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IN THIS ISSUE

Analytical Results of Poly-Mineralic Sulfide Inclusions in Diamond

by E.J. Gübelin, PhD, CG, FGA
Lucerne, Switzerland

Paper prepared for the 2nd International Kimberlite Conference
in Santa Fe, Oct. 3-7, 1977

Diamonds and their mineral inclusions appear to be a unique window into the Upper Mantle and provide unaltered samples of a wide compositional range of several rock suites. The abundance and variety of inclusions, both mono- and poly-mineralic, even within a single diamond suggest that a complex history has preceded the genesis of the host diamond. The history would appear to forerun the formation and emplacement of kimberlite. Hence, detailed investigation of the crystalline inclusions in diamonds is essential. Their coexistence with the diamond, i.e. their forming the internal paragenesis of the diamond tells us a fascinating story of evolution. The origin of the diamond has been disputed for many years and will still be in years to come and even now it is still full of riddles and secrets. Nevertheless, it is fascinating to realize that it is indisputably the guest minerals of the diamond that have delivered an incalculably instructive contribution to the clarification of the diamond genesis. Analysis of its syngenetic mineral inclusions and their trace elements actually provides valuable clues to the material composition of the mother-magma which must have been once poor in iron, chromiferous and peridotitic – and hence ultramafic – with admixtures of sulphur, titanium and carbon dioxide. Natural diamonds are generally considered to be the products of stable growth. On this assumption it has been argued that many mineral inclusions in diamond represent original phases which formed in equilibrium with the diamond – in other words: they grew simultaneously with the diamond undergoing the same conditions of crystallization.

Inspired by a previous study of J.W. Harris (1972) who had found that the black lining of cracks in diamonds often consisted of graphite and pyrrhotite, and also intrigued by relatively large black spots which occurred in all of about one dozen of diamond slabs which Mr. R. Crowningshield, Director of the GIA Gem Laboratory in New York gave me for examination, I considered it worthwhile to attempt further detailed investigation of the nature of these black inclusions. The diamond slabs had been sliced parallel to the girdle, i.e. to the maximum circumference of octahedral diamond crystals from Ghana, weighing about 3

Manuscript received 10/13/77.

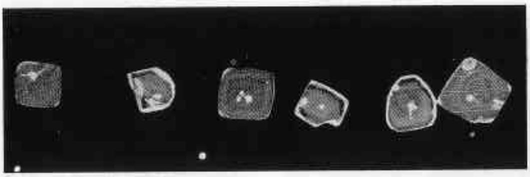

Figure 1. Some of the diamond slices mentioned in this article are photographed in short-wave ultraviolet light. The strong absorption of the ultraviolet light by these slabs classifies them as diamonds Type 1a.

to 4 carats each *(Figure 1)*. In each of the slabs one or more black inclusions of the type illustrated in *Figure 2* were present. These inclusions consisted essentially of a bright, colorless or sometimes a black mineral grain sitting more or less in the center of a system of fissures diverging in directions of the (111) faces and predominantly lined with a black substance. Testing their transparency in short-wave ultraviolet light proved that all the host slabs were diamonds of Type 1a.

As the mineral inclusions were completely encased by the diamond substance of the slabs, the latter had to be cut slimmer, until the bright and black inclusions were flush with the surface, i.e. exposed for a quantitative and qualitative analysis by conventional methods as well as by means of the electron microprobe. These examinations showed that the bright colorless inclusions were mono-mineralic while the majority of the black inclusions were poly-mineralic substances. In the bright mono-mineralic crystals, the microprobe identified the elements Mg and Si, thus they may be considered as olivines. (It is well known that olivine is the most ubiquitous guest mineral of the diamond.) The black poly-mineralic grains were mainly sulfides such as pyrrhotite ($Fe_{1-x}S$), Pentlandite $(Fe, Ni)_9S_8$, and Chalcopyrite ($CuFeS_2$). It was interesting to note that one of the black mineral grains turned colorless after grinding down the host slab, and the composing elements Mg and Si, determined by the microprobe, indicated an olivine, which had previously been wrapped by a film of either graphite or pyrrhotite.

The inclusions in slabs numbers D-1 and D-4 proved to be particularly informative. Slab D-4 contained – besides the common black grains – a tiny anhedral yellow crystal *(Figure 3)* for which the microprobe revealed the elements Fe, Ca, Mg, (Mn), Si and Al which justify the identification as a pyroxene. However, it was not possible to determine whether it was a clino- or an orthopyroxene.

The answer to this alternative would have been extremely illuminating because it could have indicated whether the host diamond originated from a peridotitic mother rock (i.e. garnet lherzolite) or from eclogite. The mineral associations of the diamond's internal paragenesis belong to two different suites of mother rocks, namely either to lherzolite or to

Figure 2. Common appearance of the black inclusions in the diamond slices examined. They usually consist of a central bright or black mineral surrounded by a system of divergent fractures. 100x

eclogite, both being deep seated xenoliths. Detailed research of the material of the Upper Mantle has revealed that each type of rock is characterized by its specific composition of minerals, to such an extent that certain inclusion parageneses refer to one or the other mother rock, even if only one discrete mineral inclusion happens to be present. Thus, the association of chrome-rich garnet (purple red, knorringite-rich pyrope), chrome diopside, enstatite (ortho-pyroxene), olivine, and chromite indicate origin from lherzolite, whereas a paragenesis of honey-brown garnet (with molecules of pyrope-almandine and grossular), omphacitic pyroxenes (clino-pyroxene), kyanite, olivine, rutile which is a frequent accessory mineral), phlogopite, and magnetite betray formation in eclogite (PRINZ, M. *et al.* 1973). The garnets in both types of xenoliths seem to excel in the same peculiarity of containing a remarkable amount of Na_2O – which implies high pressure of formation – one of the very important factors of diamond growth.

Figure 3. Yellow mineral inclusion of irregular shape, which the electron microprobe revealed to be a pyroxene. 100x

The investigation of slab D-1 offered a more provocative problem since it enclosed two black inclusions of seemingly different nature. They were first subjected to a microprobe analysis which disclosed the elements S, Fe, Ni and Cu for both grains A and B as well as a clear indication of Si for grain B *(Figure 4)*. It is however not so much the presence of Si which is astonishing but definitely its immediate proximity to a poly-mineralic grain of sulfides – an observation which seems to be unique and was made for the first time in connection

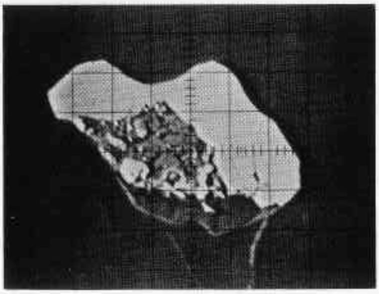

Figure 4. Electron microprobe scanning image of the poly-mineralic inclusions B in diamond slab D-1.

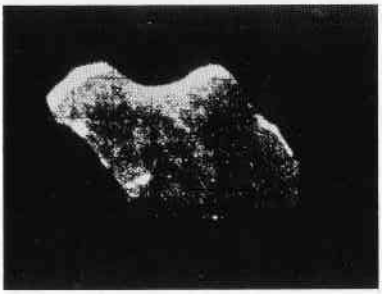

Figure 4a. Scanning X-ray image showing the distribution of elements, i.e. the content of sulphur in the poly-mineralic grain of sulfides.

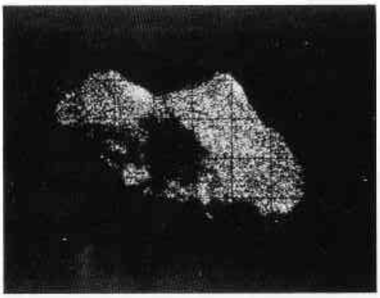

Figure 4b. Scanning X-ray image displaying the distribution of iron in the poly-mineralic sulfide grain.

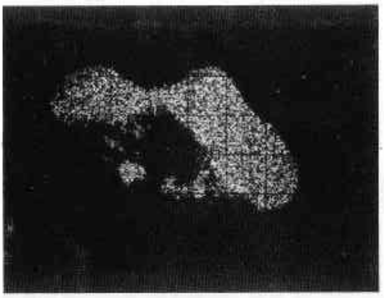

Figure 4c. Scanning X-ray image disclosing the distribution of nickel in the poly-mineralic grain of sulfides.

