Gems & Gemology

GIA

WINTER 1979-1980

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ISSN 0016-62X

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gems & gemology

VOLUME XVI *NUMBER 8*

WINTER 1979-1980

IN THIS ISSUE

Synthetic Gemstone Developments in the Nineteen Seventies

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Abstract

The nineteen seventies were an exciting period, with many new developments in the field of synthetic gemstones. It was a difficult period for the gem expert as he struggled to keep up with a series of new synthetics, imitations, and treatments. For the user of gemstones these developments have provided a wide variety of new or improved, albeit "man-made," products at costs well below the ever increasing inflationary prices and rarity of quality natural gemstones.

The decade began with a bang in 1970 with the first successful growth of gemstone-size synthetic diamonds, as well as with the introduction of YAG as a diamond imitation; this rapidly superseded all the older materials. Soon thereafter, Pierre Gilson of France announced his synthetic opal in both white and black forms, as well as synthetic turquoise, later to be followed by his lapis lazuli and coral products. Commercial production of synthetic citrine and synthetic amethyst began in the USSR, while in the USA Linde discontinued its synthetic star ruby, star sapphire, and its synthetic emerald production (the last has been reactivated by another company). An authentic synthetic alexandrite and Slocum's imitation opal have been additional new products.

Towards the end of this decade, the most significant development was the meteoric rise of synthetic cubic zirconia, which almost overnight displaced essentially all the previous diamond imitations. Newly developed testing techniques are making the identification of this diamond look-alike a little easier. Another development has been the continuing rise of treatments used to "improve" natural gem materials; this includes irradiation as well as impregnations.

In looking back over these rapid developments of the last ten years,

one suspects that the next decade will not be quite so hectic; a period to digest and utilize more fully these advances may, perhaps, be anticipated.

Parts of this article are based on material in the author's book "Gems Made by Man," *published by the Chilton Book Co., Radnor, PA 19089.*

The sequence of gemstones made by man began at the turn of this century with the duplication of ruby, the sapphires, and spinel. As can be seen in *Table 1,* there followed a long gap until the late 1940's, when a series of new duplications as well as steadily improving diamond imitations followed over the next two decades. This culminated in YAG (yttrium aluminum "garnet"), so widely used as a diamond imitation as to make almost everyone aware of the existence of such triumphs of man's technology. Some of these materials had been originally perfected for their known or hoped-for technological uses, others specifically for their gemstone potential. This process accelerated in the 1970's with a major development every year on the average. With the end of the decade, this process may be slowing down because all but the most difficult syntheses have been achieved, and also for economic reasons.

The developments of the 1970's will be discussed in the sequence: (A) synthetic diamond, (B) diamond imitations, (C) low-priced Verneuil products, (D) high-priced luxury synthetics, (E) miscellaneous materials, and (F) treatments.

A. Synthetic Diamond

After a checkered early history, including many false claims (some due to sincere errors, others due to outright fraudulence) the duplication

Table 1. The Sequence of Major Synthetic and Imitation Gemstones

Approximate Year of Availability in Quantity	Synthetic or Imitation Gemstones and Manufacturing Technique
1885	Ruby (Geneva)
1905	Ruby (Verneuil)
1910	Sapphire (Verneuil)
1910	Spinel (Verneuil)
1947	Star Ruby and Sapphire (Verneuil)
1948	Rutile (Verneuil)#
1950	Emerald (Flux)
1950	Quartz (Hydrothermal)#
1955	Strontium Titanate (Verneuil)#
1965	Emerald (Hydrothermal)
1968	YAG (Czochralski Pulling)#
1970*	Diamond (High Pressure)#*
1972	Turquoise (Ceramic)
1973	Alexandrite (Flux)
1974	Opal (Complex Process)
1974	Citrine (Hydrothermal)
1975	Amethyst (Hydrothermal)
1976	Lapis Lazuli (Ceramic)
1976	Cubic Zirconia (Skull Melting)#
1977	Opal-Essence (Glass)
1978	Coral (Ceramic)

#Process perfected for potential technological use.

*Experimental production only.

of diamond was finally achieved by H. Tracy Hall at the General Electric Co., Schenectady, N.Y., on December 16, 1954. With the publication of details by F. P. Bundy, H. T. Hall, H. M. Strong, and R. H. Wentorf, Jr., in 1955, and a detailed description of the apparatus by Hall in 1960, a synthetic diamond grit industry developed rapidly.

Today, G. E. at its Worthington, Ohio, facility produces somewhere near one half of the world's production, estimated at some 100 million carats (20,000 kilograms, 44,000 pounds) of grit per year. Diamond grit costs from one to several dollars per carat, depending on the type.

The second largest producer is probably the DeBeers organization who purchased from G. E. the rights to manufacture synthetic diamonds in South Africa and Europe with the major production facility on the East Rand in South Africa, and additional production in Shannon, Ireland, and at the ASEA facility in Robersfjord, Sweden. Smaller production occurs in Japan and West Germany and probably elsewhere. In the USSR, diamond research is conducted in Moscow with production facilities in Poltowa, Yerevan, and Kiev.

In 1970 there came another announcement from G. E. by R. H. Wentorf, Jr., H. M. Strong, and R. M. Chrenko, describing the growth of gem-size and gem-quality diamonds. Details of this, as well as of other aspects of diamond synthesis have been given by the author elsewhere [1,2].

This process can use any form of carbon-containing material (even mothballs or peanut butter!), taken to a pressure of perhaps 70,000 bars (1 million pounds per square inch) and a temperature of perhaps 1800° C (3272° F). Diamond is rapidly produced from the carbon by crystallization from some metal solvent, such as iron, and growth next occurs on a thin diamond seed-plate to form large crystals over a period of about one week.

Synthetic diamond crystals about 5 millimeters (1/5 inch) across weighing one carat were grown in 1970 and cut to yield up to 0.46 carat faceted gemstones; some of these were presented to the Smithsonian Institution, Washington, D. C. Colorless diamonds (down to "F" on the GIA color scale), yellow (containing nitrogen impurities) and blue (containing boron impurities) can all be made.

Synthetic carbonado (a tough, black polycrystalline diamond) continues to be widely manufactured and used for metal machining and other industrial purposes. Fine diamond grit also continues to be manufactured by the *shock-wave explosion process,* e.g. by DuPont at its Gibbstown, N. J. facility. Details have been published [1,2].

Various *low pressure processes* for adding diamond to existing diamond crystals have been proposed, but a typical growth rate is less than 1 millimeter per year, and it is not clear whether diamond is even produced! It may well be that the product is the "lonsdaleite" form of carbon or other, similar forms.

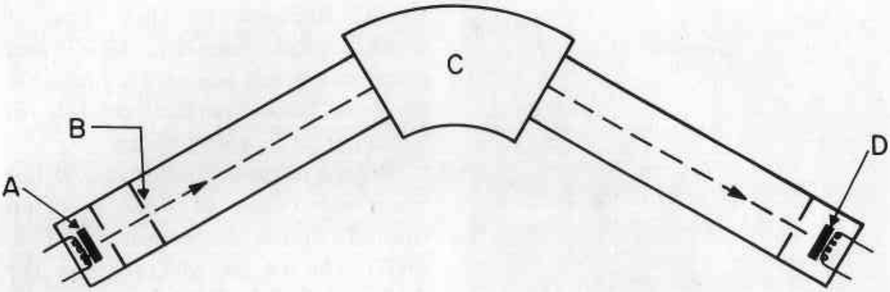

Figure 1. Schematic diagram of the ion implantation growth of diamond; both the carbon source A and the diamond B are heated by electrical coils.

A most interesting development has resulted in another low pressure process, developed by J. H. Freeman and co-workers at the Harwell Atomic Energy Research Center in Britain. This is disclosed in British patents 1,476,313, June 10, 1977, and 1,485,364, September 8, 1977. The technique used is to produce a beam of carbon ions (at A in *Fig. 1*) in a vacuum chamber and accelerate these by a high voltage at B. The beam of ions is separated from accompanying residual gas ions in a magnetic mass-spectrometer type of arrangement at C and the energetic ions are then *implanted* into a diamond at D. If the diamond is at room temperature, the implanted ions merely cause disorder, but if the implantation is conducted with the diamond at an elevated temperature, perhaps 700°C (1292°F), the disorder continuously anneals out and the implanted carbon ions add to the diamond.

