Synthetische rubine mit edelsteinqualität, isometrischem habitus und hoher zahl unbeschädigter kristallflächen (Synthetic ruby with gemstone quality, isometric habit, and a high number of undamaged crystal faces). P. O. Knischka and E. Gübelin, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 29, No. 3/4, 1980, pp. 155–189.

In a comprehensive and highly technical article, the authors describe a synthetic ruby that is made by a process described as "gradient technique." Although the authors do not include details of this process, they do state that it involves supercooling and supersaturation. The resulting crystals show bright, even growth faces that have mineralogical indices with many numbers as well as combinations that have not been seen before. The trademark for this synthetic is made from a combination of Paul Knischka's initials with the P reversed. For the purposes of this abstract, we will refer to this material as synthetic P-K ruby.

Diagrams of known corundum forms showing 8-, 14-, and 20-sided crystals are given. Synthetic P-K ruby shows at least five different mineralogical indices, and diagrams demonstrate crystals of 32 and 38 faces. There are apparently at least five different types of this synthetic. The possible forms of some are given. (One group has so much iron in the lattice that the ultraviolet reaction is nearly the same as that of natural ruby.)

Six full-color photographs of crystals and crystal groups that have 32 faces with typical forms are shown. Inasmuch as all six have different height-to-depth ratios, the explanation that the habit of corundum is due not only to the corundum structure but also to factors of its growth environment is endorsed.

As with all synthetic processes, the crystals grown by the "gradient technique" involve supersaturation. This occurs in one of three ways: (1) through sudden lowering of temperature, (2) through inherent chemical processes, or (3) through evaporation.

Comparative experiments on ruby, synthetic ruby by Verneuil, and synthetic P-K ruby types 0, 1, 2, and 3 were performed. X-ray spectral analysis yielded the following information: (1) the iron content of natural ruby can be as high as five times that of the synthetics; (2) the chromium content of natural ruby is unmistakably lower than that of synthetics; (3) a measurable content of titanium was found in all three materials; (4) silica was noticeable in natural ruby and in synthetic P-K ruby but was missing in the Verneuil product. This experiment indicated that in the future it may be possible to separate natural rubies from synthetic rubies by determining the trace elements that the material in question contains. Evidence of trace elements was also obtained through atomic absorption spectrophotometry. (It is unfortunate that in order for the above experiments to be performed the samples were pulverized.)

Gemological tests were carried out on the P-K ruby with the following results: in color and appearance this material is very similar to the natural, although the fine Burmese color has not been achieved and the synthetic appears more violet. Dichroism, refractive index, and birefringence are the same for both this synthetic and natural ruby. The specific gravity is approximately 3.97, though clusters may yield a lower value of about 3.94. Most of the spectrum of the synthetic shows the same absorptions and maximum transmissions as the natural, but differences exist in transparency in the near-ultraviolet area. (The statement was made that it would be dangerous to rely on this evidence for separations.) In the area of fluorescence, a possible difference exists because the natural ruby has more iron. The synthetic glows scarlet red under long- and short-wave ultraviolet light, and shows a weak phosphorescence for approximately seven seconds. It is in the area of inclusions that valuable indications of identity can be found. The P-K ruby appears to be cloudy but upon close examination many folded inclusions, color streaks, liquid feathers, two-phase inclusions, black platelets, and negative crystals can be seen. The liquid feather inclusions are much like those in hydrothermal synthetic ruby from Chatham and are difficult to distinguish from those in natural ruby. The platinum hexagonal platelets that are sometimes seen in synthetics but never in naturals are very valuable in making a separation. Under high magnification, it can be seen that the gas bubbles visible under low power are actually the gas phase of the two-phase inclusions. These peculiar two-phase inclusions are a clear indication of the P-K synthetic ruby. *Barbara Taylor*

MISCELLANEOUS

Contact metamorphics, part I. B. Jones, *Rock and Gem*, Vol. 11, No. 11, 1981, pp. 34–40.

Heat is the major requirement for contact metamorphism and normally is the result of an intruding magma. Since a magma may take millions of years to cool, a series of alteration zones are produced. Close to the magma, there is more heat and, therefore, more alteration so that a different set of minerals forms there than in zones farther away. With this type of alteration, impure calcium carbonate rocks or argillaceous shales form the most productive deposits.