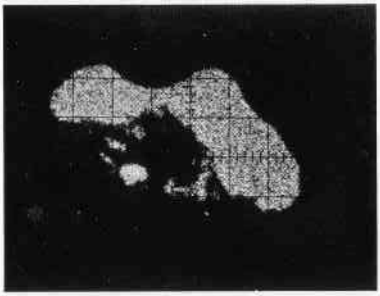

Figure 4d. Scanning X-ray image reveals that the copper content is mainly concentrated along the rim of the poly-mineralic grain of sulfides.

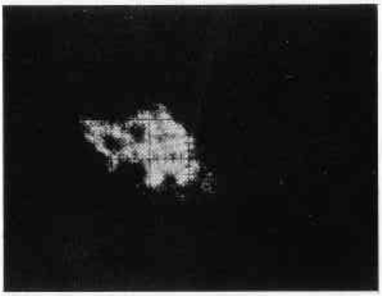

Figure 4e. Scanning X-ray image indicates the presence of a small amount of silica in immediate contact with the sulfide minerals.

with the internal paragenesis of diamond *(Figure 4e). Figures 4a, 4b, 4c* and *4d* show the distribution of the elements found in the poly-mineralic sulfide grain and they simultaneously depict that iron and nickel occur in solid solution (i.e. mixed) in the central part of the grain, whereas copper is mainly concentrated along the rim. The quantitative analysis of the two black sulfide inclusions is shown in *Table I:*

TABLE I

Microprobe Analysis of Elements in Slab D-1 Inclusions

Element	Inclusion A Wt. %		Inclusion B Wt. %
Ni	7.81	0.67	7.89
Fe	51.35	34.49	53.52
S	40.28	34.06	36.13
Co	0.46	0.06	0.44
Cu	2.67	27.24	0.57
*Total Percentage	102.57%	96.53%	98.54%

*(The analytical quantities do not exactly add to 100% because of the irregular and gradual transition (zonation) of the phases.)

The Fe-Ni-S-phases are similar in both inclusions, and the ostensible differences in all components are likely to be based on the delimitations merging into one another. The significant feature of the microprobe scanning X-ray images is the conspicuously high Ni content (which agrees with the chemical analysis of both black grains) in a mineral which is basically pyrrhotite in composition. Apparently, little or no exsolution of Ni has taken place from the original mineral during cooling, which suggests that this host diamond cooled rapidly. Most pyrrhotite can only accommodate about 1-2% Ni in solid solution, yet these two black sulfide inclusions contain 7.8% Ni (see *Table I).*

The Cu-Fe-S phase is chemically chalcopyrite, but it has recently become known that there are some high pressure polymorphs of a similar mineral known, which are chemically indistinguishable from chalcopyrite, so that the mineral in this host diamond is somewhat uncertain.

Furthermore, the Si-phase also remains dubious; it could consist of the high pressure modification of quartz – called coesite *(Figure 4e).* An attempt was undertaken to separate the pattern of the Si-diffraction from the pattern of the sulfide phases by means of X-rays, yet the extreme overlapping of the two principal components rendered the task even more difficult. However, a comparison of *Figure 4* of microphotographs (polarized) in the present article with the description and the microphotographs 1-4 (crossed-polarized) in a recently published paper by J.R. Smyth (1977, p. 829) would suggest that the Si-polymorph is a quartz pseudomorph after coesite. Be that as it may, the direct contact of a Si-phase with sulfides is an absolutely unique occurrence, which has never been mentioned in the literature before.

Considering all the factors of the sulfide inclusions analyzed in these diamond slabs, especially so in slabs D-1 and D-4, one may conclude that they were found in eclogites.

The divergent black fissures are tension cracks initiated by a higher coefficient of thermal expansion of the mineral grain in their center as against that of the diamond. In most cases the black coloration is caused by an ultra-thin film of pyrrhotite rather than graphite. The question as to how this fine lining of the fractures could occur has not been solved and continues to be a challenging problem. Nevertheless, the conclusions which may already be derived from the investigation of inclusions and applied to tentative explanation of the host diamond's genesis are already highly informative. In connection with the analytical results in this paper, it seems to be most elucidating to study the paper by H.O.A. MEYER *et al.* (1976) who stated that: "A major problem with sulphides is that they re-equilibrate very readily with decreasing temperatures, and furthermore the effect of pressure on the stability fields of these sub-solidus phases is mostly unknown. It is most likely that under the conditions of diamond and inclusion genesis the sulphides are a single discrete phase of the monosulphide solid solution. Subsequently, as the temperature decreases, it is probable that Cu-rich phases such as chalcopyrite would first be exsolved leaving a Ni-enriched monosulphide with pyrrhotite structure. Eventually, this monosulphide would undergo further sub-solidus re-equilibration to pentlandite and pyrrhotite."

I wish to extend my sincere expression of gratitude to Prof. M. Weibel of the Institute of Mineralogy and Crystallography at the Federal High School of Technology in Zürich, Switzerland, for the analytical work as well as to Dr. J.W. Harris for his competent interpretation of the analytical results.

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Developments and Highlights at **GIA**'s Lab in Santa Monica

By RICHARD T. LIDDICOAT, JR.

Exceptional Crystal

As usual, in the interim between the last set of lab notes and today, we have had a number of very interesting developments. We were asked to confirm the identity of a very beautiful and seemingly valuable emerald crystal. The first clue that came into focus was that it showed absolutely no chrome spectrum. When it was examined under magnification, large bubbles were evident which were usually flattened and elongated as seen in *Figure 1.* When the stone was examined by X-ray, it was apparent that the bubbles were due to the fact that the crystal had been core-drilled and the space between the core and the outside crystal filled with a green cement. Probably, a pale beryl crystal had been drilled and a green cement with chromium was used to hold the core in place. From what we were able to gather, an unfortunate victim had paid a very high price for the crystal.

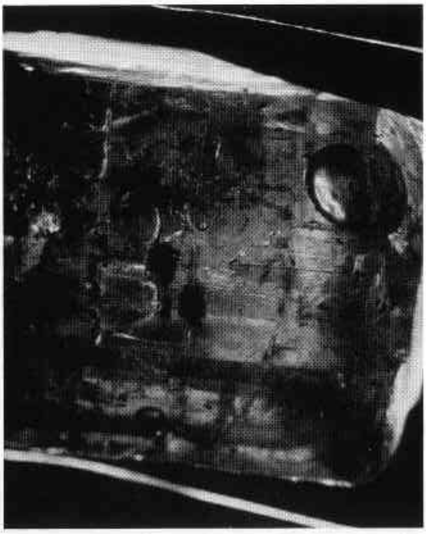


Figure 1.

Zoned Emerald

From overseas, we were sent a beautiful antique cushion-shaped emerald with a cabochon top and a faceted pavilion with a request to determine whether the color was natural or whether something had been done to enhance the stone. It turned out to have the strongest zonal coloration we ever have encountered in an emerald. It was reminiscent of the color distribution of a Burma ruby, except that the color distribution was structured. Part of the stone was colorless, and part a rich, deep emerald green. The overall effect, when looking at the stone face up, was that it was a normally colored emerald, but the strongly zoned coloration shown in *Figure 2* was apparent only in one direction.

A Lovely Amethyst Cameo

We received, just to examine, an antique brooch set with a very large carved amethyst. It is shown in *Figure 3.* The amethyst is very attractive, and the carving is delicate and appealing.

Green Cuvette

Recently, we received a man's ring in which was set a green cuvette. The soldier's head was in green, raised above a white frosted background. The interesting fact about the piece was that it had been cut from a synthetic spinel triplet. The carving had sliced through the crown, and had removed the colored cement layer, which left the frosted background of the colorless spinel base as seen in *Figure 4.* Most of the carving of the head had been done in the upper portion of the doublet, leaving the color. It was an interesting use of the colored cement.

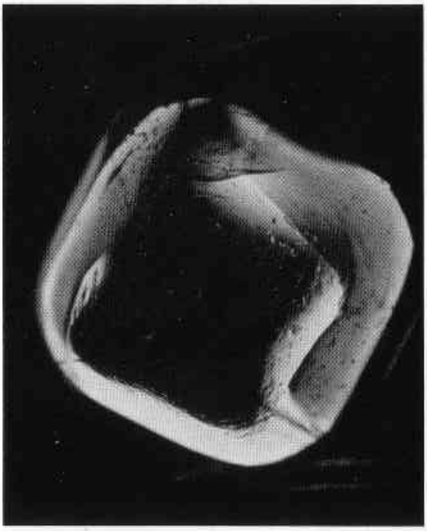


Figure 2

Figure 3.

