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Colorless and Green Grossularite From Tanzania

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Introduction

When the original East African finds of transparent green grossularite were made in the late sixties, the excitement created by this new gem overshadowed the simultaneous finds of colorless, yellow, and golden grossularite. All of these varieties were discovered in excellent gem quality. Dr. H. Bank, in 1968, was the first to describe colorless grossularite.(1) The green variety was promotionally introduced to the public by Tiffany & Co. in September, 1974, under the name "tsavorite."(2) But the other varieties received no special names. Tsavorite was named after the Tsavo National Park, a park in Kenya located near the discovery site in Tanzania. Even though tsavorite has received widespread recognition and acceptance, information in the literature on this green variety is limited.(1 thru 11) Literature references on the other varieties are frequent but very limited in content.(1,2,4 thru 12)

Discussions with a number of dealers who have bought and sold large quantities of Tanzania and Kenya grossulars, and who have subjectively estimated the relative quantities of the various varieties of grossularite, lead to these conclusions:

Yellow or golden grossularite is substantially more rare than green grossularite, and colorless grossularite is the rarest of all.

Furthermore, according to these dealers, all colorless grossularite is from finds in Tanzania. No more than ten cut colorless grossulars in excess of four carats are known to exist, none larger than eight carats. All or most of these stones are in the possession of private collectors. It is noteworthy that even the Smithsonian Institution by May 1978 did not have a colorless grossular on display. A reasonable estimate is that there are about forty stones ranging from two to four carats and a few hundred between one and two carats. The total weight of the stones below the size of one carat should be about six-hundred to eight-hundred carats.

We were fortunate to acquire a large number of cut East African gemstones for examination. All were reported to be grossulars and to have been found in 1968 and without a doubt from the early finds in Tanzania. They were machine cut and in a variety of colors. Some were pure colorless. All were transparent and of excellent gem quality. The examinations presented here were restricted to stones which were pure colorless or green. The green stones had various intensities ranging from near colorless with only a touch of green, through medium green, to deep green.

Our main objective was to determine the characteristics of the colorless stones, so that it could be verified that they were in fact colorless grossulars. Such information on the Tanzania colorless grossulars was not in the literature. Another objective was to better understand the cause of green color in grossularite.

Colorless Defined

The colorless and near-colorless gemstones were color graded against a GIA-Graded Diamond Master Set. Such grading presented no difficulties, even though the gemstones tended to have greenish tints and the diamonds of the diamond master set, yellowish tints. During the color grading of a great number of stones, consistent results were always obtained by different gemologists working independently.

The best GIA grade found among hundreds of small stones evaluated was G/H. And the best GIA grade found among the many stones over one carat was *I*. Typically, the GIA grade for a stone was K or L. We classify an N grade and grades of darker tones as near colorless. Even with a small brilliant cut, an N rated gem is noticeably colored to the naked eye.

Many dealers offer as colorless grossulars, stones that will grade between O and Z. In fact, all Kenya "colorless" stones we have seen and graded have been darker than O with clearly observable green or other tints. This may be why most prominent dealers claim that all colorless grossulars come from Tanzania despite the fact that in the literature there are references to colorless grossularite from Kenya, Canada, California, and Mexico.(2,5,9,11)

Chemical Analyses

Three colorless gemstones and one near-colorless gemstone were chemically analyzed by the nondestructive technique of X-ray energy spectrometry (XES). Their GIA grades were G/H, I, M, and O, respectively. Twelve tsavorites which had been selected to form a color suite with colors ranging from very light green to deep green, in small increments, were also chemically analyzed. All stones were brilliant cut and about 3 mm in diameter.

We used a Jeol Electron Microscope Model 100-C with a Kevex-Ray Model 5100 Energy Spectrometer for the analyses. This Kevex 5100 system identifies and provides a quantitative analysis of the chemical elements of a sample by measuring in the spectrum the dispersive X-ray energy that is a unique characteristic of each element. The X-ray spectrum is induced in the sample by placing it in the electron microscope and bombarding the sample with electrons. For accuracy of chemical composition, tsavorite, calcium carbonate, and some high-purity oxides were used as comparative standard. It is recognized that oxygen and lighter elements cannot be detected by this method. Therefore, it was assumed that oxygen was present

TABLE I
CHEMICAL COMPOSITION OF GROSSULARS
(X-Ray Energy Spectroscopic Analyses)