The added material has been shown to be true cubic diamond, and impurities can be added during growth. At present the growth rate is too slow for useful gemstone diamond growth. Nevertheless, the possibility for improvements in this process exists and will bear watching.

B. Diamond Imitations

By about 1972, the production of *YAG* (yttrium aluminum "garnet," $Y_3Al_5O_{12}$) used as a diamond imitation peaked at about 40 million carats (8000 kilograms, 17,600 pounds) per year. This was more than the market could absorb, there was a fall in price, and a number of manufacturers discontinued production. With the arrival of cubic zirconia in 1977, YAG is now joining earlier diamond imitations such as rutile and strontium titanate in small-size production only.

Early in the 1970's, many crystal growth studies were performed on *GGG* (gadolinium gallium "garnet," $Gd_3Ga_5O_{12}$) for use in "bubble domain memory" units. For this purpose, the GGG must be essentially flawless, even free of disloca-

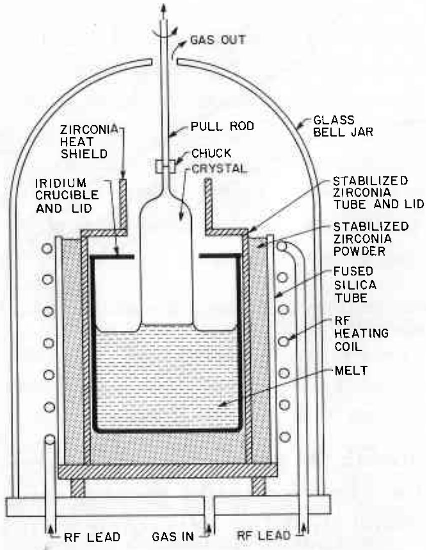

Figure 2. Apparatus for the Czochralski-pulling growth of large high-melting crystals such as synthetic ruby, YAG, or GGG; the diameter of the iridium crucible may be as large as 15 cm (6 inches).

tions! Because of this type of technological necessity, GGG and electronic grade silicon are probably the two most perfect crystals in existence in quantity today.

With a refractive index of 1.98 (an incorrect value of 2.02 is often quoted) and a dispersion of 0.038, GGG was an improvement on the 1.83 and 0.028 of YAG. It is much more expensive to produce, however, and was displaced by cubic zirconia before it ever became popular.

The chemistry of the "rare earth garnets" such as YAG and GGG has been described by the author[1,3]. Produced by Czochralski pulling from the melt, as shown in *Figs. 2 and 3,* crystals 5 centimeters in diameter and 20 centimeters long (2 inches by 8 inches) weighing 9000 carats (1-3/4

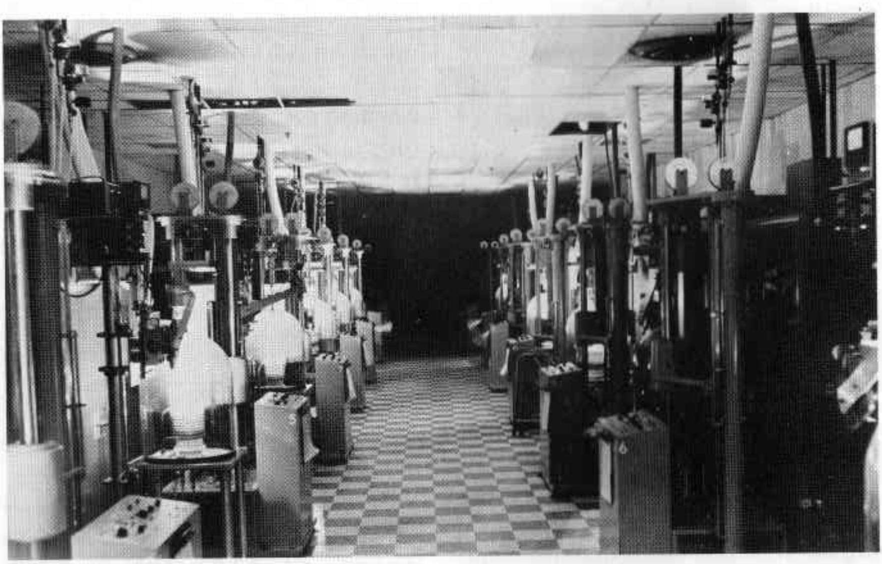

Figure 3. Czochralski apparatus as in Figure 2, used for synthetic ruby growth. *Courtesy of Litton Systems.*

kilograms, 4 pounds) are readily grown.

Cubic zirconia, produced by the "skull melting" process, began with small-scale production in 1977 by the Ceres Corp. in the USA, by Djevahirdjian S. A. in Switzerland, and at the Lebedev Physical Institute in Moscow, USSR. These, as well as other manufacturers have scaled up, so that by now a production rate of some 30 million carats (6000 kilograms, 13,200 pounds) per year can be estimated. There is a rapid fall in the price and there may soon be a parallel with the peaking of YAG in 1972.

Cubic zirconia is zirconium dioxide, ZrO_2 (the monoclinic mineral baddeleyite), stabilized to remain cubic by the addition of some yttrium oxide Y_2O_3 or calcium oxide CaO. The process is difficult because of the high melting point of ZrO_2, 2750° C (4980° F), necessitating the skull melting shown in *Fig. 4.* Full details of the process[1,4] and the product[1,4,5] have been given by the author and others.

Cubic zirconia is by far the best diamond simulant to date. It has a refractive index of about 2.16, somewhat below the 2.42 of diamond, which is nicely balanced by the 0.060 dispersion, which is higher than the 0.044 of diamond. With a high specific gravity of about 6.0, a cubic zirconia gemstone the same size as a 1 carat diamond will weigh almost 1-3/4 carats. A convenient size-weight conversion figure for diamond imitations has been published by the author[1,6].

Figure 4. J. F. Wenckus growing synthetic cubic zirconia in a small skull-melting apparatus. *Courtesy of Ceres Corp.*

To aid in distinguishing between diamond and cubic zirconia, a number of new techniques can be used. There are reflectometers, such as the Sarasota Instruments, Inc., *Jemeter,* the contact angle tests, e.g. used in the GIA *Diamond Pen*[7], and, probably the most rapid and most convenient of any testers, the Ceres Co. *Diamond Probe,* which tests for the uniquely high thermal conductivity of diamond[7,8].

C. The Verneuil Products: Ruby, Sapphires, and Spinel

The majority of synthetic ruby, sapphires, and spinel for gemstone use is Verneuil-grown because of the large production facilities available and the attendant low costs, only a few cents per carat. As a result, synthetic rubies, sapphires, and spinels in wide range of colors are available in faceted form from less than one dollar to a few dollars per stone, depending on the size. In the Verneuil technique, powdered material is sprinkled downward through a vertical flame to melt and build up on a growing "boule."

With some half dozen large manufacturers, mostly in Europe, and several smaller ones, a world-wide Verneuil capacity of well over 1 billion carats (200,000 kilograms, 440,000 pounds) per year is in existence. The bulk of the production is used for the "jewel" bearings in watches and instruments. When used for this purpose, only about one percent of the weight of the boule ends up as finished bearings, all the rest being lost in the cutting and shaping steps! Demand has fallen somewhat with the rise of electronic watches which do not use bearings.

The Linde Air Products Co., later a division of the Union Carbide and Carbon Corp., was the major manufacturer of Verneuil products in the USA at its East Chicago facility. Due to the pressure of lower labor costs in Europe, most Verneuil growth had been discontinued before 1970, but the growth of synthetic *star ruby* and *star sapphires* continued, covered by a series of US patents.

Synthetic stars are made by including some excess rutile (titanium oxide, TiO_2) in the feed powder. The grown boules are annealed, typically 24 hours at 1300° C (2372° F) to permit the rutile to precipitate as fine needles which reflect light to produce the star effect.

Figure 5. Czochralski-pulled synthetic ruby (4.2 kilograms, 9¼ pounds) and synthetic colorless sapphire (10 kilograms, 22 pounds). *Courtesy of Union Carbide Corp.*

Details are given elsewhere[1]. Even this production ceased in 1974 with the closing of the East Chicago facility, representing the cessation of all gemstone work by Linde.