"Horsetail" Inclusions

People in the Laboratory were very much intrigued by a green glass that showed milky swirls which, at first glance under magnification, were reminiscent of "horsetail" inclusions of demantoid. They are pictured in *Figure 5.*

Diamond Substitutes

In this day of GGG and cubic zirconia, some dealers are becoming paranoid about the thought of being cheated by an erstwhile customer. One of them has resorted to scratching the table of stones offered to him with the presumption that they are diamonds. For this test, he uses a diamond hardness point. Since most diamonds in the trade are 4-point stones, the

Figure 4.

result can be, and usually is, a noticeable scratch on the table of even a diamond. Recently, our Laboratory had in for examination a 1-7/8-carat diamond, on which our strong-fisted friend had put very noticeable scratches on the table of the diamond. These are clearly visible in the center bottom half of the table in *Figure 6.* It is unfortunate that the jeweler in this case did not know that diamond scratches diamond.

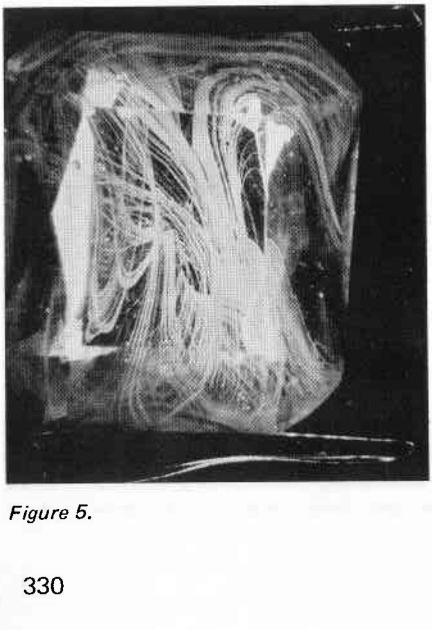


Figure 5.

An Early Flame-Fusion Synthetic

There were quite a number of angular appearing inclusions in an early synthetic ruby sent to the Santa Monica Laboratory for identification. These are pictured in *Figure 7.* There was no difficulty in identifying the stone. *Figure 8* shows the tightly curved striae that were obvious, but a first glance at the angular inclusions could have been misleading.

Interesting Green Stone

Chuck Fryer and I were puzzled by a stone we thought might be tourmaline and which showed refractive indices of 1.62 — 1.64. It was a strong green in color, but showed no extinction in the polariscope and no dichroism. Under magnification, it had the roiled or heat wave look of serpentine,

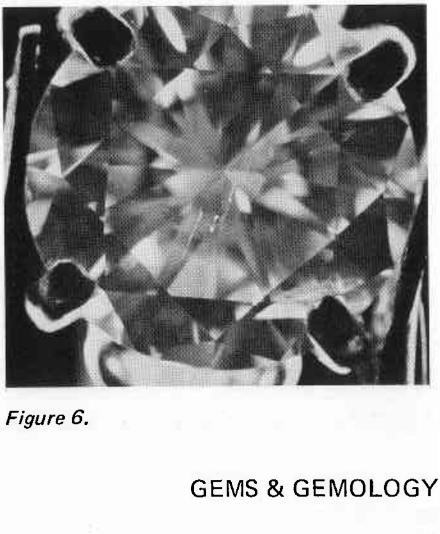


Figure 6.

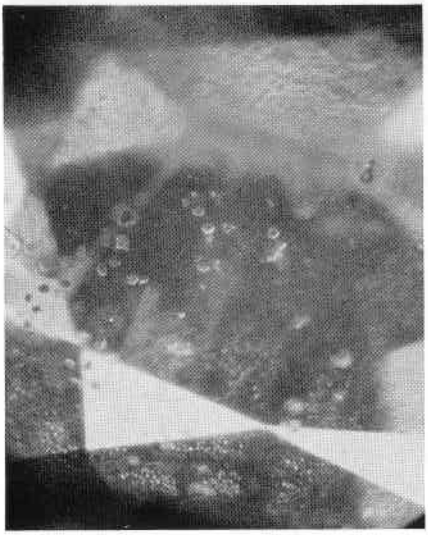


Figure 7.

Figure 8.

or hessonite. There was a quasi-fibrous structure to it. We felt that it probably was actinolite.

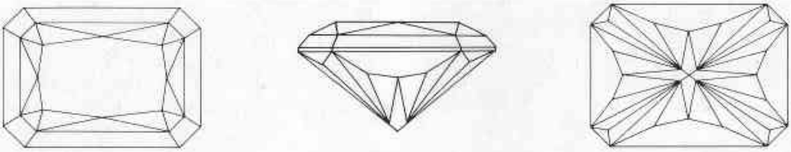
Using the energy dispersive unit of the scanning electron microscope to obtain the stone's chemistry, Dr. Manson found magnesium, aluminum and silicon present in large quantity with minor amounts of calcium and iron. We decided it would be necessary to check by another technique. A tiny amount of material was scraped from the girdle to get the X-ray diffraction powder pattern.

After all of this, and much to our surprise, the X-ray diffraction powder pattern showed the stone to be tourmaline. The lack of dichroism and the crystalline aggregate reaction in the polariscope showed that this is not a single crystal. It has a semi-fibrous appearance and the roiled look under magnification suggested that the cut stone was made up of a number of not quite parallel crystals. The 1.62–1.64 refractive indices would tend to bear out the fact that there was some parallelism, but not enough to give obvious extinction in the polariscope.

Amethyst-Colored Spodumene

We were very pleased to have the opportunity to examine a large, magnificent deep amethyst-colored spodumene. It was deeper in color and more purple than we had ever encountered. The closest color similarity to described its appearance would perhaps be that seen in one direction in a very large, very deeply colored kunzite crystal. It was indeed a handsome color, but not one that we would associate ordinarily with spodumene.

One of the staff who had observed the stone by unaided eye remarked that it was unfortunate that it had a feather all the way across the center of the stone more or less at right angles to the long direction. Upon examination, under magnification, there was



Crown Side Pavilion

RADIANT CUT

no feather to be seen. Very interestingly, there was a layer caused by twinning across the stone at right angles to the keel line, about a millimeter in thickness. The orientation, being different from that of the host crystal, showed up as a bright bar in the extinction position of the main body in the polariscope. In the photograph shown in *Figure 10,* the twin portion is in the extinction position and appears as a dark bar, visible to the right of the keel line – it appears as a light bar to the left of the keel line, which runs from 3:00 to 9:00.

We had never seen a spodumene with this depth of color, either treated or untreated. Also, we did not have an opportunity to perform other tests other than those needed to determine that it was indeed spodumene. The owner, a stone dealer, insisted that the stone was untreated. We have never heard of spodumene being treated to this color.

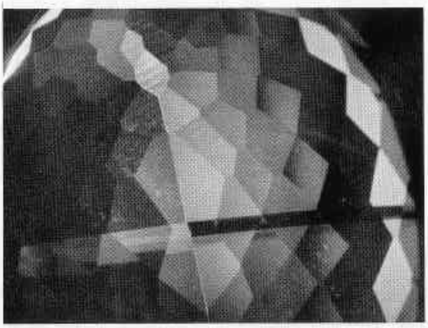


Figure 9.

The New “Radiant-Cut”

In the Winter 1976-1977 issue of *Gems & Gemology,* pages 234 and 235, two diamonds were illustrated and captioned as “Barion Cuts.” They are, in fact, the new “Radiant-Cut.” Since our Laboratory had no knowledge of the new “Radiant-Cut” at the time the stones were examined, they were described as modified “Barion Cuts.” The “Radiant-Cut” is a cushion octagon modified brilliant style of cutting patented by Gem Trade Laboratory member Henry Grossbard which has similarities to the “Barion Cut.”

Unthinkingly, instead of maintaining our normal Laboratory policy of using descriptive cutting terms rather than naming different patent cuts, we used such a term – and incorrectly. However, since only a slight modification of cutting may be sufficient not to infringe upon a patent, it would be difficult, as well as an unnecessary burden, for our Laboratories to have to determine whether or not a facet pattern matches a patented one. As is the policy of our Labs, we will continue to avoid naming patented cuts in our reports and regret this oversight of using “Barion Cut” for “Radiant-Cut.” For clarification, a diagram of Henry Grossbard’s patented “Radiant-Cut” is shown in the illustration. The "Radiant-Cut" is described as a "brilliantized" step cut stone with a straight edged polygonal shaped girdle. It has a generally pyramidal base and a crown with at least girdle and table breaks wherein at least one of these breaks is cut with triangular shaped facets.