Sample No.	Weight Percent *									Color **
	$Ca0$	Al_2O_3	SiO_2	$Mg0$	TiO_2	$Mn0$	$Fe0$	Cr_2O_3	V_2O_3	
1	38.5	21.2	39.7	0.1	0.3	0.1	0.1	ND***	ND	Colorless, G/H
2	38.0	20.9	40.3	0.4	0.2	0.1	0.1	ND	ND	Colorless, I
3	39.7	19.9	39.5	0.1	0.4	0.2	0.1	ND	0.06	Colorless, M
4	32.3	22.8	43.3	1.0	0.3	0.1	0.1	ND	0.05	Near Colorless, 0
5	35.1	21.3	41.9	0.9	0.4	0.1	0.1	0.09	0.10	VL Green
6	33.9	22.4	42.1	0.9	0.4	0.1	0.1	ND	0.09	L Green
7	34.5	21.5	42.8	0.5	0.3	0.2	0.1	ND	0.11	L Green
8	34.5	20.5	43.0	0.3	0.2	0.6	0.1	0.09	0.7	M Green
9	34.8	21.7	41.6	0.1	0.3	0.4	0.03	0.06	1.0	MD Green
10	33.6	21.6	42.2	0.4	0.4	0.6	0.1	0.09	1.0	MD Green
11	33.7	21.1	42.5	0.7	0.2	0.5	0.04	0.10	1.1	MD Green
12	35.5	20.5	41.9	0.4	0.2	0.3	ND	0.02	1.2	MD Green
13	34.5	20.5	42.5	0.3	0.3	0.5	0.1	0.12	1.2	MD Green
14	34.6	21.0	42.0	0.3	0.2	0.4	0.03	0.14	1.4	D Green
15	34.9	20.5	41.9	0.4	0.3	0.4	0.1	0.15	1.4	D Green
16	36.3	20.6	40.3	0.2	0.2	0.2	ND	0.10	1.5	D Green

* Ideal grossular is: 37.36% $Ca0$, 22.63% Al_2O_3, 40.01% SiO_2.

** Grossulars are ranked according to GIA diamond color grade and depth of green color; VL = Very Light; L = Light; M = Medium; MD = Medium to Deep; D = Deep.

*** Not Detectable

in such amounts as to form perfect metal oxides, and that elements of atomic number less than oxygen were not present.

The determined chemical compositions of all gemstones, ranked according to color grade or intensity of green color, are given in *Table I* in terms of oxide weight percentages. Their chemical compositions in terms of the number of metal atoms per twelve oxygen atoms are given in *Table II*. *Table II* is a convenient way to compare the measured chemical compositions of the stones with that of colorless, ideal grossularite. Colorless, ideal grossularite has a stoichiometric formula of $Ca_3 Al_2 (SiO_4)_3$, indicating that there are three calcium atoms, two aluminum atoms, and three silicon atoms for every twelve oxygen atoms. As is customary, it was accepted when constructing *Table II* that magnesium, manganese and iron replace calcium; that chromium and vanadium replace aluminum; and that titanium replaces silicon. There is doubt that this can be applied strictly.(13,14) However, considering the low concentrations of these impurity elements, the results would not be significantly different.

The chemical analyses showed that the chemical compositions of the colorless or near-colorless gemstones were similar to those of the tsavorites and very close to the calculated, theoretical composition of colorless, ideal grossularite. Sample No. 1 and Sample No. 2, the two most colorless stones, were found to be calcium-aluminum silicate of 99.6% and 99.5% purity, respectively. Colorless Sample No. 3 had a purity of 99.4%. These purities were all weight percentages calculated from the chemical compositions, assuming that there were twelve oxygen atoms to every eight metal atoms. We recognized that the oxygen atoms associated with the impurity metal atoms were not impurity oxygen atoms but oxygen atoms of the basic, ideal crystal.

The X-ray energy spectrum of colorless Sample No. 2 is shown in *Fig. 1.* For comparison, the X-ray spectrum of tsavorite with a deep green color is shown in *Fig. 2.* The similar nature of the silicon, aluminum, and calcium peaks of the colorless gemstone and tsavorite may be seen by comparing *Fig. 1A* with *Fig. 2A* between 0.5 and 3.5 KeV. In *Figs. 1B* and *2B* the 2.8 to 7.9 KeV range is magnified to show (a) the absence of vanadium and chromium in the colorless gemstones, (b) the vanadium and chromium peaks in the tsavorite, and (c) the lower manganese and iron peaks in the colorless gemstones.

The statement is often made that pure or nearly pure garnets do not exist in nature. However, the colorless grossulars we examined are very close to the pure end member grossularite. They are probably as pure a grossularite as can be found in a natural deposit. The purest grossular previously reported in the literature had a purity of 98.9%.(3) However, the color of this stone was pale yellowish green rather than colorless. This is in agreement with the lower purity observed. We calculated the purity of this grossular from the reported chemical composition and used the same assumptions as before. The reported