Bob Jones begins his discussion of individual metamorphic minerals with the amphibole and pyroxene groups. Pyroxenes are single chains of silicon and oxygen tetrahedrons held together by magnesium or iron ions. Amphiboles are double-chain silicates that are also held together by magnesium or iron ions. In these groups, the metallic ions may vary in proportion with each other or may exchange for other metallic ions, thus creating many complex minerals. Visually, amphiboles tend to form long needles with a diamond-shaped cross section, while pyroxenes form stubbier equidimensional crystals. Jones concludes part I with a review of specific minerals from these two groups, including hornblende, epidote, vesuvianite, pectolite, prehnite, and diopside. *GSH*

Mineral fakes. P. J. Dunn, R. E. Bentley, W. E. Wilson, *Mineralogical Record*, Vol. 12, No. 4, 1981, pp. 197–219.

In an extensive article on faked mineral specimens and their detection, the authors define a fake as "an object represented as a natural mineral specimen but having one or more falsified characteristics of synthesized parts." Falsified characteristics may include attachments, color, luster, clarity, shape, faces, or surface composition. The oldest fake the authors found dates from 1724. Entitled "Moor with tray of emeralds," it is a statue of a man holding a specimen of emeralds in matrix. The emeralds have been implanted in holes carved into the matrix. The specimen itself appeared much earlier than the statue, and has been traced to around the early 1500s when it was apparently presented to King Charles I of Spain. This historical review describes other fascinating accounts of fakes.

Turning to recent efforts at fakery, the authors examine in detail eight different types, the minerals involved, and methods of detection. One particularly interesting fake is produced in chalcedony or chrysoprase by immersing a slab in aqueous copper solution and shooting a laser beam through the center. This causes the copper to crystallize into a "bloom" or flower within the structure of the slab.

In the detection section, the authors begin by reminding the reader that the most effective method is careful visual examination aided by 5–15× magnification. They then discuss techniques for detecting the different types of fraud, such as checking for glue in ultraviolet light because most glue fluoresces. Lastly, the authors warn that faked specimens are abundant and should be watched for by the collector. *SFM*

The occurrence of gold in the gem beds of Sri Lanka. C. B. Dissanayake and S. W. Nawaratne, *Economic Geology*, Vol. 76, No. 3, 1981, pp. 733–738.

The authors report on the significance of small flakes of gold found in association with alluvial gem materials near the Ratnapura district in Sri Lanka. Nine tenths of Sri Lanka is said to be composed of Precambrian metamorphic rocks, which are subdivided into the Highland Group, the Vijayan Complex, and the Southwest Group, each having specific mineral assemblages. The authors relate the complex metamorphic environments of the Highland and Southwest Groups and the volcano-sedimentary components of the terrain, suggesting this environment as a possible source for the gold.

Two geologic maps illustrate the detailed geology of Sri Lanka and the sampling area in the southeastern part of Ratnapura. Geologic cross sections of the gold-bearing gem pits in a stream bed in the Ratnapura region are also included, each with sedimentation features that are characteristic of several cycles of deposition. Gold, occurring as dust or flakes, is found mixed with these gravel deposits. Associated minerals include pyrite, ilmenite, garnet, monazite, magnetite, rutile, and quartz. *Stephen C. Hofer*

BOOK REVIEWS

Robert Effler, Editor

EMERALD AND OTHER BERYLS

*By John Sinkankas, 704 pp., illus., Chilton Book Co., Radnor, Pennsylvania, 1981. US$37.50**

In the preface to this impressive work, Captain Sinkankas states that the inspiration for *Emerald and Other Beryls* was Joseph E. Pogue's classic book on turquoise, and that the objective of this newest of his publications is the same as Pogue's: that is, to "arouse a greater interest in a fascinating field—that concerned with precious stones and their relation to mankind." Certainly, Sinkankas has accomplished this. *Emerald and Other Beryls* is one of those rare books that, when published, generates such excitement that it is destined to be an "instant classic." It is very difficult to imagine a more definitive or exhaustive work on any subject. Suffice it to say that the book represents 15 years of research.