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We wish to express our sincere appreciation for the following gifts:

To *Mr. M. Aronowicz,* Berlin, Germany, for the selection of emerald triplets of a type which was much needed.

To *Mr. Conrad Abrahmson,* Concord, California, for a very large medium greenish-blue faceted YAG (29.42 carats), and a 35.96-carat section of boule of the same material for use in our reference collection.

To *Mr. Barry D. Blower,* G.G., International Import Co., Edmonton, Alberta, Canada, for an unusual and attractive ammonite triplet which will be added to our display collection.

To *Mr. George A. Bruce,* International Import Co., Stone Mountain, Georgia, for a kornerupine cat's-eye for our display collection.

To *Miss Ruth Cooper,* Originals, Inc., Bristol, Tennessee, for an interesting specimen of emeralds in matrix.

To *Mr. William C. Ilfeld,* G.G., Montezuma, New Mexico, for a very generous gift of turquoise and optical quartz. The turquoise should supply our Gem Identification Course demands for some time and the quartz will be put to good use in our new faceting class.

To *Mr. J. Digby Matheson,* F.G.A.A., G.G., Los Angeles, California, for an unusual selection of synthetic opal "cultured" triplets.

To *Mr. Jim Mears,* correspondent student, for a nice specimen of rough yellow opal from Idaho for research.

To *Mr. J. J. Merkle,* Jacksonville, North Carolina, for garnet rough from the Barton Mine at Gore Mountain, North Carolina. It will be used to advantage in our Gem Identification Classes.

To *Mr. C. D. Parsons,* Burbank, California, for a generous gift of unusual cut and uncut stones including apophyllite, peridot, barite, datolite, fluorite, smithsonite, spodumene, sunstone, tourmaline, petalite, beryl, danburite, rhodochrosite, topaz, tugtupite, prehnite, and bustamite. All of which are much needed for our Gem Identification classes.

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To *Mr. Don Young,* Roseburg, Oregon, for a beautiful faceted sunstone which will be a nice addition to our display collection.

Historical Notes on South American Gemstones

BY JOHN SINKANKAS
San Diego, California

Columbus's epic voyage led other European adventurers to further explore the New World with the Spanish and Portuguese directing their efforts toward the south. In point of time, the first contacts with the continent of South America were made in 1500 when the Spaniard Alonzo de Ojeda (1465?-1515) sailed along the coasts of what is now Colombia and during 1508-09 unsuccessfully attempted colonization at Cartagena. It was not until Jimenez de Quesada (1500?-1579) penetrated inland to defeat the native Chibchas on the Altiplano in 1536-38 that the Spanish conquest and colonization of this country, then dubbed New Grenada, was assured.

The Portuguese, exploring farther south, discovered Brazil in 1500 when Vicente Yanez Pinzon (1460?-1524?) sighted Cape Augustine some 20 miles south of present-day Pernambuco. In the same year, Pedro Alvares Cabral (1460?1526?) discovered another part of the Brazilian coast at Alagoas and took possession of the land in the name of the King of Portugal, but permanent settlements were not established until 1532 at São Vicente.

Thus the first decades of the 16th century saw the stage set for inland penetration, exploration and exploitation of the wealth of both Colombia and Brazil.

Colombian Emeralds

The sources of emeralds in Colombia, namely Muzo and Chivor, were originally found and exploited by the natives for an unknown length of time before the advent of Europeans. Traded to other tribes, the emeralds found their way throughout northern South America, into Central America and even into Mexico. In his report on his explorations in the grave sites of Coclé, Panama, Lothrop[1] describes numerous emeralds which he tentatively asserts as having been traded into Panama from Ecuador. However, on the basis of present geological knowledge it seems clear that no source for such stones exists anywhere in Mexico, Central America or Ecuador and that these stones must have originated in one of the Colombian deposits.

The stocks of emeralds held by the Indians and subsequently confiscated by the conquistadores surpasses belief. Sent to Spain as part of the loot from the New World, these gems, along with gold, enormously increased the wealth of Spain and its political power. Yet all of this raises the intriguing question – where did all of the Spanish emeralds go? Consulting Twining's massive history of European crown jewels[2], it is soon discovered that "strictly speaking there are no Spanish crown jewels" (p. 579) and also, "the great emerald mines of Peru *[sic]* provided an immense source of this beautiful stone" (p. 615). Twining's descriptions of such jewels as have survived show that emeralds are virtually absent. Twining suggests that the trappings of royalty were less important to the Spanish rulers than in other kingdoms and that this could explain the paucity of regalia. However, another explanation could be set forth, that is, that the Spanish regarded emeralds primarily as disposable wealth in the same class as gold and used them in the same way. The love of gemstones so characteristic of the nobility and merchant princes in other lands, both in Europe and in the East, seems not to have been a strongly developed trait of the Spanish.

Records of large emeralds still to be found in royal treasuries of lands far removed from Spain suggest that the major portion of the Spanish hoard of emeralds was sold to eager buyers and that scarcely any were retained in Spain itself. For example, consider the astonishing stock of emeralds in rough and cut forms in the crown jewels of Iran in Tehran[3], also the extremely large polished hexagonal crystals and cut gems in Turkey's Topkapi Museum in Istanbul[4], the Devonshire emerald in England which has been frequently described in English gemological literature, and the truly enormous quantity of emeralds in cabochon forms, carved cabochons, or polished hexagonal cross-sections that were discovered in the treasuries of the maharajahs of India.[5] The latter have often been called "Indian" in origin and various sources for them have been suggested but again it seems plain on the basis of current geological knowledge of the Indian sub-continent that these can be nothing other than Colombian emeralds traded into India soon after their shipment to Spain.

The two principal deposits, or rather, groups of deposits in Colombia are centered about Muzo and Chivor respectively and lie north of Bogotá in a high-altitude, rain-forest environment which does much to impede exploitation. The location of Muzo was quickly wrested from the Indians by the Spanish conquistadores and the mine placed in operation soon after the country was subdued. These mines have been in intermittent operation since then and are still capable of producing emeralds as fine as were ever known. Chivor, or as it was then known among the Indians, Somondoco, is another matter. Although it too was exploited at an early time, the mines were allowed to lapse and gradually all knowledge of their exact location was lost for several hundred years. It was not until some detective work among old records in Ecuador that a clue to their location was obtained in 1904 by Francisco Restrepo, a citizen of Bogotá. Fritz Klein (1882-1953) of Idar-Oberstein, Germany, while traveling for rough gemstones in South America, joined forces with Restrepo to locate the deposits and commence their first modern exploitation. The exciting tale of the events that led to the rediscovery of Chivor and its initial mining in the period before World War I are told by Klein in a book of memoirs.[6] It was during Klein's regime that the famous large multiple emerald crystal, called the "Patricia," was found at Chivor. For many years this crystal mysteriously disappeared from veiw but just recently it resurfaced and was given by an anonymous donor to the American Museum of Natural History in New York.

Returning to Germany upon the outbreak of the first World War, Klein lost his rights to mine the Chivor deposits to an American syndicate which placed Peter Rainier, a mining engineer, in charge. The latter wrote *Green Fire*[7], a colorful tale of adventure describing in vivid detail his experiences at the mines and valuable as being the only eyewitness account of the time. A succeeding period of exploration is also described by Anderton who was placed in charge of the Chivor mining enterprise after Rainier. His book, entitled *Tic Polonga*[8], is also filled with colorful anecdotes and again is valuable for its firsthand accounts of the emerald mines. However, the best overall view of emerald deposits and mining in Colombia is certainly the thorough and detailed work by Dominguez, entitled *Historia de las Esmeraldas de Colombia.*[9] This work has the virtue of including modern geological-mineralogical studies by competent earth-scientists.

The emerald deposits of Colombia are virtually unique because they form fracture fillings in a black limestone, the contents of the veins being primarily calcite in the case of the Muzo deposits but containing much albite in the Chivor veins. The geological problem is to account for the presence of beryl (emerald) in such veins because the major portion of beryl occurs in granitic pegmatites wherein the crystals have been deposited through the agencies of high temperature and pressure. In contrast, the formation of beryl in the Colombian deposits seems to have occurred at low temperature at near-surface pressures. The other major type of emerald deposit can be called the "schist-type" inasmuch as the crystals are generally found enveloped completely in mica flakes as in the famous Uralian and the Pakistani mines and others of similar type in Africa and Brazil. However, in these deposits the source of the beryl can be traced to pegmatite veins and no particular paradox is presented. Despite numerous studies the origin of emerald in the Colombian deposits remains unclear.