TABLE II
NUMBER OF ATOMS PER 12 OXYGEN ATOMS IN GROSSULARS *

Elem.	Sample No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ca	3.10	3.06	3.20	2.60	2.82	2.73	2.78	2.79	2.80	2.72	2.72	2.87	2.79	2.80	2.83	2.93
Mg	0.01	0.04	0.01	0.12	0.10	0.10	0.05	0.04	0.02	0.04	0.08	0.04	0.03	0.03	0.05	0.03
Mn	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.03	0.04	0.04	0.02	0.03	0.03	0.02	0.02
Fe	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00	ND	0.01	0.00	0.00	ND
	3.13	3.12	3.23	2.74	2.94	2.85	2.86	2.87	2.85	2.81	2.84	2.93	2.86	2.86	2.90	2.98
Al	1.88	1.86	1.78	2.02	1.89	1.98	1.90	1.82	1.92	1.92	1.87	1.82	1.83	1.87	1.82	1.84
V	ND	ND	0.00	0.00	0.01	0.01	0.01	0.05	0.07	0.06	0.07	0.07	0.07	0.08	0.09	0.09
Cr	ND	ND	ND	ND	0.01	ND	ND	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
	1.88	1.86	1.78	2.02	1.90	1.99	1.91	1.88	2.00	1.99	1.95	1.89	1.91	1.96	1.92	1.94
Si	2.99	3.02	2.97	3.22	3.14	3.14	3.21	3.24	3.13	3.19	3.20	3.16	3.22	3.17	3.17	3.07
Ti	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01
	3.00	3.03	2.99	3.24	3.16	3.16	3.23	3.25	3.15	3.20	3.21	3.18	3.23	3.18	3.18	3.08

* Ideal grossularite: Ca = 3 atoms; Al = 2 atoms; Si = 3 atoms; 0 = 12 atoms.

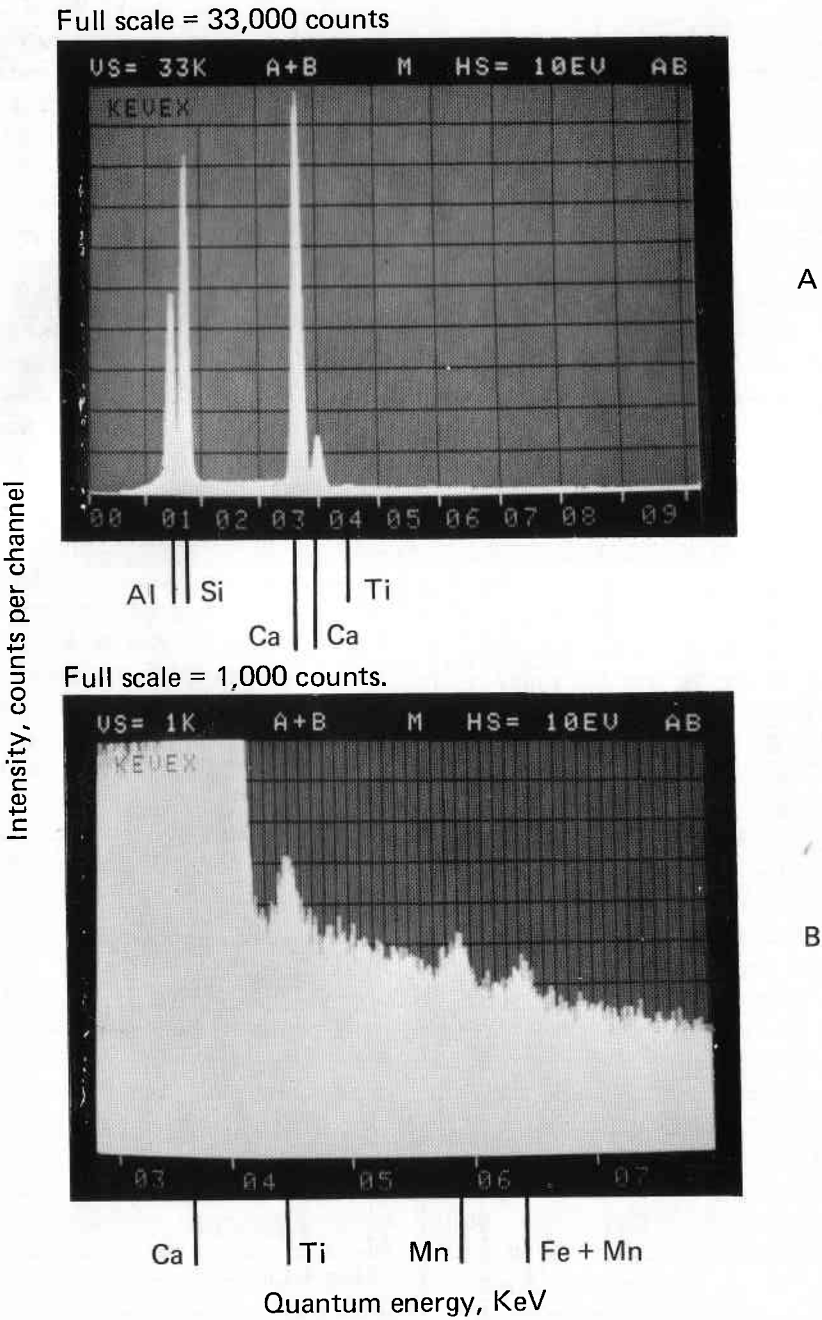

Figure 1. X-ray energy spectrum of colorless grossular (Sample No. 2).