Ruby and sapphires of higher quality than the Verneuil product are required by industry (e.g. for the "SOS," silicon-on-sapphire semiconductor technology) and Linde as well as others have used Czochralski pulling similar to that of *Figs. 2 and 3*. The sizes attainable can be seen in *Fig. 5!*

Small-scale production of synthetic ruby and sapphire by the flux process continues by C. C. Chatham of San Francisco, California, and F.

Truehart Brown of Ardon Associates, Inc., of Dallas, Texas. In view of the high cost inherent in the flux process, there appears to be little demand. The major use seems to be in as-grown clusters of crystals used in jewelry without faceting.

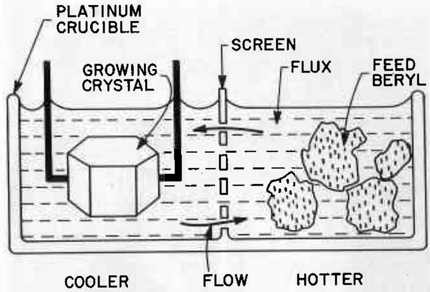

Figure 6. Schematic diagram of the flux-transport growth of synthetic emerald used by Gilson.

D. The Luxury Synthetics

Excellent synthetic equivalents of natural emerald, opal, and alexandrite are nowadays available. These are made by difficult processes and hence sell in the one to several hundred dollars per faceted carat range. This is, nevertheless, still low-priced compared to the cost of the equivalent quality natural gems!

Flux-grown synthetic emerald was first marketed by Chatham in the 1950's, to be joined in the mid 1960's by the similar product of Pierre Gilson of France[1,9]. The latter has now achieved excellent control of his flux growth and is able to use a *flux transport* process, with emerald feed being dissolved in one part of the container and being transported to the seed section, where growth occurs, as shown in *Fig. 6.* Growth occurs at about 1 millimeter per month; completed crystals can be seen being removed from the growth-furnace in *Fig. 7.*

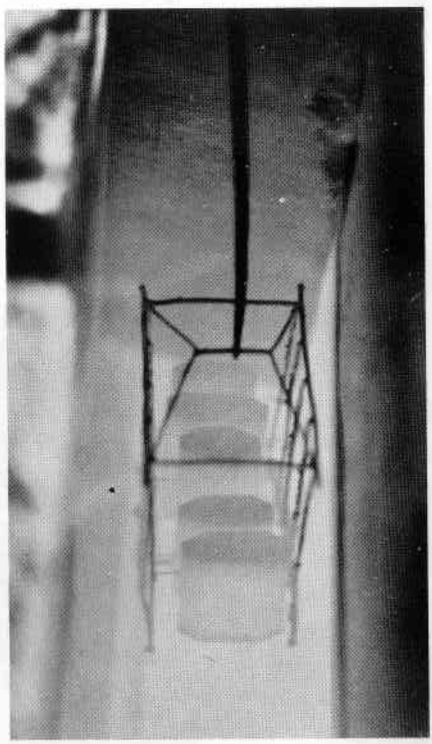

Figure 7. Gilson flux-grown synthetic emeralds being removed from the growth furnace; crystals are 63 mm (2½ inches) long and weigh about 400 carats. *Courtesy Ets. Ceramique Pierre Gilson.*

Hydrothermal synthetic emerald was involved in the early unsuccessful overgrowth product of Lechleitner, which was never produced in quantity. The Linde Division of Union Carbide perfected a hydrothermal process, involving a strong acid solvent, and began marketing in

Figure 8. Hydrothermal synthetic emerald growth at Linde, about 1965. *Courtesy of Union Carbide Corp.*

1965 in jewelry of its own manufacture under the "Quintessa" name. A part of the early production facility is shown in *Fig. 8*. Because of overproduction (200,000 carats per year at its peak) and marketing problems, the manufacture was halted in 1970 and marketing ceased in 1975 with considerable amounts of unsold stock. The equipment was subsequently sold and a patent-use license was granted to Vacuum Ventures, Inc. of Sunnyvale, California, and Pompton Lakes, New Jersey, who have reactivated the process using the name "Regency Created Emerald." Other emerald growth processes have been claimed over the years, but none has produced a usable product.[1,9].

There had been much speculation about the cause of color in opal which was finally established in 1964. The electron microscope revealed a

Figure 9. Gilson Opal during its one-year settling period. *Courtesy of Ets. Ceramique Pierre Gilson.*

structure consisting of a very regular array of equal sized spheres of silica, with the diffraction-grating effect[1,10] producing the color. Only eight years later Pierre Gilson, Sr., of France, announced a successful duplication and marketing began in 1974. The *synthetic opal* process involves the precipitation of silica spheres and a long settling period, as shown in *Fig. 9*. Both white and black synthetic opal are made by Gilson. The full details of the opal process have never been revealed, but some parts can be deduced[1].

An alexandrite imitation, using vanadium impurity in corundum, has long been known, but in 1973 a true *synthetic alexandrite* was announced by Creative Crystals of San Ramon, California, based on US Patent 3,912,521, 10/14/1975. Both pulling from the melt and flux-growth are described in this patent. The product, sold under the name "Alexandria-created Alexandrite," is clearly flux-grown. It has an excellent color change. A similar product is made in Tokyo, Japan, by the Kyocera Co., and sold under the names "Crescent Vert Alexandrite" and "Inamori-created Alexandrite." Experimental Czochralski-pulled material has also been seen.

E. Miscellaneous Material

Production of colorless *synthetic quartz* by the hydrothermal technique of growth from superheated water/steam under pressure has been carried out on a commercial scale since about 1950. In the USA the largest producers are the Sawyer Research Products, Inc., Division of Brush Wellman, Inc., in East Lake, Ohio, and the North Andover, Massachusetts, facility of Western Electric, the manufacturing arm of the Bell System. There is also the General Electric Co., Ltd., in Great Britain. The product is used mostly in communications equipment, including CB (citizens' band) radios. With a decline in demand in recent years, the annual production has fallen somewhat from a peak of 700,000 kilograms (1-1/2 million pounds). Details of the early history and current technology of colorless and colored synthetic quartz may be found elsewhere[1].

Synthetic citrine and *synthetic amethyst* are made by adding iron under carefully controlled conditions and, in addition, also using irradiation for the amethyst (synthetic colorless quartz can also be irradiated to give *synthetic smoky quartz,* should it be desired). Details of the processes have been revealed in a series of patents by Russian workers, e.g. US Patents 3,936,276, 2/3/1976, and 4,021,294, 4/3/1977. Commercial production is under way in the USSR and the product recently has been made available in the USA. A wide range of colors can be obtained in synthetic quartz, including purple amethyst, yellow citrine, smoky, blue, and green quartz. This is one of the few instances where tests for distinguishing the natural from the synthetic materials have not yet been developed; the prices are in the same range.

Turquoise and Lapis Lazuli are poly-crystalline materials, which can be synthesized by ceramic techniques. *Synthetic Turquoise* has been marketed since 1972 by Gilson; material containing veins of "matrix" has also been made. *Synthetic Lapis Lazuli,* both with and without pyrite inclusions, has been introduced by Gilson in 1976 (it is somewhat more porous than the natural material). Both products provide excellent duplications of the appearance of the natural gems. Color illustrations and details have been presented elsewhere[1].

Glass, plastic, ceramics, and composite *imitations* are also discussed and illustrated there. Items of particular interest which might be mentioned are Slocum's imitation opal ("Slocum Stone" or "Opal-Essence") made of glass, the various partly crystallized glass products of Imori Laboratory, Ltd., of Tokyo, Japan ("Victoria Stones," "Meta Jade," etc.), and Gilson's coral imitation made in a wide variety of colors by a ceramic technique and coming very close to being a synthetic[1,11].