At the present time, the Colombian deposits still represent the world's major resource of this gemstone. Geological reconnaissances of the limestone formations and their extensions strongly suggest that emeralds may be found in the future anywhere along a belt that may stretch for several hundreds of miles.

The mining of Colombian deposits is done very simply: cliffs of limestone enclosing potential emerald-bearing veins are systematically broken down and the exposed facades carefully examined for traces of emerald. When such are found, hand-tool work is employed to recover the stones. The Muzo mines are under strict government control, sometimes operated in behalf of the government, sometimes operated by private concerns under lease arrangements. The Chivor mines have always been privately held due to a decree obtained by Restrepo in the early part of this century when the mines were rediscovered. An excellent modern account of the Chivor emerald mines and their minerals was provided a few years ago by P.W. Johnson.[10]

Diamonds of the North

A large, wild, sparsely inhabited region of northern South America next merits our attention because it continues to produce a steady supply of small but generally high quality gem diamonds. This region stretches from the southern tip of Venezuela, the Gran Sabana, into Brazil's State of Roraima, thence into the Guianas. It is far removed from the coast and accessible only by boating expeditions up the rivers and into the headwaters where gold-seekers first made their way and then discovered among the gold-bearing sands and gravels the small diamond crystals mentioned. Van Kooten[11] notes that a few alluvial diamonds were found in Surinam as early as 1880 while Pollard, *et al.*[12] indicates the first discovery in British Guiana occurred in 1887. Venezuelan diamonds apparently were first found at a much later date. According to Freeman[13], a pioneer rancher in the Gran Sabana, L. F. Peña, discovered diamonds along with gold about 1930.

All diamonds occur as loose stones in sands and gravels of stream beds and are obtained simply by scooping up the bottom material and screening it. In more modern explorations small power dredges and divers equipped with air-breathing apparatus have been used. Both Van Kooten *(ibid,* p. 53 ff.) and Pollard, *et al.* (*ibid,* p. 13 ff.) give details on mining methods, recovery of stones, types and sizes, etc., as well as the geology and mineralogy of the deposits. As is true in the case of the Brazilian diamonds to be discussed later, no original source for them has yet been discovered.

On the whole, the diamonds are principally remarkable for their small average size, about 10 stones per carat, although a number are found in excess of two carats. On the other hand, Pollard, *et al.* (*ibid,* p. 13) note that two-thirds of the stones are gem quality, a high proportion. Perhaps more valuable than the money realized from these diamonds is the enrichment of adventure literature by a series of books written by explorers of the region who couple diamond, gold, savages, and danger into exciting accounts whose royalties fetched more than the meager returns from their mining efforts. Among these are books by Dennison[14] who wrote about his adventures along Venezuela's Caroni River, Greatorex[15] recounting his accomplishments in the Mazaruni watershed of British Guiana, la Varre's account[16] along the same river, and, better than most, the stories of Norwood.[17, 18]

Brazilian Diamonds

Oakenfull, that indefatigable reporter of the current scene in Brazil, wrote a series of handbook-guides commencing with his *Brazil in 1909*[19], and issuing thereafter yearly revisions, culminating in his *Brazil – A Centenary of Independence*.[20] His handbooks still provide much interesting and valuable information on Brazil as a whole, including excellent summaries of colonial history and material on the mineral wealth, including gemstones. We note from the first issue of his handbook (*ibid*, p. 59) that "in 1699, the first great discovery of gold took place, and was followed, 30 years later, by that of diamonds." However, he later revised this date to state that diamond "was first recognized in Brazil in 1721." It was in this year that Bernardo da Fonseca Lobo, a gold miner, discovered diamond while working gravels in the vicinity of the city now called Diamantina in the State of Minas Gerais.

While Oakenfull gives a good account of the early history of Brazilian diamonds, no better information on the famous diamonds of this country can be found than in Reis's *Os Grandes Diamantes Brasileiros.*[21] In his book, Reis lists finds made throughout Brazilian history of stones ranging from about 80 carats to over 400 carats, including such famous examples of rough as ultimately furnished the Dresden, Empress Eugenie, Star of the South, Vargas, Victoria and many others. Details on these and other famous Brazilian diamonds may also be found in Copeland, *et al*.[22] and Freyberg.[23] Interesting early accounts of the diamond mining, the miners, customs, etc. may be found in Mawe[24] and Burton.[25] The work of Mawe is particularly recommended because he was a mineralogist/gemologist famed for his perspicacity and accuracy.

As in the diamond deposits in the north of the continent, the original host rocks of the diamond crystals remain unknown despite much past speculation, "proof" of host rock sources by some authorities, and modern intensive geological exploration of the regions presently yielding diamonds. The extent of the controversy as to origin can be readily appreciated by consulting the many entries on diamond in Iglesias's bibliography.[26] Some Brazilian diamonds are found in a sort of matrix to be sure, this being a conglomerate of well-rounded small pebbles cemented together with sand and iron oxides and locally called *cascalho* by the miners. However, no diamond-bearing kimberlites have been found in all of Brazil unlike the case in South Africa, which land is now believed to have been adjacent to Brazil according to the continental drift theory first expounded by Wegener in 1912.

The Brazilian diamonds occur in gravels along river beds and are obtained most easily by washing the gravel in a batea, a flattened cone basket, which is oscillated under water to wash away the lighter minerals and leave behind the "heavies," including such diamonds as may be present. While much of the diamond washing is conducted even today by individuals, the so-called garimpeiros, large-scale operations have been conducted in the past, including diversions of streams via flumes to leave bare the bottoms and permit almost perfect cleaning of gravel down to bedrock. More recently, power dredges have been employed where gravels form extensive deep deposits.

There are several principal diamond mining regions, the major one of the early colonial period being centered about Diamantina in Minas Gerais with other important regions around Cocaes, the Serra do Cabral, Rio Macahubas, Serra do Grão Mogol and Abaeté in the same state. Diamonds also occur in the Coxim district of Matto Grosso state, and in the states of São Paulo, Goiaz, Paraná and Bahia. While production is by no means so large as that of Africa, Brazil continues to supply the market with considerable quantities of rough and small amounts of cut gems. In addition to providing a remarkable number of large diamonds, Brazil is also noted for production of carbonado and ballas diamond, both being curious cryptocrystalline aggregates of numerous very small diamond crystals more or less firmly adherent and broken only with great difficulty in the case of carbonados. The ballas diamonds form radiate structures of crystals and when best developed resemble glittering grayish to whitish pellets or shot.

Brazilian Gemstones (Other than Diamond)

One may justly say that almost any country the size of Brazil is certain to have some gemstone treasures worth speaking of, but Brazil is especially endowed by virtue of possessing a large variety of basement rocks richly furnished with gemstone deposits. Among all important gemstones only the corundum family of rubies and sapphires is poorly represented and in regard to precious opal, once almost absent from the roster of major Brazilian gemstones, this has lately been rectified by discovery of high quality stones. Of all types of deposits represented in this Western Hemisphere gem chest, it is the granitic pegmatite that has furnished virtually all of the important production. Pegmatites are masses of feldspar, quartz and mica crystallized from emanations from large bodies of granite and commonly found as vein-like or pod-like bodies of no great size intruded into overlying schists and gneisses. There are several characteristics of pegmatites which make them eagerly sought for and exploited, first being the fact that the crystals in them are much larger than is the case in ordinary rocks, and second, the minerals in them often contain elements found sparsely elsewhere. Thus pegmatites furnish large plates of mica, rare elements as tantalum, niobium and beryllium, the last obtained from beryl crystals, the same mineral which provides aquamarine, goshenite, morganite and other gem varieties of this species. As previously noted, some pegmatites also provide the special color variety of beryl known as emerald. Some pegmatites, but statistically rare, also contain voids or "pockets," in which crystals develop to a degree of perfection that makes them desirable both for gemstones and mineral specimens. Typical pegmatite gemstones not only include the beryl varieties mentioned but also tourmaline, topaz, quartz, and a host of rare species as spessartine, euclase, beryllonite, brazilianite, amblygonite, and others more sought for by collectors of the rare than the dealer in commercial gems. Amazonite, the green feldspar, is also a product of pegmatites.

In Brazil, vast areas of gneissoid rocks intruded by pegmatites occur from the State of Paraná in the south and extend roughly parallel to the coastline of the South Atlantic northward into the states of Ceará and Rio Grande do Norte. The principal belt, however, occurs in Minas Gerais and it is in that state that most productive pegmatites have been found. If these regions were superimposed on the Western United States, they would cover all of the coastal states and lap into Mexico and Canada. Thus the total area is enormous in extent, not fully explored by any means, and is capable of producing gemstones for an indefinite period in the future.