Emerald and Other Beryls is broadly divided into three parts: "History and Lore," "Chemical and Physical Properties," and "Beryl Localities." Part I covers a wide range of subjects. It starts with the use of beryl in ancient Egypt and proceeds through its early use in the Americas. Next, Sinkankas reviews the subject of beryl from the standpoint of the early literature, describing references to this gem material by such authors as Agricola, DeBoodt, and Haüy. "Beryl in Magic, Mystery, and Medicine" is discussed next, starting again with early Egyptian lore and then examining the occult properties of this material, including its effects on personal traits, love and marriage, and even business transactions. Sinkankas also delves into the therapeutic uses of beryl—including its prescription in various cultures as a cure for such problems as eye disease, epilepsy, fever, complications of pregnancy, and digestive-tract ailments. In this first part of the book, Sinkankas also talks about the biblical references to beryl, beryl as a birthstone, and emeralds in fable. He concludes the section by discussing the engraving of beryl and describing some of the most important specimens of engraved beryl found in major collections around the world. He lists these collections by country.

Part II addresses the scientific aspects of the beryl family. It discusses in great detail such topics as the crystal structure and chemical composition of beryl, its physical and optical properties, crystallography, color, and luminescence. There is a particularly interesting section on artificial and synthetic beryl, and inclusions found in beryl. Part II of the book also includes a discussion of the cutting and polishing of beryl, and closes with a section on the various types of deposits in which beryl is found. Sinkankas divides these deposits into volcanic, early magmatic, late magmatic, metamorphic-hydrothermal, hydrothermal, and sedimentary.

This general discussion of deposits forms a firm basis for part III of the book, "The Beryl Localities." This third, and by far largest, section of the book comprises at least half of the total work. It is the section that will have the greatest appeal and use for the collector and museum curator. Sinkankas describes all known sources of all types of beryl from ores, to specimens for the collector, to gem deposits. The locality section is an easy-to-use reference because the localities are arranged by country in alphabetical order. References to the literature on a given deposit are also included at the end of the discussion of each country. What makes this discussion of beryl localities unique and of even greater importance is Sinkankas's practice of placing particular emphasis on those localities about which information is difficult to obtain or little has been published in the past. The well-known deposits are covered, but not in as exhaustive a manner as one would expect given the detail of the rest of the book. These descriptions are left to existing literature. The information that Sinkankas has amassed on beryl localities is virtually unprecedented. For example, how many readers are aware of the two-inch bluish-green beryl crystals from Commonwealth Bay, Adelic Land, Antarctica? This locality information is beautifully supplemented with maps, photographs, and sketches of the occurrences.

One of the most important aspects of any book from the perspective of the researcher is its bibliography. In the case of *Emerald and Other Beryls,* the bibliography is another indication of just how exhaustive the research was and how much a labor of love this book has been for John Sinkankas: over *700 references* to beryl are presented. In addition, Sinkankas includes an appendix of beryl nomenclature, listing over 500 names for beryl that he encountered during his research.

Emerald and Other Beryls is the ultimate reference on beryl and is a definite must for the library of anyone interested in gems.

PETER C. KELLER
Santa Monica, California

LAPIDARY CARVING FOR CREATIVE JEWELRY

*By Henry Hunt, 144 pp., illus., Desert Press, Bouse, Arizona, 1981. US$12.95**

For the gem enthusiast or lapidary desiring a good introduction to gemstone carving techniques, this book is indeed a welcome addition to publications on the craft. The author describes all the equipment needed to carve and then thoroughly explains the uses of all items. He even describes the making of wheels, points, and the like, which is not an

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* *This book is available for purchase at the GIA Bookstore, 1735 Stewart St., Santa Monica, CA 90404.*

uncommon practice for those who carve. Although suppliers have excellent assortments of wheels and polishing points, many advanced carvers make what they need for a particular job.

The book deals primarily with the carving of transparent gem materials. The author thoroughly explains how to work each stone, such as amethyst, citrine, peridot, beryl, and even some synthetics, each in a separate chapter. Hunt has pursued a rather different end product than most carvers. Much of his work has been directed toward bringing out the optical effects possible from the particular gem material. Such effects as internal reflections, refraction within curved polished surfaces, changes of color due to thickening or thinning areas within the carved object, and the like, are pursued in order to utilize the material to what the author perceives to be its greatest potential beauty. For example, from chapter 1, "Optical Qualities of Transparent Stones," we note: "you cannot see through the stone. Light is reflected internally back and forth, with the result that the carving scintillates as it moves around. The light seems to come from within the stone." And, further along, we read: "The optical qualities of the stone become part of the aesthetics of the carving. The surface form and the color of the carving is not the end of the story. What happens to the light inside the stone, how it defines the shape, becomes equally important."