F. Gemstone Treatments

Of all the treatments used on natural gemstones, *irradiation* produces the most spectacular results[12,13]. The irradiation of diamonds to produce "fancy" colors continues. There has been an increase in the use of irradiation to turn colorless rock-crystal into smoky quartz[13], particularly the magnificent mineral specimens from Hot Springs, Arkansas; with the existence of large, intense gamma irradiation sources employing Cobalt-61 or Cesium-134, only a few minutes exposure may be required, and size is no problem. Pearls are also still being turned "black" with radiation[12].

There have been two major irradiation developments during the last decade, each involving a blue color. The first was the arrival in 1972 of magnificent dark blue beryls from Brazil, said to be of natural origin. Investigation by the author and co-workers demonstrated conclusively that these were treated stones and that they faded rapidly in bright light[14,15]. Various types of irradiation can be used on pink beryl from one locality in Brazil or on some pale beryl from Rhodesia, North Carolina, and elsewhere, to produce this *deep blue irradiated beryl,* which can also properly be called "Maxixe-type Beryl" by analogy with a similar, but not identical beryl found in 1917 in Brazil in the Maxixe mine; it should not be called aquamarine, from which it differs in important respects[14,15].

The second development arose about the same time, and was at first unrecognized. Unusually large numbers of blue topaz gems, some darker in color than usual, were seen in the jewelry trade, apparently without the discovery of any new deposits. During irradiation work[12,16], the author accidentally discovered that while most colorless topaz (a very plentiful and low priced material) can be irradiated to a brown color, some of this material subsequently would convert to a blue color on gentle heating instead of merely returning to colorless. It appears that this was being done commercially at the time, and continues to be done. The resulting *irradiated blue topaz* may have a deeper color than the usual natural blue topaz, but the color appears to be caused by exactly the same color center[10], with the same stability to light and heat as natural blue topaz[16]. There is no distinguishing test known at present.

It should be noted that some irradiation-produced colors are unstable and will revert on light or heat exposure, such as the irradiated Maxixe-type beryl and irradiated brown topaz; some irradiation-induced colors are perfectly stable to normal heat and light exposure such as the irradiated blue topaz, irradiated smoky quartz, and irradiated diamonds. The physical basis of these color changes has been described elsewhere[1,10].

There are many changes in color induced by bleaching, dyeing, and heat-treatments. Impregnations are used to hide flaws, change the color, and improve the apparent quality of gemstones; as one example, there is hardly any turquoise that has not been impregnated or "color stabilized." A summary has been given[1]. Quite recently it has been discovered that some almost colorless opal can have its play of color revealed by a plastic impregnation[17].

The Outlook for the 1980's

If we judge the future as being but a continuation of the past, then we would have to conclude that gems made by man will continue to proliferate at an ever more rapid rate and that diamond imitations will further close the small gap still remaining. As against this, it would be argued that a slowing-down should be expected since the easier syntheses have been achieved and only the most difficult remain to be explored. This factor, however, is balanced, at least partly, by the ever-improving technological capabilities. Consider, next, that several of the most recent new synthetic and imitation gem materials, YAG, GGG, alexandrite, and cubic zirconia have all come to the gem field as by-products of technological research. There is, currently, some slowing down of new crystal synthesis, partly because the easier materials have been prepared and the work involved in new crystals increases while the potential returns to be expected become less and, partly, because so much work still remains to be done to bring the existing technological materials to the limits of their potential. In balance, it would be safe to assume that new synthetic and imitation gem materials will continue to come from this source, albeit at a much slower rate.

The only other source of recent new synthetic and imitation gem materials appears to be from laboratories devoted to this purpose, namely those of Gilson (opal, turquoise, lapis, and coral), and the glass and plastics efforts of Slocum and Imori. More, no doubt, can be expected from these sources.

The step of taking a new and yet better diamond imitation from the laboratory to the market place is, however, another matter. Since cubic zirconia is already so close an imitation of diamond at a not unreasonable price, any new material would have to represent a significant improvement in appearance and wearability at an equal or lower price to justify the promotion necessary for its introduction.

With the right stimulus, additional new synthetic gemstones other than diamond imitations easily could become important. Thus synthetic zircon has been grown as small crystals from the flux, and silicon carbide (synthetic moissanite) shows great promise if the size and color could both be improved. Other single crystal gemstones which could undoubtedly be duplicated with suitable research and development efforts are colorless, pink, red, blue, and green elbaite tourmalines; topaz in colorless, orange, red, and blue shades; the various naturally occurring silicate garnets in many shades, including orange, red, and the brilliant green of demantoid garnet; blue iolite; and green peridot. Yet it is questionable whether the commercial returns could possibly justify either the research for finding appropriate growth techniques and conditions for a new material or the additional development which would then be returned to attain usable size at reasonable cost. Here again, technological advances may initiate the next new synthetic gem material.

A relatively untapped field is that of gems showing special optical effects. The synthetic star ruby and sapphires have been available for some time and synthetic opal has recently joined the list. Nevertheless, the star phenomenon is quite widespread among natural gem species, occurring also in beryl, rose quartz, spinel, garnet and others, although generally only on rare occasions. Then there is the "eye" phenomenon or chatoyancy seen in some natural quartz tigereye and in chrysoberyl and tourmaline cat's-eyes. Additionally, there are two feldspars, the moonstone variety with its "adularescence" as well as the labradorite variety with its color flashes. It would be intriguing to see the duplication of such attractive natural gem materials.

Another field providing scope for further work is that of the polycrystalline materials. Here potential new synthetic gemstones might include malachite and the two jades: nephrite and jadeite. With their toughness derived from tiny interlocking crystals, the jades should provide interesting preparation problems to the materials scientist. And, for a real challenge, there is always the possibility of a truly synthetic pearl; this may be an even more difficult materials problem than was opal, but could fill a real need if the continuing destruction of pearl beds by oceanic pollution is not halted in time to preserve both the natural and the cultured pearl industries.

There are many less well-known and rarely seen gemstones, the synthesis of which would be pointless in the absence of an existing or created demand. Perhaps the most useful next development would be a significant cost reduction in the most difficult of the existing gemstone syntheses, those of emerald and diamond. The last few years have seen an increase in the sophistication with which suppliers of natural gemstones modify and improve their wares by heat treatments, irradiations, and similar processes. All of this is making the task of the gemologist more difficult, and ever-continuing research and education are essential for keeping abreast of new developments with respect to new treatments, new synthetics, and new imitations, as well as improvements in existing ones.

As a last point, it should be noted that with the growing world population and increasing prosperity, the demand for gems has been rising at the same time that the supply of natural gemstones has been falling. The continuation of this trend would be a most significant long-term factor in the future expansion of man-made gemstones.

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Gold Corals — Some Thoughts On Their Discrimination

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Brock and Chamberlain's 1966 discovery[1] of commercial quantities of precious pink coral *(Corallium secundum)* in the deep waters of the Makapuu Bed — off the *southeast* corner of the Hawaiian island of Oahu — stimulated a wave of exploration which ultimately led to the discovery and exploitation of a new jewelry coral — *gold coral.*

Gold coral[1,2,6] [*Gerardia* (sp.) = *Parazoanthus* (sp.)] is an organic coral *(Fig. 1)* which grows, in symbiotic association with pink coral, at depths from 300m to 400m below the surface.

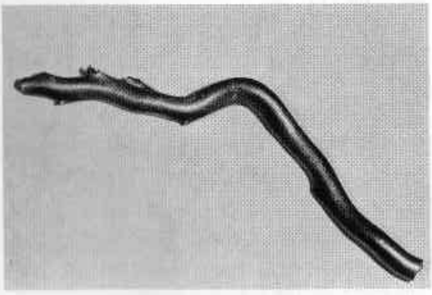


Fig. 1. Branch of gold coral with its coenenchyme removed.

Commercial harvesting of gold coral commenced in 1973, when the miniature submarine Star II was hired by Maui Divers to mechanically harvest this deep coral. Although the distribution[3] of gold coral on the Makapuu Bed is sparse and irregular (.003 colonies/m^3), 1,307 kg of gold coral — valued at $160,000 — was harvested between the years 1975-1977. Harvested coral must be cleaned to remove the adherent coenenchyme, dried, sorted and graded before sections cut from the branches of this lustrous, flexible coral are manufactured in Honolulu into attractive items of jewelry such as[4] freeform shapes for pendants and brooches, variously shaped cabochons for inclusion into a wide range of hand-made jewelry, and beads. Gold coral jewelry currently forms a small yet increasingly important contribution to the Hawaiian jewelry industry.