The initial finds of gemstones were made soon after penetration of the interior by miners who found waterworn pebbles of gemstones in stream gravels along with gold and diamonds. Such pebbles represent the debris of millions of years of weathering of the host rocks enclosing the pegmatites as well as the pegmatites themselves. All of this was favored by a warm, humid climate, abundant rainfall, and development of vegetation which promoted chemical attack of the less resistant rock-forming minerals, notably feldspar, and permitted the more chemically resistant and more durable minerals, particularly gemstones, to migrate downslope into gravel beds. For this reason the first major production of gemstones took place in river beds, particularly in the watersheds of the São Francisco, Jequitinhonha, Mucuri and Araçuaí rivers. Indeed it seemed that nowhere in this pegmatite-rich region one could not find gemstones but most efforts were confined largely to areas around Governador Valadares, Belo Horizonte and Téofilo Otóni in Minas Gerais. Again exploitation was merely a matter of choosing a promising site and digging pits into the gravels until the waterworn crystals were found, or if not, moving to some other place. Gemstones found in such alluvial deposits showed all signs of wear, from crystals still retaining most of their growth faces to others that were completely rounded by the pummeling and abrasion suffered during the movement of pebbles in flood periods. Much of this material was of highest quality since the stream wear soon crushed the flawed stones, wore off weak spots, and generally left behind only the strongest cores which also happened to be the best gem material.

While the initial phase of gemstone exploration confined itself to searching the gravels, it was gradually found that in-place sources could also be tracked down and gemstones recovered directly from rotted pegmatites. In these, the decay of the feldspar made excavation easy: one merely used pick and shovel to dig away the kaolinized feldspar until the untouched contents of gem-bearing pockets were reached. Direct mining of pegmatites was greatly encouraged during World War II when teams of experts from the U.S. Geological Survey were sent to Brazil to systematize the mining of pegmatites for mica, a critical electronic insulating material in short supply, as well as other minerals which concentrated in pegmatites. Another factor favoring direct mining was the discovery that excellent quality crystal groups could be removed from the pegmatites and sold as mineral specimens to augment profits realized from sale of gemstones. Today many Brazilian pegmatites are being carefully and systematically mined almost entirely for the sake of the mineral specimens which are now in great demand and fetch high prices in better qualities.

In general, the best known Brazilian gemstones are those produced from the pegmatite bodies just discussed and include colored beryls as aquamarine in numerous shades, green beryls, golden beryl, pink morganite, and minor quantities of rarer varieties as cat's-eye beryl and star beryl, a large color spectrum of tourmalines, mainly greens but also pinks and reds, topazes which range in hue from colorless to blue and sometimes faintly yellow or brown, spodumene, chrysoberyls, but the last still largely obtained in gem pebbles from alluvial deposits, and a host of mineralogical rarities, some of which can be faceted into collector's stones as brazilianite, euclase, phenakite, and others. Aquamarines of pure blue shades are now extremely scarce and fetch high prices while the lovely chartreuse chrysoberyls are now also difficult to find and have risen sharply in value.

Other important gemstones include amethyst, citrine and other varieties of crystalline quartz, with the first two named largely obtained from quartz veins rather than from pegmatites. Important sources of vein amethyst are located around Jacobina in the State of Bahia. Andalusite, a gem that has the startling property of displaying several colors at once, is still mined from gravels at several points in Brazil and is also a non-pegmatite mineral. Of great importance, though a relatively cheap material, is the agate found in the form of nodules and geodes over an extensive area of Rio Grande do Sul, the southernmost state of Brazil. There the nodules originally found weathered from lava flows and collected from the surface are now mined from the native rock in shallow pits. This agate-producing region extends over the border into Uruguay and also produces some excellent amethyst from crystals lining agate geodes. Many of the latter are very attractive when broken open and find a ready sale as mineral specimens or decorator pieces. While emerald in South America is most importantly produced in Colombia, Brazil also has its share of emerald deposits of the schist type, with several areas in Minas Gerais producing large quantities of flawed crystals but capable of yielding very small gems of good color.

Sound detailed information on gemstone deposits of Brazil is not easily obtainable despite the long history associated with their mining since colonial days. Only one monograph worthy of the name was ever written, that being a modest volume in German by Calmbach and published in 1938.[27] Freyberg's excellent review of mineral resources of Minas Gerais, which includes diamond and other gemstones, has already been mentioned[23]; it remains an excellent source of reliable information but is now difficult to find. A systematic account of beryl deposits in Brazil with descriptions of important finds of gem-quality crystals appears in a series of articles in the *Lapidary Journal* by Sinkankas.[28] Many excellent articles on Brazilian gemstones written by others also appeared in this journal during the last decade and are worthy of consultation. A now rare compilation of information on all the then-known minerals of Brazil can be found in a compendium of large size assembled by Ferraz[29] and published in 1928. A recent book, in three volumes, actually a "picture book" of Brazilian minerals, by Franco, *et al.*, appeared in 1972 but is disappointing because of its lack of specific locality information and virtually no discussion of gemstones.[30] Standard gemological texts, as the now out-dated but still useful massive work by Bauer[31] and the very recently published works by Smith[32] and Webster[33] provide considerable, albeit piecemeal information on Brazilian gemstones and their sources.

Rhodochrosite of Argentina

A discussion of South America gemstones would not be complete without mentioning the most attractive banded pink rhodochrosite found as cavity linings in the zinc-lead mines of Capillitas, Catamarca Province. Rhodochrosite is not a rare mineral but it is only in this deposit that it reaches such a degree of perfecting in terms of providing fine-grained masses readily capable of being shaped into many types of ornamental objects as ashtrays, bookends, bowls, carvings, and slices cut across stalactitic formations to reveal handsome circular patterns of differing shades of pink. The fascinating story of one man's attempt to publicize and commercialize this material is to be found in Mansfeld's monograph of 1943[34], handsomely illustrated with color plates of typical specimens and cut gems. A recent mineralogical study of the deposit and the rhodochrosite in particular was published in 1949 by Radice[35].

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Developments and Highlights at GIA's Lab in New York

By ROBERT CROWNINGSHIELD

Cubic Zirconia

From all reports the front runner in the sweepstakes for best diamond imitation is cubic zirconia. Not only does it have a refractive index closer to diamond and dispersion greater than diamond, but the color is believable and the hardness greater than the most recent contender, "GGG." In line with the policy of the Institute to have new stones, synthetic and natural, worn in jewelry to be better able to answer questions about durability, we have replaced a GGG in a ring that has been worn for the past three years. *Figure 1* illustrates the stone chosen in which a fracture at the girdle very much resembles a diamond flaw. The rather unusual girdle finish of this particular stone is shown in *Figure 2.* Of course, girdle finish is a function of time and care and in the future economics may determine if attempts will be made to make them more diamond-like. Properties and the identification of cubic zirconia have been tabulated elsewhere in *Gems & Gemology* but some observations of this newcomer may be of interest. In *Figure 3* a round brilliant is

Figure 1

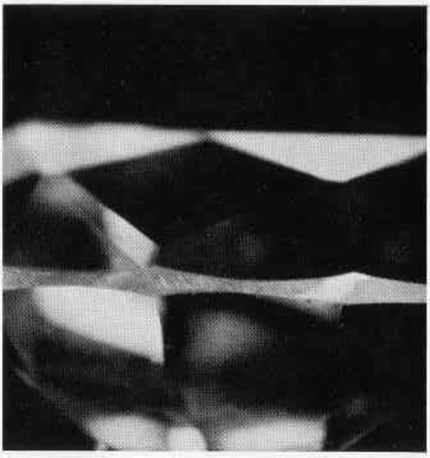

Figure 2.

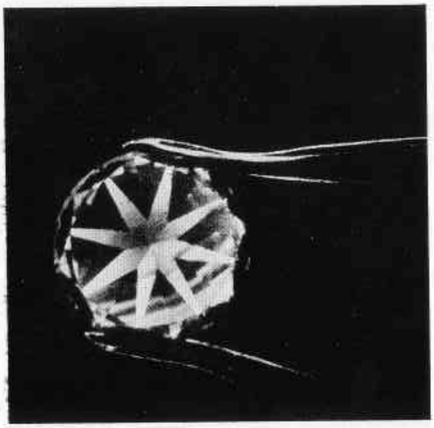

Figure 3.

shown over the iris diaphragm of a Gemolite. The pavilion facets are a monochromatic color – red, orange to yellow. The same effect, due to the higher dispersion than diamond, has been seen with colors at the shorter end of the spectrum. Although it is not a conclusive test, such strong delineation of the pavilions in dispersive colors has been unreported in diamond. In *Figure 4* we see a very natural appearing "feather" paralleling the edge of the table in a round cubic zirconia. *Figure 5* shows the GGG brilliant removed from a ring after approximately 3 years' wear. The large chip occurred when the ring was worn in the modern manner along side another stone ring. The hardness of less than 7 mitigates its use for every day wear.