The objects carved by the author certainly have interest value, but they may not be aesthetically exciting for everyone. Many black-and-white pictures appear throughout the book.

Ideally, carving is the ultimate expression of the art of working gemstones. When one can combine proper techniques of working the gemstone to its greatest potential beauty with artistic and creative talent, to execute a meaningful, worthy object that will delight all who may see it, then he or she has arrived at a plateau deserving of much recognition. This book will certainly help the lapidary along that path.

BILL KERR
Santa Monica, California

GEM NEWS

Stephanie Dillon, *Editor*

EXHIBITS

The Wernher Collection—Luton Hoo, Luton, Bedfordshire LU13TQ, England. Telephone: (0582) 22955.

Luton Hoo is a country house open to the public. The collection includes Renaissance jewels and a large group of Carl Faberge's works. The collection is open from April 3 to October 10.

National Museum of History—49 Nan Hai Road, Taipei, Taiwan. Telephone: (2) 361-0278.

This museum of Chinese history and art has an extensive collection of jade from the Shang, Chou, Chin, and Han dynasties to the present. "Chinese Jade in 4,000 Years" is an event for which many collectors have lent their jade to augment the museum's collection. The exhibit, to be held in spring 1982, will give a comprehensive view of Chinese jade.

Heimatmuseum—6580 Idar-Oberstein 1, Hauptstrasse 436, West Germany. Telephone: 06781-24619.

The Heimatmuseum houses crystal specimens from around the world, as well as cut gems and a collection of antique and modern jewelry. Bowls, figures, and cameos are displayed in a special exhibit on the carver's art. There is an old agate-grinding mill with water wheel as well as an old-fashioned goldsmith's workshop. There is also a darkroom with fluorescent minerals displayed under ultraviolet light. The museum is open to the public year round.

Museu de Minerais e Rochas do DNPM—Av. Pasteur 404, Praia Vermelha, 22291 Rio de Janeiro, Brazil.

The museum's permanent collection comprises various pieces of ornamental stone and 300 cut specimens of quartz, topaz, tourmaline, beryl, spodumene, and several nonsilicates. The museum is open to the public Monday through Friday all year.

ANNOUNCEMENTS

The 28th Annual Tucson Gem & Mineral Show will be held February 12–14 in the Tucson Community Center, 260 South Church, Downtown Tucson, Arizona. The show will feature lectures and programs by curators, mineralogists, and hobbyists, as well as competitive exhibits, including a best-of-species competition in malachite. There will be more then 120 cases of special exhibits containing mineral specimens from museums and private collections throughout the world. Annual meetings will be held by Friends of Mineralogy, the Mineral Museums' Advisory Council, and Species Collectors; also convening will be the Neal Yedlin Memorial Micromount Symposium. Information: Tucson Gem & Mineral Show Committee, P.O. Box 42543, Tucson, Arizona 85733.

The 1982 American Gem Society Conclave meets at the Fairmont Hotel in New Orleans, Louisiana, April 23–27. Numerous AGS and GIA personnel will lead the activities of the five-day program, which carries the theme, "Your AGS Image: the Formula for Success." After beginning with a day of workshops, the agenda continues with the theme session, the Shipley luncheon, the Intergold luncheon, an evening program on diamonds, young people's and spouses' sessions, and three days of concurrent laboratories, seminars, and conference groups in the areas of gemology and sales promotion. For further information, contact: American Gem Society, 2960 Wilshire Boulevard, Los Angeles, California 90010.

The National Association of Jewelry Appraisers, newly formed, is conducting a membership drive. Dedicated to maintaining professional standards and education in jewelry appraisal, the association plans to publish a monthly newsletter and an annual membership directory. Richard E. Baron is executive director of the organization. Information: National Association of Jewelry Appraisers, 7414 East Camelback Road, Scottsdale, Arizona 85251; telephone: (602) 941-8088.

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SUBJECT INDEX

This index gives the first author (in parentheses) and *first page* of the article or Gem Trade Lab Notes (GTLN) section in which the indexed subject occurs. The reader is referred to the author index for the full title and the coauthors, where appropriate, of the articles cited.

Indexes prepared by Dona Dirlam

AUTHOR INDEX

This index lists, in alphabetical order, the names of authors of all articles that appeared in the four issues of Volume 17 of *Gems & Gemology.* Full citation is provided under the first author only, with reference made from joint authors.