For several years, a second "gold" coral[5] — of similar color to that of the Gerardia coral, but possessing a slightly different surface texture — has appeared in the market place. This highly lustrous organic coral seems to be used primarily for the manufacture of beads. The golden color of this coral is not natural; it has been induced into the horny axis of a variety of Whip coral (probable genus = *Cirrhipathes*[6] by an acid (nitric acid?) treatment. [Ed.'s note: We believe the treatment to be a simple H_2O_2 (Hydrogen peroxide) bleaching.] This *golden coral (Fig. 2),* as the Hawaiians named it, is produced in the Philippines, where the treated coral is used to manufacture a range of cheaper quality "folk" jewelry.

Although the two "gold" corals are superficially similar in appearance, significant differences in value between the two corals necessitated the development of discriminatory tests which could be confidently applied by gemologists.

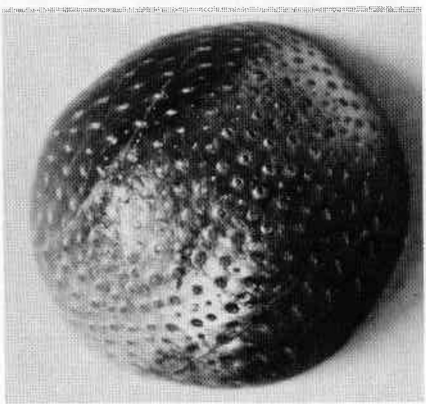


Figure 2. A bead manufactured from treated golden coral.

Taxonomy

Investigations into the taxonomy of corals, from which the polyp containing coenenchyme has been removed, are fraught with problems and frustrations. As a result of this investigation it has been established that both of the corals studied were hexacorals — corals with six tentacled polyps whose coenenchyme secretes the flexible skeletal axis that supports the colony. The gold coral from Hawaii *(Gerardia sp.)* has been classified as a Zoanthid[1], while the golden coral from the Philippines has been tentatively classified as a member of the sub-species of Antipatharian (thorny black) corals known as Cirrhipathes[6] or Whip coral.

Gemological Properties

Conventional gemological properties were determined *(Table 1)* for each of the "gold" corals.

As no significant differences in gemological properties could be demonstrated between gold coral and golden coral, it must be concluded that routine measurement of these properties will not assist positive discrimination.

Hand Lens Observation

Surface Appearance

A 10x magnification hand lens examination of the surface of the "gold" corals was usually quite sufficient to facilitate discrimination of gold coral from golden coral.

Golden coral *(Fig. 3A)* possessed a

TABLE 1.
Gemological properties established for gold coral and golden coral

Gemological Property	Gold Coral[1] (Gerardia sp.)	Golden Coral (Treated Cirrhipathes)
Hardness	2-3	2
Fracture	Splintery	Splintery
Specific Gravity	1.44	1.40
Refractive Index	1.56	1.55-1.56 (DR)
Diaphany	Opaque	Opaque-Treated sections are transluscent
Luster	Greasy-Chatoyant	Greasy-Resinous
Absorption Spectrum	Not Diagnostic	Not Diagnostic
Fluorescence	Inert	Inert
Solubility	Insoluble - HCl	Insoluble - HCl
Heat Sensitivity	Thermoplastic	Thermoplastic

rough spiny surface, while gold coral *(Fig. 3B)* was characterized by displaying an irregularly dimpled surface.

Both corals exhibited a similar deep yellowish brown lustrous surface.

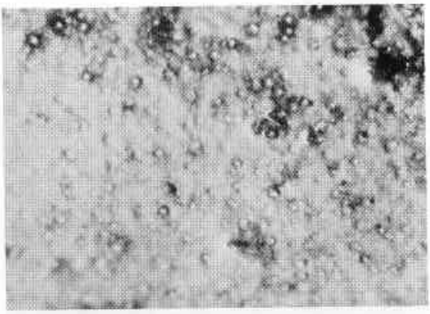
Appearances in Cross Section

Hand lens (10x magnification) of cross sections of both corals indicated that neither coral was of gorgonian origin, as samples of both corals possessed:

- A central longitudinal canal.
- A well developed circumferential lamellar structure.
- A gelatinous texture.

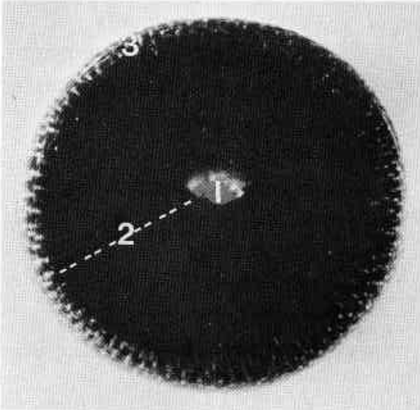
A detailed examination of the

3A. Golden Coral.



3B. Gold Coral.

Figure 3. Photograph of the surface of "gold corals," viewed through a hand lens, illustrating (A) the irregular, spiny surface of golden (Treated Cirrhipathes) coral and (B) the irregularly dimpled surface of gold (Gerardi sp.) coral.



4A. Golden Coral.

4B. Gold Coral.

Figure 4. Photograph of cross sections of "gold coral," viewed through a hand lens, illustrating their diagnostic structural differences: A. Central canal (1), radially arrayed spines (2), external layer of denatured protein (3).

B. Central canal (4), shrinkage spaces between concentric lamellae (5), short radially oriented "dash" like markings (6). NOTE: Lamellae of golden coral are tightly packed and do not display shrinkage cracks.

prepared cross sections showed that diagnostic structural differences could be established for each of the two "gold" corals *(Fig. 4)*.

Golden coral *(Fig. 4A)* can be readily discriminated from gold coral *(Fig. 4B)* by observing the two features which characterize golden coral:

1. Golden coral, in cross section, displays radially arrayed spines.
2. Golden coral, in cross section, displays a golden colored external layer of acid denatured protein. The internal lamellae of this coral are unaffected by the acid treatment and maintain their original blackish brown color.

Golden coral's color is totally derived from the thin layer of denatured protein that covers its external surface. The extent of the induced color is illustrated in *Fig. 5*.

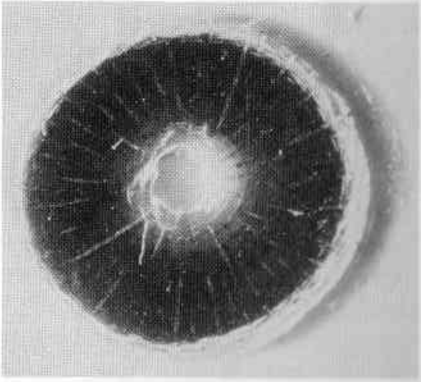


Figure 5. Photograph of a cross section of treated golden coral Cirrhipathes illustrating its characteristic radially arrayed spines, and the superficial extent of the external protein denaturization that is responsible for the coral's golden color.

Summary and Conclusions

Discrimination of Hawaiian gold coral from Philippine treated golden coral is not difficult. If the below listed steps are followed, positive discrimination will be assured.

Step 1: Feel the surface of the coral.

Gold coral has a smooth texture, while golden coral has a rough abrasive surface.

Step 2: Examine the surface of the coral with 10x magnification.

Gold coral has an irregular dimpled surface, while golden coral has a surface that is covered with spines.

Step 3: Examine a cross sectional view of the coral.

Gold coral has a uniform color distribution. Golden coral has a dark center core which is surrounded by a thin golden layer of denatured protein.

Acknowledgements

I wish to acknowledge the photographic assistance of my colleague, Des Lund.

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The Brewster Angle Refractometer

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This paper describes a novel refractometer which determines the refractive index of a gem by measuring the Brewster angle. Conventional refractometers based on the phenomenon of total internal reflection have an upper refractive index limit of 1.8. This Brewster Angle Refractometer can measure refractive indices of any value. It is simple in construction and does not require a refractive index liquid as in conventional refractometers. Gems and minerals of any size and shape can be measured with this instrument, the only requirement being a flat polished surface of dimensions about 3 mm square. Mounted stones need not be unset from their mountings.