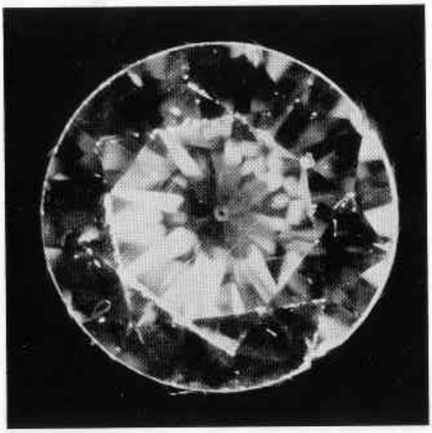

Figure 5.

Figure 4.

Diamond Observations

Diamond also can show unexpected wear and this is clearly seen in *Figure 6*. The stone which was removed from a ring shows considerable wear on facet junctions of the pavilion. Perhaps it originally was used in some other type of jewelry where other diamonds were allowed to come into contact with it. In *Figure 7* a ghostly truncated octahedron under the table of a round brilliant cut diamond is clearly seen. Two mountain ranges appear to be trapped in another brilliant shown in *Figure 8*. We only rarely test a green

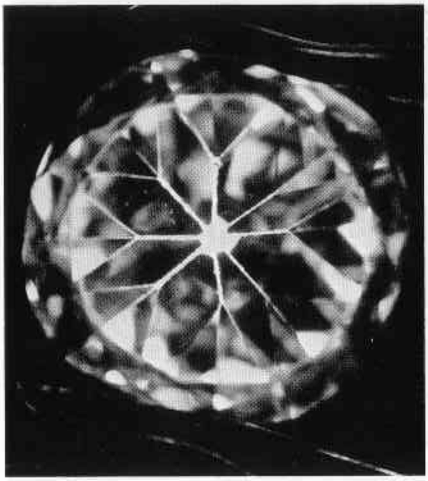

Figure 6.

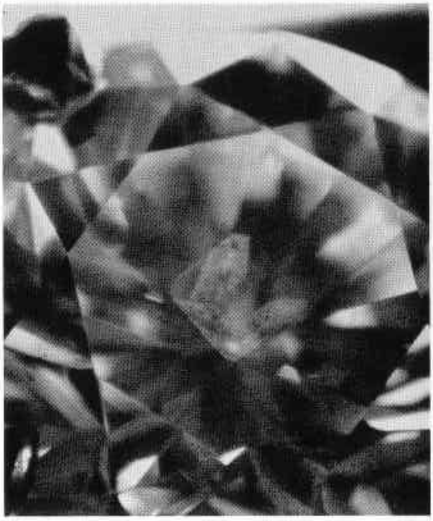

Figure 7.

diamond and find it to be radioactive and thus suspected of having been radium treated. In many, but not most cases we can see evidence of surface coloration in the form of small mossy patches. *Figure 9* was an attempt to capture an area of mossy patches on Polaroid film.

Cultured Pearls

A most unusual baroque cultured pearl weighing 129.65 carats was identified in the Laboratory and it was found to be mostly a blister with an 8½ mm. nucleus lost in the empty space. It appears that the nucleus must have been rejected by the mollusc but was not eliminated entirely and be-

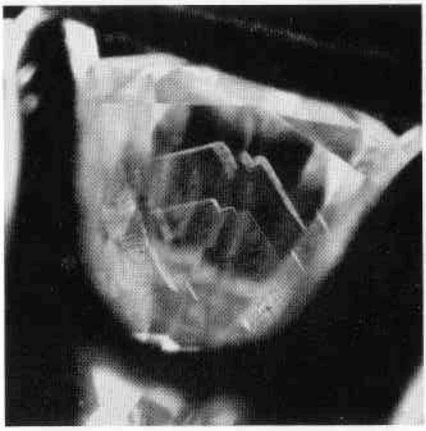

Figure 8.

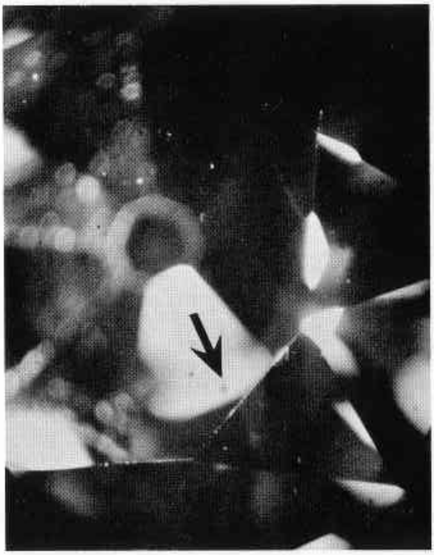

Figure 9.

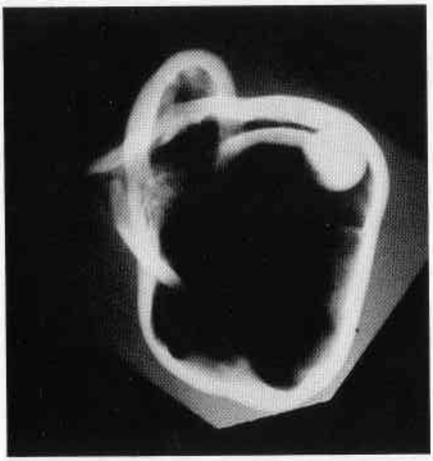

Figure 10.

came the focus for a blister *(Figure 10)*. In *Figure 11* we see part of a strand of what we have determined as "accidental salt water non-nucleated cultured pearls." A better term would be "baroque tissue nucleated salt water cultured pearls."

We had a chance to examine our first lot of untreated black cultured pearls from Tahiti *(Figure 12)*. Some were as large as 12.00 mm. and most were quite round. The X-ray photograph of a selection of them shows a fairly healthy culture as shown in *Figure 13*. We are indebted to Mrs. Denise Garnier for a nice specimen for the collection and for her visit with Jill Fisher in Santa Monica to share her experiences in the culturing of the pearls on an atoll nearly a thousand miles from Tahiti in presumably "safe from pollution" waters.

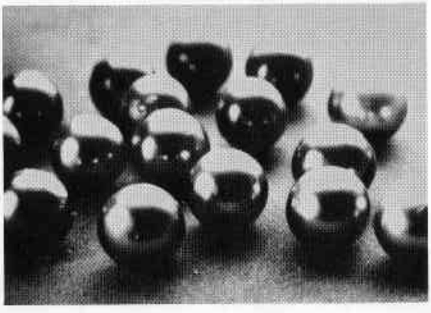

Figure 12.

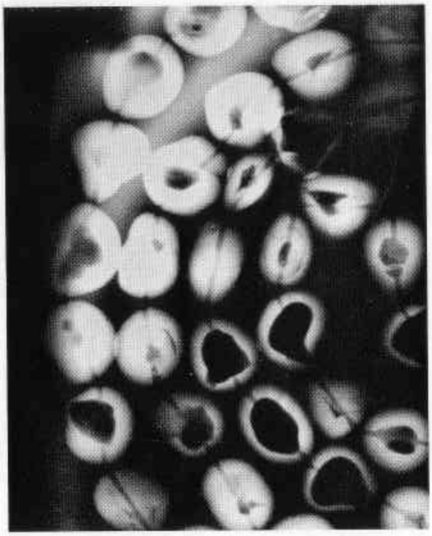

Figure 11.

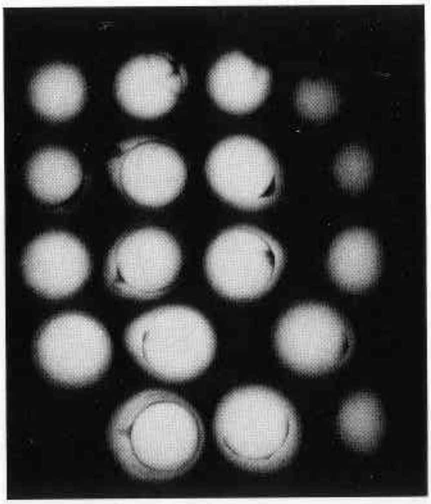

Figure 13.