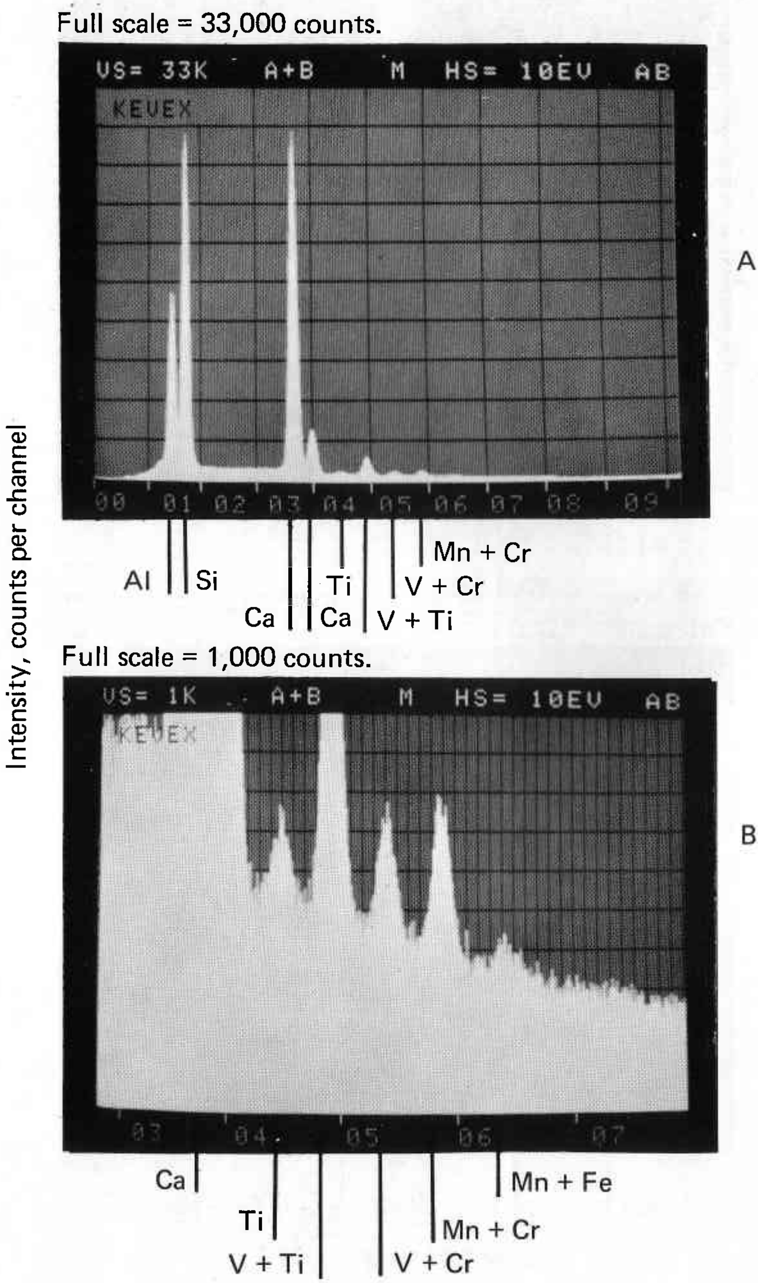

Figure 2. X-ray energy spectrum of tsavorite.

chemical composition had been determined by a technique of X-ray spectrometry comparable to our own.

The results of the chemical analyses, augmented by our physical and optical property determinations, further showed that the colorless and near-colorless stones formed an expanded color suite with the tsavorites. This expanded suite consisted of the sixteen grossulars listed in *Tables I and II*, with tones and intensities of green ranging all the way from G/H colorless to deep green. This greatly facilitated the evaluation of the effect of chemical composition on color.

A direct relationship was found between the vanadium content and the intensity of the green color of the grossulars, as may be seen in *Table I.* No vanadium or chromium was detected in the two most colorless stones. And as the vanadium-oxide content gradually increased to 1.5%, the intensity of the green color gradually increased to deep green. In the colorless grossular that graded an M color, the vanadium-oxide content was 0.06%, but no chromium was detected in this stone, either. In fact, no chromium was detected in the first seven grossulars of the color suite except for Sample No. 5, and the color of Sample No. 6 was already rated as light green. Therefore, chromium could not account for, nor contribute to, the green colors of these grossulars.

Unfortunately, there was no stone in our color suite that contained chromium without vanadium. Therefore, we were not able to determine the effect of chromium without vanadium. However, Sample No. 5, which contained 0.09% chromium-oxide and 0.10% vanadium-oxide, was lighter green than Samples No. 6 and No. 7, which contained no chromium and about the same amount of vanadium. Except for the chromium-oxide content, the chemical compositions of these three grossulars were very similar. Therefore, it appeared that chromium did not increase the intensity of the green color, but rather, had a slightly negative, or lightening, effect. The chromium-oxide content was mostly not greater than about 0.1%. It was 0.15% as a maximum. Therefore, the effect of chromium on the green color of the grossulars of this investigation seemed to be insignificant.

Except for influencing the tones of the colorless and near-colorless stones, no remaining element at the levels present seemed to influence color significantly.

The magnesium-oxide content varied erratically between 0.1% and 1.0% in the color suite, with no significant effect on the green color.

In the colorless stones, the manganese-oxide content was only 0.1% or 0.2%. The manganese-oxide contents of the remaining stones varied erratically between 0.1% and 0.6%. Within this range, the manganese did not noticeably modify the green color of the tsavorites. However, the green color was always of high intensity at the high levels of manganese. This may have obscured any effect of manganese on color.