Light is a form of transverse electromagnetic wave. The optical vector causing the sensation of light is always perpendicular to the propagation direction of the light beam. Natural and the usual artificial light are unpolarized, that is, their optical vectors may point in any direction as long as they are perpendicular to their propagation directions. A linearly polarized light beam is obtained by passing an unpolarized beam through a sheet of polaroid. The optical vector of the linearly polarized light always points in a direction parallel to the polarization direction of the polaroid. A second polaroid sheet placed with its polarization direction parallel to that of the first polaroid will allow the linearly polarized light to pass through. If its polarization direction is perpendicular to that of the linearly polarized light it will block the passage of the light beam.

The reflectance R of a surface is defined as the ratio of the intensity of the reflected light to that of the incident light. The reflectance R_p for a linearly polarized light beam with its direction of polarization parallel to the plane of incidence is different from R_s, the reflectance of a beam of

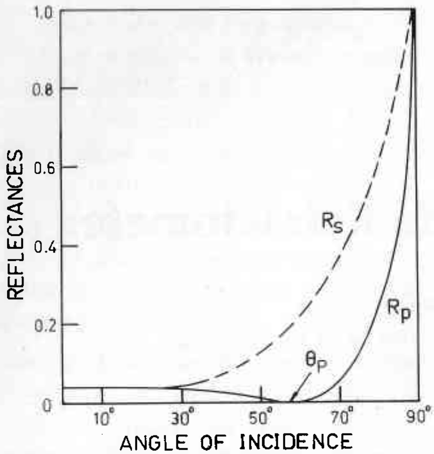

Figure 1. Variation of reflectances with angle of incidence

linearly polarized light with polarization direction perpendicular to the plane of incidence. Moreover they vary with the angle of incidence θ in different ways. *Fig. 1* shows how the reflectances R_p and R_s for glass of refractive index 1.5 vary with the angle of incidence.

For the sake of brevity, linearly polarized light with direction of polarization parallel to the plane of incidence will be called the "parallel component" while a linearly polarized light with direction of polarization perpendicular to the plane of incidence will be called the "perpendicular component." The reflectance curve for the "parallel component," i.e. the R_p curve, shows a broad valley. The reflectance R_p becomes zero when the angle of incidence θ is equal to the Brewster Angle θ_p which is related to the refractive index n of the reflecting material by

$$\tan \theta_p = n \qquad (1)$$

This is known as Brewster's law after the discoverer Sir David Brewster (1781-1868) who also invented the kaleidoscope.

Eq. (1) suggests that the refractive index of any gem can be found by measuring its Brewster angle θ_p, i.e. the angle of incidence for which the reflected "parallel component" becomes zero. The construction of such a Brewster Angle Refractometer is shown in *Fig. 2.* S is a transparent plastic ruler serving as a scale. It is illuminated by a fluorescent lamp L such as the Sylvania F4T5/CW4-watt fluorescent lamp. A strip of milky white plastic sheet D is placed in front of the lamp L to diffuse the light and render the lighting more uniform. Light from the illuminated scale S is reflected from the polished surface of the gem G and observed through a sheet of polaroid P. The polaroid is oriented so that its polarization direction is parallel to the plane of incidence. Thus only the reflected "parallel component" will

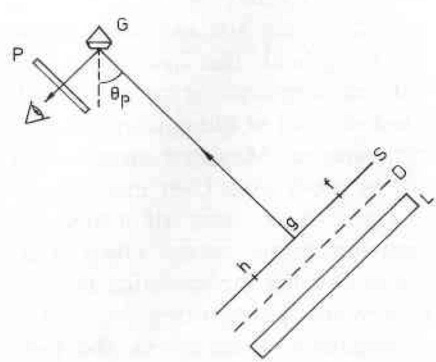

Figure 2. The Brewster angle refractometer

be visible to the observer, the reflected "perpendicular component" being completely blocked out by the polaroid. Various points such as f,g,h on the illuminated scale S subtend different angles of incidence at the reflecting surface G. For example, the point f subtends a larger angle of incidence than the point h. If the point g should subtend an angle of incidence equal to the Brewster θ_p for the gem, the reflected intensity becomes zero and the point g would appear dark to the observer. Since the R_p curve in *Fig. 1* has a broad minimum at θ_p the observer sees a dark band around the point g in an otherwise uniformly illuminated scale S. The position of the dark band on the scale S indicates the magnitude of the Brewster angle and hence the refractive index of the gem. Using Eq. (1) the scale S can be marked to read the refractive indices directly.

In the arrangement just described that part of the illuminated scale corresponding to the Brewster angle appears dark to the observer, hence the scale reading at this dark band cannot be read easily. *Fig. 3* shows an alternative arrangement in which the polaroid P is dispensed with, instead a strip of polaroid Q is placed in front of the upper half of the illuminated scale S. The polarization direction of Q is oriented parallel to the plane of incidence. With this arrangement the same effect of a dark band corresponding to the Brewster angle for the gem is observed in the upper half of the illuminated scale S, while the lower half of the scale remains bright and hence the position of the dark band can be easily read on the refractive index scale.

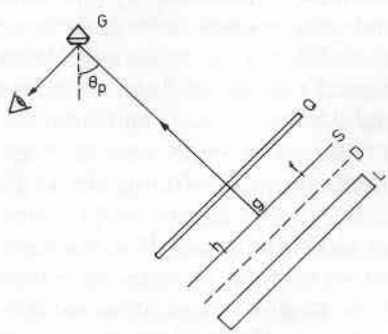

Figure 3. The Brewster angle refractometer (alternative arrangement).

With the Brewster Angle Refractometer the refractive index of a gem is determined by the position of complete darkness on the illuminated scale, corresponding to zero R_p for angle of incidence θ_p. Since the human eye cannot pin point precisely this position of maximum darkness in the fairly broad dark band, the refractive index cannot be determined exactly. The accuracy of this instrument at the present stage of development is inferior to that of conventional refractometers. This weakness is amply compensated by its unique merits such as an unlimited refractive index range and dispensation with a refractive index liquid. The Brewster Angle Refractometer may have great potential when visual observation is replaced by solid state photon detectors and digital displays.

NOTE: Dr. Yu's work on the Brewster Angle Refractometer is independent of Mr. Peter Read's work that has priority and appeared in the *Journal of Gemmology,* October 1979.

Know Your Diamonds

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The GIA Diamond Course has always been considered to be the first word in knowledge about diamonds. But what information is available beyond the Diamond Course? What other books would interest the diamond retailer and gem broker? What information is available that you, the professional jeweler, can use to keep ahead of the competition? It's not as hard as it sounds! The diamond world has a wealth of books and magazines from around the globe to fill this need. Other lists of recommended resources include rare books and journals that are out of print, but today's market needs today's information. All of these materials are currently available in libraries or bookstores. Purchasing and subscription information follows the recommendations.

Many general books on diamonds are available. The long-awaited second edition of *Diamonds* by Eric Bruton is very useful. Diamonds in the U.S.S.R. and recent developments in the diamond industry are included. The sections on mining and cutting are especially good. *Diamonds* is an essential reference for every gemologist.

Even in French, *Le Diamant — Mythe, Magie et Realite* would be an outstanding addition to any diamantaire's library. The English edition will be available this spring, and will include a chapter on the certification of diamonds written by Richard T. Liddicoat, Jr. The text and exceptional photographs are comprehensive, covering history, mining (including Brazil, Venezuela and Africa), cutting and diamonds in jewelry. A series of unusually good photographs illustrating the various clarity grades far surpasses a similar set in Bruton's text. This reference is the only book in years to compare with Bruton's text as a source of technical information.

The Diamond by George Blakey,

Diamonds Eternal by Victor Argenzio, *The Book of the Diamond* by Joan Dickinson, and *Diamond* by Emily Hahn, all emphasize the history and legend of the diamond. *The Diamond* has unusually good photographs and the amusing story of the attempted theft of the English Crown Jewels in 1671. *Diamonds Eternal* has a very complete guide for consumers on how to buy a diamond. The history of diamond fashions is eloquently told in *The Book of Diamonds.*

Diamond tells the tale of Emily Hahn's travels to DeBeers in London, plus descriptions of the diamond mining operations in South Africa. All of these four are fascinating and easy to read. Since history, legend, and famous diamonds are the basis of many sales presentations, these stories are a great source for what the customer wants to hear.