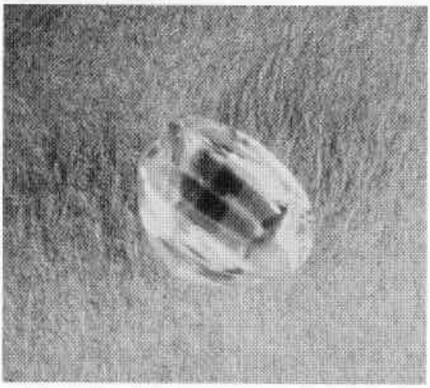

Figure 14.

Another Arkansas Diamond Find

The bright yellow diamond crystal recently found at Murfreesboro, Arkansas, weighed 4.23 carats and in the clarity and unblemished "skin" resembled closely the famous yellow diamond known as the Garry Moore. *Figure 14* does not do justice to this beautiful stone, of course. We have heard reports of another recent find of a crystal weighing more than 16.00 carats. Beginning with the Jewelry Trade Show issues of the jewelry trade magazines, we have noticed several advertisements for items that heretofore have been considered outside the professional jewelry field. Such items as picture jasper seen in *Figure 15* and petrified dinosaur bone are among them.

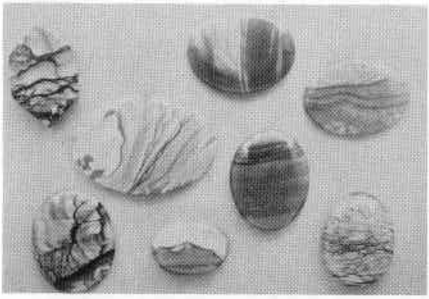

Figure 15.

Acknowledgments

We wish to express our sincere thanks for the following gifts and courtesies:

To Gem Trade Laboratory firm members *Goldberg-Weiss* for several fancy cut diamonds which have already proven of great value in diamond classes.

To *Lazare Kaplan and Sons* for the many times they share with us unusual diamonds they encounter as well as gifts of same – including recently a sawed stone exposing a negative crystal which we assumed to be cubic in habit.

To the firm of *Fortunoff,* Westbury, N.Y., for gifts of various stones, many high fashion items, for use in resident classes.

To *Mr. Fred Wurzburger,* New England Diamond Corp., for his continued interest in GIA and his frequent gifts of stones of great use in resident classes.

To GIA booster, *Mr. Willard Rose,* for an excellent selection of opal rough and cut for class demonstrations and display.

To *Mrs. Gunvor Simpson* who accompanied the GIA round the world tour picking up all the gem oriented books and slides she could find many of which she brought back with her to give to GIA. Mrs. Simpson is a G.G. in residence and lab staff member.

To *Church and Company,* Bloomfield, N.J., for a fine selection of natural sapphires and rubies.

Irradiation Colors in Topaz, Quartz and Beryl

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Color changes produced by irradiation such as X-rays and gamma rays usually involve color centers.[1] For each color the gemologist needs to know the answer to three important question: 1) is the color stable with respect to light exposure, 2) can the material be distinguished from the naturally occurring gem having the same color and, if so, then 3) how is it distinguished.

A. BROWN TOPAZ

Almost all topaz turns yellow to imperial color to cinnamon brown on irradiation.[2,3] These color centers are quite unstable and reversion to the original color occurs in hours to days of exposure to light. Since almost all natural brown topaz is stable to light exposure, this in itself provides a good distinction.

B. BLUE TOPAZ

Upon extended irradiation, some topaz turns an olive brown color, consisting of the above brown plus an additional blue-producing color center.[2,3] Only the blue color remains after the brown color is removed by exposure to light or by gentle heating (for a few hours to perhaps 200°C). This color can often be a deeper blue than that of naturally occurring topaz, but appears to be just as stable to light and heat. Distinction from natural topaz is presently not possible; it may never be, since it appears likely that this color is identical with the natural blue (which probably has been produced by a similar irradiation process from naturally occurring radioactivity in adjacent rocks).

C. SMOKY QUARTZ

The full range of pale tan through brown to pitch black colors observed in nature can be produced in most natural quartz by irradiation. Here the color is identical with the natural radioactivity produced smoky color. The stability is therefore the same and distinction is not possible.

D. GREENISH-YELLOW QUARTZ

Much smoky quartz (whether naturally or artificially irradiated) will turn a greenish-yellow color when heated. Heating must be done gradually in steps, since a little too much heating will turn the quartz colorless again.[4,5] Some natural quartz of this color does occur, often in combination with smoky, and has generally been labeled as smoky. The color is, however, distinct from the smoky color and from the iron-caused citrine; color illustrations have been published.[4] This color center is reasonably stable and distinction is not possible.

E. MAXIXE AND MAXIXE-TYPE BERYL

Some colorless, pink, green or blue beryl can be irradiation colored to acquire an added intense deep blue (Maxixe-type).[6, 7] Even ultraviolet light can produce this color center, which accordingly involves a very shallow and therefore unstable trap[1] and is rapidly bleached by light exposure (in days to a few weeks). Maxixe beryl itself of a similar color was found naturally occurring in Brazil in 1914, but had a slightly different type of spectrum, although it faded just as rapidly. The best way to distinguish these fading blue types from the stable blue of aquamarine beryl is by the use of a spectroscope or with a polarizer: in aquamarine the blue is carried by the extraordinary ray, in Maxixe and Maxixe-type the blue is carried by the ordinary ray.[6] The exact color of Maxixe-type irradiated beryl (or even emerald, perhaps) will depend on the original color, to which the material will return after the Maxixe-type component has faded.

F. GREEN AQUAMARINE AND GOLDEN BERYL

Most greenish and yellowish beryls are heated routinely in the hope of developing any blue aquamarine color that may be present. This change does not involve a color center but a change of valence of some of the iron present: the specific Fe^{3+} impurity which causes a yellow color is changed to Fe^{2+} which is colorless; the iron impurity causing the blue color is not affected.[8] If the resulting blue color is too weak to produce a saleable blue aquamarine, it is possible to recover the original green aquamarine or golden beryl color by irradiation; e.g. by gamma rays. The resulting color is stable and could probably be considered to be "natural", since the effect of the previous heat treatment has merely been reversed!

Other irradiation colors, not discussed above, include the blue, green, yellow, and brown irradiated diamonds [treated in gemology texts[9]], blue or black pearls,[4] green kunzite,[4] pink and yellow tourmaline,[10] amethyst, and so on. Gamma ray irradiation has been described elsewhere.[2]

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Official State Gems

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Sixteen of the United States have official state gems or gemstones *(Table 1).* In addition, Arizona has the turquoise bola tie as its official neckwear.

A few of the legislature-decreed state minerals, rocks and stones have also been used as gems and/or for other decorative purposes. Especially noteworthy among these are the following:

Table 1. STATE GEMS*

STATE:	GEM:	Year of legislation:
Alaska	Jade	1969
Arkansas	Diamond	1967
Florida	Moonstone	1970
Georgia	Quartz	1976
Idaho	Star Garnet	1967
Michigan	Chlorastrolite	1972
Minnesota	Lake Superior agate	1969
Montana	Sapphire & agate	1969
Nebraska	Blue chalcedony	1967
New Mexico	Turquoise	1967
Ohio	Flint	1965
So. Carolina	Amethyst	1969
So. Dakota	Fairburn agate	1966
Texas	Blue topaz	1969
Wyoming	Nephrite jade	1967

*Some are termed Official Gemstones rather than Official Gems.

State rocks – Alabama-marble, California-serpentine, Florida-coral, Iowa-the geode, Missouri-the chert called mozarkite, Nebraska-prairie agate, and Oregon-the "thunder egg"; state minerals – Alaska and California-gold, Connecticut-garnet, Georgia-staurolite, Maine-tourmaline, and South Dakota-rose quartz; state "stones" – Michigan-the Petoskey stone, North Carolina-emerald, and Texas-petrified palmwood; and state fossils – Georgia-the shark tooth, and North Dakota-Teredo petrified wood.

The recency of some of the legislation suggests that other states are likely to establish additional official State Gems in the future.

Acknowledgments

The data compiled in this note were supplied directly by or at the behest of the State Governors for all but five states. For those, U.S. Senators Case, Eastland, Pell, Ribicoff, and Roth were the correspondents. Their aid is gratefully acknowledged.