The titanium-oxide content was always in the range of 0.2% to 0.4%, and the iron-oxide content was never more than 0.1%. Under these conditions, no noticeable influence of these elements on the green color of the tsavorites was observed.

None of the gemstones examined had a measurable nickel content.

Optical and Physical Properties

The optical and physical property determinations were restricted to the colorless gemstones. We evaluated birefringence, refractive index, ultraviolet fluorescence, and specific gravity. In addition, some gemstones were microscopically examined for inclusions.

Birefringence: None of the colorless gemstones examined exhibited birefringence under the GEM Illuminator Polariscope. All were found to be singly refractive but with medium strain.

Refractive Index: The small colorless gemstones, Sample No. 1, Sample No. 2, and Sample No. 3, all showed a refractive index of 1.731 to 1.732. Their GIA color grades were G/H, I, and M, respectively. Ten colorless gemstones which were one to two carats in size showed an average refractive index of 1.732. Five of these measured 1.731, and five measured 1.732. Their GIA color grades ranged from I to M. All refractive indices were determined with the GEM Duplex II Refractometer.

Ultraviolet Fluorescence: Under both short and long wave length ultraviolet radiation, the colorless grossularite fluoresced a weak to moderate golden-yellow visible light. The color of this light could also be called yellow with a touch of orange. The ultraviolet fluorescence was determined with the UVSL-25 Combination Mineralight Lamp using an ultraviolet viewing cabinet.

Specific Gravity: The specific gravity of the colorless grossularite was 3.62 as determined by the direct-weighing method. The small colorless stones of our color suite were too small for accurate, reliable measurement of specific gravity. Therefore, we made three different batches of large grossulars, each consisting of three stones, and determined the joint specific gravity in each case. The weight of each batch was between four and five carats. And the measured specific gravities were 3.61, 3.62, and 3.62.

Characteristic Inclusions: We examined many of the colorless grossulars under the microscope at magnifications up to 60x for inclusions. To date we have not been able to catagorize any of the inclusions we observed as "characteristic." One stone exhibited short stubby inclusions *(Fig. 3).* Another showed two long parallel needles *(Fig. 4).* A third had short needles and angular inclusions *(Fig. 5).* And a fourth displayed a plane of small "fingerprint-like" inclusions *(Fig. 6).*

Further Discussion

Bank reports the refractive index of colorless grossularite to be in the range of 1.732 to 1.736.(1) Eppler reports pure synthetic grossularite as having a refractive index of 1.734.(5) And Mackowsky gives 1.735 for the refractive index of pure grossularite.(1) Webster reports 1.738 to 1.744 for transparent green grossularite (tsavorite).(1) The GIA shows 1.736 to 1.742

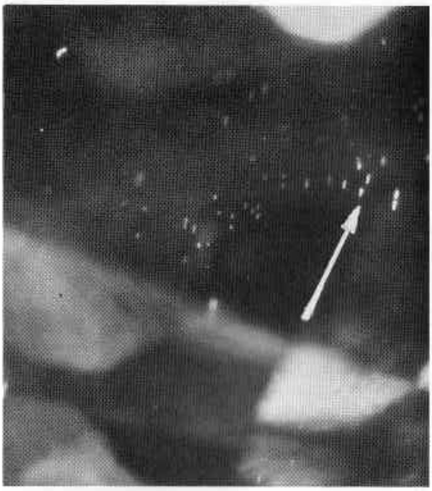

Figure 3. Colorless grossular with short stubby inclusions (60x). Arrow points to cluster of inclusions.

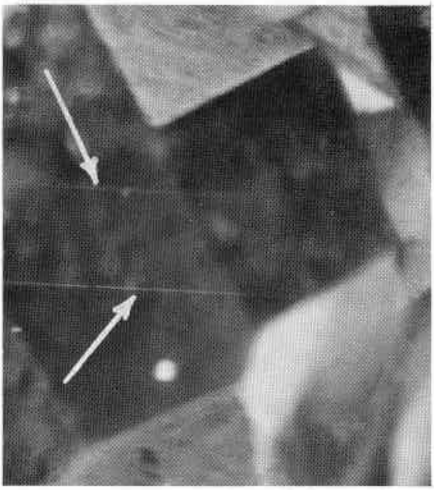

Figure 4. Colorless grossular with long parallel needles (60x). Each arrow points to a long needle-shaped inclusion.

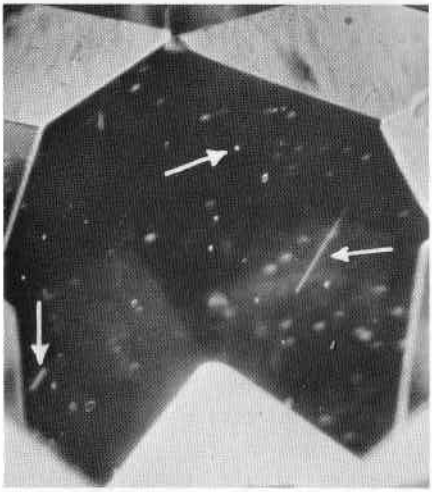

Figure 5. Colorless grossular with short needles and angular inclusions (60x). Two arrows point to short needles, and one arrow points to one of numerous angular inclusions.