Diamonds have always been the playthings of the famous and infamous. Histories of many unusual diamonds can be found in the GIA *Diamond Dictionary,* and all of the other books just mentioned. This reference is filled with photographs of these diamonds and of winners of the Diamonds-International Awards. For detailed histories of noted diamonds and color photographs of many diamonds in their fabulous settings, GIA's *Diamonds...Famous, Notable, and Unique* is the source. The enchanted, but unlucky, history of the Hope diamond is retold in *Blue Mystery* by Suzanne Patch. Even today, the Smithsonian Institution, home of the Hope diamond, receives thousands of letters each year blaming the troubles of the United States on this lovely gem.

Legend and lore may add to a sales presentation, but the basis of each sale should be proven selling procedures. To learn a variety of techniques, read *Beans About Carats* by Rick Thomas. For a totally different approach, read *Diamonds, Love, and Compatibility* by Saul Spero. Although his "Diamond Shape Game" may be like astrology for diamonds, everyone will enjoy playing. Customers will love the personal attention and the humor that the shape preferences reveal.

The beginnings of the diamond industry in South Africa fascinate many diamond collectors with tales of fortunes lost and won. By using letters and newspaper accounts, Marian Robertson takes us back to 1866-1869 in *Diamond Fever.* But it is the tales of the diamond brokers such as Rhodes and Barnato that give an insight into this dynamic era. *The Diamond Magnates* by Brian Roberts gives the details of each move in the war between Rhodes and Barnato for control of the diamond mines. After the death of Rhodes, DeBeers and the diamond industry prospered under the guidance of the Oppenheimers. The history of DeBeers and the reasons for its pivotal role in the diamond industry are retold in *Oppenheimer and Son* by Anthony Hocking. Along with the facts of the industry's growth in Africa, *The History of Diamond Production and the Diamond Trade* by Godehard Lenzen includes a thorough review of diamonds in India and Brazil. For the study of historical diamond prices, this text is quite valuable.

As diamonds have become a major industry, the scientific community has become interested in what the diamond can tell us about the inside of the Earth. *The Mineralogy of the Diamond* by Yu Orlov explores the various shapes of diamonds from the U.S.S.R. and has a superb bibliography on specialized topics. Although most customers want to hear about the history and mystery of diamond, a few may ask technical questions that would be answered by this text.

Many reference books have an excellent chapter on diamonds. As an introduction for a new sales staff, or as a supplement to the GIA Diamond Course, there are several outstanding books. *Gems* by Webster has a long chapter on diamonds that describes sources, mining methods, cutting, and grading. As a single source of gemological information, *Gems* is essential for every knowledgeable and professional gemologist. *Mineralogy for Amateurs* is another reference that should be on every gemologist's shelf. Although the title sounds impressive, this book is easy to read and will make lessons 1-6 of the GIA Diamond Course seem simple!

An essential reference book is the GIA *Diamond Dictionary*. It is well worth the investment, since its short definitions cover terms, diamond-producing countries, fashion, and famous diamonds. The *Jeweler's Dictionary* by Jeweler's Circular-Keystone magazine also has clear, short definitions, while *An Illustrated Dictionary of Jewellery* by Mason and Packer emphasizes the history of jewelry. GIA's latest reference book, *Gill's Index*, has 48 pages of references to articles on diamonds alone. Information in "Gems and Gemology," "Journal of Gemmology," "Lapidary Journal," and the "Australian Gemmologist" is easy to find with *Gill's Index*.

With so many changes in the world of diamonds, it is essential to subscribe to industry journals to keep posted on the news. Many of the major diamond producing countries publish their own magazines but the best source for current information on diamonds is "Jeweler's Circular-Keystone" magazine. Each month's issue includes a survey of the past month's diamond market and a price index. The September issue is always devoted to diamonds, and the cover story for this September's issue is an analysis and expose of DeBeers and its role in the diamond industry. "National Jeweler," the twice monthly newspaper of the industry, frequently has articles on the market. The "National Jeweler" emphasizes recent activities and news, while the "Jeweler's Circular-Keystone" emphasizes comprehensive feature articles.

For information on activity in the diamond centers around the world there are a host of magazines. "Diamant" is published monthly in Antwerp, and has a summary of the news from every major diamond center. South Africa is represented by "Diamond News and South Africa Jeweler," which describes mining, production, and trends in the South African market. India publishes "Diamond World," which is a good source of information on import-export practices and the diamond cutting industry of India. Each month "Israel Diamonds" reports on growing use of automation and on the Israeli reactions to DeBeer's policies. Israel also publishes a quarterly journal called "Diamond World Review." This magazine is a superb source of information on the latest trends in every diamond market. From DeBeer's successful campaign to increase engagement ring sales in Japan to political upsets in Africa, every country is described in detail. The price of each diamond sold today is affected by action in markets halfway around the world, so an awareness of the market in these trading centers is vital.

Gemological magazines are also an excellent resource for information on diamonds. Years of scientific research or discoveries of diamond sources may be condensed into a single article. "Gems and Gemology" has brought its readers information on all of the major gem deposits, plus the latest techniques for identifying substitutes. "The Journal of Gemmology" also emphasizes the science of gems. These two publications are essential reading for every gemologist.

This list is only an indication of the resources that are available to anyone in the world of diamonds. Many new books and magazines appear each day, so those that are not included may also be worthwhile to read. By keeping track of changes in the industry, and watching for trends, a world of diamond profits can be realized.

Time is money, and for years the GIA courses have shown that time invested in education leads to increased profit. It is no longer enough to watch competition in one area alone. The consumer-oriented market requires a professional attitude and comprehensive knowledge of the world of diamonds. Today's professional jeweler realizes that lifelong learning is the key to success in the diamond world.

These books and magazines can be ordered from the addresses listed below:

BOOKS

Beans About Carats by R. Thomas, Gem Publications, Logan, Utah, 1978. $12.50 through the GIA Bookstore.

Blue Mystery: The Story of the Hope Diamond, by S. Patch, Smithsonian Institution Press, Washington, D.C., ISBN 0-87474-165-3. $7.95 through the GIA Bookstore.

The Book of Diamonds by J. Dickinson, Crown Publishers, Inc., New York, NY, 1965. This book is available in many libraries.

Le Diamant — Mythe, Magic et Realite, edited by J. Legrand, Flammarion, 1979. Approximately $50 for the English edition, which will be available later this year.

The Diamond by G. Blakey, Grosset and Dunlap, New York, NY, 1977, ISBN 0-448-22062-8. $19.95 through the GIA Bookstore.

Diamond by E. Hahn, Doubleday and Co., Inc., New York, NY 1956. This is also available in many libraries.

The Diamond Dictionary by the GIA Staff, Second Edition, Gemological Institute of America, Santa Monica, CA, 1977, ISBN 0-87311-008-0. $16.95 through the GIA Bookstore.

Diamonds...Famous, Notable, and Unique, by the GIA Staff, Revised Edition, Gemological Institute of America, Santa Monica, CA, 1974, ISBN 0-87311-005-6. $7.50 through the GIA Bookstore.

Diamond Fever by M. Robertson, Oxford University Press, Johannesburg and London, 1974, ISBN 0-19-570002-3. Public libraries often have this reference.

The Diamond Magnates by B. Roberts, Charles Scribner's Sons, New York, NY, 1972, ISBN 684-132344-x. Libraries often have this book.

Diamonds by E. Bruton, Second Edition, Chilton Book Co., Radnor, PA, 1978, ISBN 0-8019-6789-9. $25.00 through the GIA Bookstore.

Diamonds Eternal by Victor Argenzio, David McKay Co., Inc., New York, NY, 1974, ISBN 0-679-50427-3. Public libraries usually have this text.

Diamonds, Love, and Compatibility by S. Spero, Exposition Press, Hicksville, NY, 1977, ISBN 0-682-48826-7. $7.50 through the GIA Bookstore.