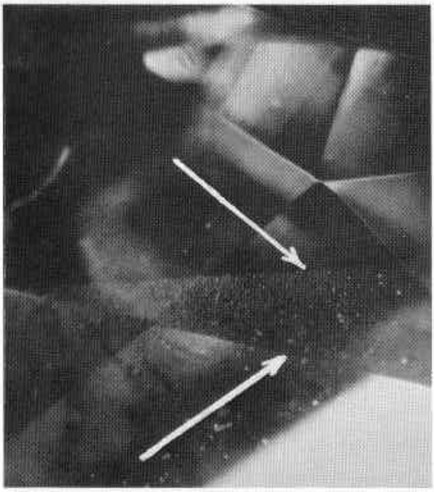

Figure 6. Colorless grossular with small fingerprint-like inclusions (60x). Arrows point to plane with small inclusions in "fingerprint" pattern.

for green transparent grossularite (tsavorite).

The colorless gemstones we examined showed an average refractive index of 1.732. Therefore, our experimental results are in agreement with the data reported by Bank for colorless grossularite, even though some of our colorless stones measured 1.731, the lowest refractive index ever reported for colorless grossularite. It should be noted that the measured refractive indices of our colorless grossulars were at the lower end of the 1.732 to 1.736 range reported by Bank. And they were lower than the 1.734 reported for pure synthetic grossularite by Eppler and lower than the 1.735 reported for pure grossularite by Mackowsky. Since we define colorless rather tightly, it appears that many of the stones examined by the other investigators were near colorless rather than colorless. This seems especially true since the GIA shows a refractive index of 1.736 to 1.742 for green transparent grossularite (tsavorite).

Previous work by Switzer suggested that the green color in tsavorite was related to the vanadium content and probably in part to the chromium content.(3) However, both vanadium and chromium were always present in the four green grossulars Switzer examined, so that the effectiveness of each of these elements alone to impart green color could not be determined. Also, an interaction of vanadium and chromium could not be ruled out.

The present work clearly showed that vanadium is the effective element that gives tsavorite its intense, beautiful green color. The presence of chromium is not essential. Furthermore, it appears that chromium at the low levels found in tsavorite during both investigations – 0.3% chromium oxide or less – does not have any significant effect on green color, neither in a positive nor negative sense.

Conclusions

The chemical compositions and the optical and physical properties, determined during this investigation, verify the reports that the colorless gemstones discovered in Tanzania in the late sixties are colorless grossulars. Such grossulars are exceedingly rare and have characteristics that qualify them as desirable gemstones. It appears that most, if not all, "colorless" grossulars from Kenya are not colorless, but "near colorless" with clearly observable green or other tints.

Similar to diamonds, colorless grossulars can be color graded accurately and with consistent results. A GIA-Graded Diamond Master Set is suitable for such grading.

The beautiful green color in tsavorite is caused by vanadium alone. Chromium is not essential. In the absence of chromium, a vanadium-oxide content of 0.1% already causes a light green color. And a vanadium-oxide content of 1.5% causes a deep green color. Presumably, the tsavorites that black out have higher vanadium-oxide content. It appears that chromium at the levels found in tsavorite during this investigation has no significant effect on green color. The chromium-oxide contents were about 0.2%, or less.

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Quartz: Myth and Magic, Science and Sales

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From the intrepid cavedweller who believed that a special type of stone arrowhead would never fail to reach its target, to the romantic modern couple who believe that a diamond will help their love to last forever, humans have always displayed a belief in the magical properties of gemstones. Western philosophers of the middle ages described gems as the flowers of the mineral kingdom, while in the East gemstones are considered to be the mines of cosmic rays. The ancients of many cultures believed that rocks and stones were the bones, the very skeleton, of the Earth Mother, and therefore the repository of much of Her power.

To the gemologist, who is aware of the physical properties of gems and the scientific facts of their creation, it may seem odd to accord a respectful examination to the superstitions surrounding gemstones. But for the majority of people who buy and wear gems, it is their beauty and romance which is attractive, and the jeweler who can enhance this intuitive attraction is in a position to increase sales. The famed Occultist Dion Fortune described magic as: "The art of causing change in accordance with will." Magic has the same root word as "image". To cause magic, one begins with an image, a vision, and directs energy towards it. A good sales person works in a very similar manner, and the lure of gemlore can produce a magical effect on a customer's interest.

As a survey of the magical properties accorded to every gemstone would require an article of encyclopedic length, this examination will limit itself to a study of the quartz family. In an article on Quartz[1], Cornelius S. Hurlbut notes that, "More than any other mineral, quartz has been the birth place and the testing ground for the concepts and methods of mineralogy." It also provides a good focus for our explorations of the link between magic and gems. From wine-dark amethyst to the smoky cairngorms of Scotland, the quartz family has retained its mysterious allure to this day. Few images conjure more of the thrill of the occult than the crystal ball, that sphere of unknown potentialities, a cosmic television set programmed by fate. Quartz is found all over the world, in many varieties, including amethyst, whose name is Greek for "not drunk," believed to counteract the effects of liquor; cat's eye, used by Witches as a jewel of fascination to draw the mind and eye; rose quartz which contributed its beauty to the first "rose-colored glasses," and rock crystal, whose name reflects the belief that it was a form of ice that would never melt. While each variety is considered to be endowed with its own uniquely mystical properties, many types from the quartz family have the reputation for producing clarity of vision, whether freedom from the foggy spirits of alcohol or communion with benevolent spirits under the influence of the "second sight" stimulated by a faceted crystal or crystal ball.

The belief that quartz does, in fact, possess special magical qualities is virtually universal. For the Australian aboriginal medicine-man, quartz is a vital part of his repertoire of healing. The Apache Indians held crystal in the highest regard as "good medicine" and the aboriginal Tasmanians held that quartz crystals could be used to communicate with persons living or dead. Pieces of milky quartz were commonly placed on graves and in tombs all over the British Isles and Europe up to the 1800's. Mircea Eliade reports that liquefied quartz was sprinkled on aboriginal medicine men as part of their initiation rituals, and that this act enabled them to see the dead, to ascend into heaven, and to predict the future. Tribes in Burma revered quartz stones as living creatures and "fed" the stones by rubbing blood over them. Crystal gazing itself is a practice of great antiquity. Several large crystals of fine quality were found in the ruins of the Egyptian Temple of Hathor, estimated to be over 8,000 years old.

All of the claims made for the efficacy of quartz in healing, divination, etc., may seem too extraordinary to be considered rationally. It can be easily observed that a person wearing an amethyst is just as likely to become inebriated as one who has no such talisman on his person. The notion that amethyst could prevent drunkenness is based on what is called "sympathetic magic" – the idea that what looks like wine has corresponding powers over wine. The idea of "looks like, acts like" is the type of analogical thinking seen among children, easily dismissed by adult logic.

But not all magical thinking can be classified as a combination of symbolism and wish fulfillment. It is im-

[1]"Quartz," *Mineral Digest*, Cornelius S. Hurlbut, Jr.

portant to remember that magic in its original form consists of phenomenological observation and the development of a corresponding science. As a civilization degenerates, its sciences also degenerate into superstition. Timothy Leary has said that "Ritual is to the internal sciences what experiment is to the external sciences." Magic is a combination of experiment and ritual designed to implement coincidence control – enhancing the human ability to predict, to create, and to change.

With this in mind, we can look for possible physiological and psychological explanations for the persistent belief in the powers of quartz. The obvious explanation which comes to mind is the extraordinary ability of quartz to hold and transmit a charge. The structure of quartz is arranged in a helix or spiral, and an equal number of right-handed and left-handed specimens have been observed. As a result of low symmetry of the quartz crystal structure, rock crystal easily develops pyroelectric charges when passed quickly through fire. More remarkable is the fact that rock crystal is also piezoelectrical, meaning that it can develop a charge from pressure. Rock crystal is so sensitive that even a light pressure, as could easily be conveyed by the fingers, will create a piezoelectrical effect. In 1921, quartz was discovered to be invaluable for controlling and maintaining the wavelengths of a broadcast emission due to its piezoelectric properties. When properly mounted and vibrated at the correct frequency by means of electrical stimulation, the frequency of radio transmissions could be stabilized and "the crystal set," a new form of long distance communication, was born.

One is irresistibly reminded of the medicine man's claim that he (or she) could use quartz to communicate with people at great distances, including the dead. Could our ancestors have intuited qualities which have now been validated by scientific research? Quartz has also been used to improve the accuracy of watches and clocks. Unlike glass, it is transparent to ultraviolet rays, and is therefore utilized for lenses of especially sensitive photographic equipment. The crystal gazers of old were not alone in their use of quartz to develop a clear picture! While the spiral structure of quartz was not officially discovered until 1926, it is a curious fact that the spiral has been a universal symbol of life and rebirth from time immemorial. Coupled with the observation that the Celts, who constructed spiral barrows for their dead, also considered quartz an essential part of their burial ritual, makes for a very interesting coincidence.

It seems likely that the piezoelectric and vibratory capacities of quartz may have contributed to its acceptance as the supreme material aid to the art of scrying, which is the art of inducing prophetic or meaningful visions. An expert on the subject of crystal gazing, Sonor C.E.S., provides the following information on this ancient art: "Let it be noted here that nothing is actually seen in the crystal. The object used for scrying serves as a meeting point for the imaginative visualizing force of the mind and the eyes, thus creating a vision. Crystals give the clearest sharpest visions."

The importance of quartz to the ancients is underscored by the fact that they frequently transported enormous blocks of quartz or quartz-bearing granite to be used as standing stones at their ritual sites, ignoring other species of rock both plentiful and adjacent to the area. The recent hypothesis that Stonehenge and the other great henges of Great Britain were used as gigantic seasonal calendars raises an interesting question; could the quartz henge have served the same purpose as a monolithic Swiss watch?