Gems by R. Webster, Third Edition, Shoe String Press, Hamden, CT. 1977, ISBN 0-208-01491-8. $67.50 through the GIA Bookstore.

Gill's Index to Journals, Articles and Books Relating to Gems and Jewelry by J. Gill, Gemological Institute of America, Santa Monica, CA, 1979, ISBN 0-87311-009-9. $24.50 through the GIA Bookstore.

The History of Diamond Production and the Diamond Trade by G. Lenzen, Praeger Publishers, New York, NY, 1970. This text is still available in many libraries.

Jeweler's Dictionary edited by D. McNeil, Third Edition, Jeweler's Circular-Keystone, Radnor, PA, 1976. $39.95 through the GIA Bookstore.

Mineralogy for Amateurs by Captain J. Sinkankas, USNRET, Van Nostrand Reinhold, New York, NY, 1964, ISBN 0-442-27624-9. $12.95 through the GIA Bookstore.

The Mineralogy of the Diamond by Y. Orlov, John Wiley and Sons, New York, NY, 1977, ISBN 0-471-01869-4. $29.95 through the GIA Bookstore.

Oppenheimer and Son by A. Hocking, McGraw-Hill Book Co., New York, NY, 1973, ISBN 0-07-091255-6. $12.95 through the GIA Bookstore.

MAGAZINES

"Diamant", Conscienstraat 7, 2000 Antwerpen, Belgium. Monthly.

"Diamond News and South African Jeweler", Box 60, Lyndhurst, Transvaal, South Africa. Monthly.

"Diamond World", Journal House, A-95, Janta Colony, Jaipur 302-004, India. Six issues per year.

"Diamond World Review", Box 1381, Tel Aviv, Israel. Issued quarterly.

"Gems and Gemology", Gemological Institute of America, Box 2100, Santa Monica, CA, 90406. Issued quarterly.

"Israel Diamonds", Box 3237, Ramat Gan, Israel. Six issues per year.

"Jeweler's Circular-Keystone", Chilton Co., Chilton Way, Radnor, PA, 19098. Monthly. (215) 687-8200.

"Journal of Gemmology", Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London EC2V 8AB, England. Quarterly.

"National Jeweler", Gralla Publications, Inc., 1515 Broadway, New York, NY 10036. Two issues per month. (212) 869-1300.

Book Reviews

INTERNAL WORLD OF GEMSTONES by Dr. E. J. Gübelin. Second Edition 1979. Butterworths, USA, Publishers. 234 pages with 360 illustrations in color. Available through GIA Bookstore.

Dr. Eduard Gübelin's book is probably the most remarkable book published in the gemological field as an object of beauty. The 360 color plates are of a quality that is unsurpassed in any book with which we are familiar, within or without the gemological firmament. One unexpected dividend is the fact that the book has such beautiful photomicrographs that it should provide a real inspiration to designers, because of the beauty of the many patterns of inclusions and their vivid coloring.

Dr. Eduard Gübelin is undoubtedly the foremost student of inclusions in the gemological field. He has studied inclusions not only for their value in identification of the gem mineral, but for the information they provide with respect to the conditions prevailing at the time of the growth of the host mineral. Since he started his detailed studies of the inclusions in diamond, this has become a very important field for geoscientists in their efforts to learn more about the conditions that exist beneath the crust of the earth. Some of the early conclusions reached from their appearance about the nature of diamond inclusions have been dramatically altered by the use of the electron microprobe to determine the exact nature of the inclusions.

In his preface, Professor Dr. W. F. Eppler points out that Eduard J. Gübelin started to examine inclusions in gemstones about forty years ago. His contributions in this field are unparalleled. In addition to calling attention to characteristic inclusions that help in identification, his research has been of value in the mineralogical field in determining the conditions under which the host minerals grew. This is an important contribution to the field of gemology.

The book is undoubtedly the most comprehensive work on inclusions in gemstones ever written and, in addition, it is a magnificent volume.

In his foreword, Dr. Gübelin says, "The present book deals with the inclusions in gemstones and is devoted to one of the most fascinating themes in scientific gemology. Nevertheless, it is no textbook in the narrow sense, although it does indeed aim primarily at offering a comprehensive presentation and scientific classification. The publication is, rather, first and foremost a work conceived from the aesthetic point of view, setting itself the pleasant and elegant task of revealing to our gaze the inimitable artistry of nature once again in all its — often hidden — variety and uniqueness. And that by means of pictures which until now had never been seen in such richness and scientific perfection. From a collection of about 5,000 color negatives amassed over a period of 30 years of intensive research work (and which possibly constitute the greatest wealth of pictorial material on gemstone inclusions anywhere!), about 360 photographs have been selected. These splendidly colored documents of the hidden beauty within a microscopically small space are the center and pivot of this book. They should give pleasure to all those who are receptive to the beauties of nature and furthermore should also serve to stimulate and inspire those active in artistic pursuit."

In this paragraph, Dr. Gübelin has summed up the nature of his book. Much of it is written in Eduard Gübelin's inimitably colorful English. For example, he states, "Tiny crystals float there in the unreal red, green or yellow light of an apparently limitless space. Petrified growths stand there in the imaginary glitter of light reflection. In the deep green shimmer of an underwater background, forests of algae and groves of scouring rushes seem to spread over shining crystal treasures."

In the introduction he shows the instruments used in his research, and describes some of the processes employed. He shows the same inclusions in normal light and under crossed Polaroids, showing how much more revealing one may be than the other. He also contrasts photographs taken by light field illumination with those under dark field illumination, those taken with or without phase contrast, with the diaphragm open and closed or under ultraviolet or normal light. This is fairly illustrative of the options available to the photographer with all of the necessary equipment.

The book covers the nature of the formation of different minerals and the relationship thereto of various inclusions. Gübelin distinguishes among protogenetic inclusions, i.e., those that were formed before the growth of the host crystal and included in it as it grew; syngenetic inclusions, or those that developed simultaneously with the growth of the host crystal; and epigenetic inclusions, those developing after the growth of the host. He classifies syngenetic inclusions into mineral solids, or liquid inclusions, and breaks those down into various types. There are sections on each of these types of inclusions. The typical inclusions of the individual gemstones is the subject of most of the remaining portion of the book. After covering the descriptions of typical inclusions in natural gemstones, he also has a section of synthetics.

If there are any criticisms to be made of the book, that would have to be involved with the fact that many of the photographs are taken under higher magnifications than are available to the average gemologist. Several of the photographs are taken at 250x, which is beyond the capacity of most of the equipment available to American gemologists. On the other hand, there are many that are taken under 10x, 20x, or 30x, which is well within the range of the equipment available to most gemologists. Even though some of them are taken at magnifications higher than available, this does permit a detail to be shown that would not otherwise be clear in a photograph, and many times this is an important factor in instruction.

Another helpful addition to the second edition would have been to include a detailed index of the color plates for quick reference. Minor errors included in the first edition were corrected in the second. For example, Dr. Gübelin, through experimentation, has found that the partially resorbed mineral grains in Sri Lankan hessonite garnets are apatite rather than diopside or zircon, and this has been changed in the second edition.

The *Internal World of Gemstones* is without doubt the most beautiful book in the gemological field. It is also invaluable.

Acknowledgements for Gifts Received By The Institute

Santa Monica Headquarters

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

To *Lewis A. Bannon,* Labannon, Baton Rouge, Louisiana, for a .10-carat diamond that has excellent examples of trigons to show to our students.

To *Craig Beagle,* Craig Beagle Jewelers-Gemologists, La Habra, California, for a variety of stones to be used in our student test sets.

To *Arthur G. H. Bing, M.D.,* Columbus, Ohio, for an unusual assortment of beryl to add to the display collection and to the student study sets.

To *Dr. and Mrs. Michael Braunstein,* Las Vegas, Nevada, for an unusual brown opal of 106.39 carats, an orange opal of 94.09 carats plus several other gems to be a part of the research and display collections.

To *B. J. Cassin,* Los Altos Hills, California, whose benevolent donation of an irradiated blue topaz crystal weighing an amazing 10,400 carats will enhance our display collection.

To *Mrs. Anne Carlton Davis,* Rochester, New York, for an aquamarine of 82.36 carats and a kunzite of 48.78 to augment our research and display collections.