This leaves us with the alleged healing powers of quartz. The most common method of healing with quartz or agate was to immerse the stone in water for a given period of time and then to have animals or humans drink the resulting liquid. This charm was thought to be proof against serpent bites, hydrophobia, and childhood diseases of all kinds. In their book, *The Secret Country*, Janet and Colin Bord speculate that stones from the quartz family were held to have special healing and divination powers because of their ability to "retain a charge, either of earth currents or human energy produced by a healer." They theorize:

"As a battery will hold a charge of electricity, so certain stones of a specific granitic crystalline structure could have the property of storing the subtle health-giving energies, perhaps for centuries. When these stones are brought into contact with the life-field of the human body, or with a liquid, they are able to charge it with some of the stored energy. Perhaps some of these small stones were originally in the possession of a saint or a pre-Christian healer whose life-field has left a lasting impression on the stone, from which beneficial radiation can still be obtained by those in need."

They continue to expound on the practice of dipping quartz amulets into water to distill a healing brew:

"Although this practice at first glance appears to be mere superstition, it could well be soundly based. If quartz and other minerals have vibratory potencies that can restore a natural harmony to tissues and cells that are diseased, then using pure well water as a medium for conveying the healing properties makes good sense. Similarly in modern medical practice a substance of natural origin is isolated, concentrated, and ingested by the patient as a liquid medicine or a pill taken with water."

Of course, it is also possible that the stones were simply used as tools to focus human concentration on the task at hand. Simple belief in the efficacy of a "magical" stone can produce a placebo effect, resulting in a "magical" cure. Modern Witches and Shamans will often employ a piece of faceted crystal as part of a healing ritual. They use the crystal to focus the powers of the healer, much as a magnifying glass may be used to focus and intensify the sun's rays to a point of great heat. Whether the end result is due in part to physical as well as psychological factors is uncertain. But before one dismisses such ritual healing as all "superstition," one should remember that it was the Witches of the middle ages who discovered that foxglove (which contains digitalis) was a potent remedy for heart disease, and that other herbal remedies are now being acknowledged by science to be useful in healing a wide variety of illnesses. It may be that the structure of crystal makes it uniquely suited for types of healing not yet accepted by the medical establishment.

Perhaps these thoughts amount to no more than educated fantasy; or perhaps they are the infant archaeology of an ancient science. As we break through the chauvinism of the Industrial Age, we are constantly becoming aware that our ancestors were not as ignorant as we once supposed them to be. Only a few years ago, herbalism was regarded as the province of quacks. Today herbal remedies may be seen on the shelves of every health food store. Is "gem therapy" really any more far fetched than cures derived from fungi and molds? One thing is certain; occult information now holds more glittering fascination for the popular imagination than it has for centuries. And all that glitters is not dross. This bit of magical philosophy contains a principal which applies to gem sales as well as to the occult: "Logic gets you what you need; Magic gets you what you want."[2]

[2]*Another Roadside Attraction,* Tom Robbins, New York, W.H. Allen, 1973.

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An Examination of the New Gilson "Coral"

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Bernardsville, N.J.

Abstract

A new "coral" has been produced by Pierre Gilson, well known for his synthetic emerald, opal and turquoise. A wide range of colors from an almost pure white to a deep oxblood red is available.

The major component is calcite, just as in natural coral, and the hardness, luster and general appearance are also an excellent equivalent of natural coral. There is, however, a low density with some porosity, extra phases are present as observed on X-ray diffraction and on thermal analysis. Also there is a significant silicon content. Accordingly it is felt that the material is not similar enough to be considered a synthetic coral and the designation "imitation coral" would seem to be more appropriate.

A. Introduction

The gem coral, used in jewelry, is the tree-like scaffolding upon which the less than 2-mm size coral polyps, *corallium nobile* or *corallium rubrum*, live on the ocean floor, as shown in *Fig. 1*. The "tree" is built up by the polyps from chemicals they extract from the sea water. Since the coral is built up over the life of the colony, it is laid down in layers of tiny fibrous crystals, and a tree-ring-like structure can usually be seen, with a grainy structure within the rings in cross-section and a striped pattern along the length of the branches. A good description of natural coral can be found in Webster's book[1].

The composition of natural coral is almost pure calcium carbonate in the calcite structure, usually containing a little magnesium, traces of iron, and a few per cent of organic matter. Both the iron as well as the organic matter are believed to contribute to the color which can range from an almost pure white through a pale pink "angel's skin," rose, salmon, red, and to a dark "oxblood" red. (There are also blue and black forms of coral which are not in the corallium grouping and are not composed of calcite but of a horn-like organic substance.)

Over the years many substances have been used to imitate coral. These have included a stained vegetable ivory and even wood, glass, plastic, wax, and a variety of finely powdered substances such as marble, bone or even coral pigmented to provide the desired color and compacted under pressure, often with an organic binder added. Some of these later compacts may be porous and coarse-grained in structure, and some do not take a satisfactory polish. Very few of these imitations have properties which would make them particularly likely to be mistaken for natural coral by anyone with even a little gemological knowledge.

There is one problem which has to be faced by the manufacturer who should wish to claim a real synthetic coral. Since the exact nature of the organic substances contributing to the color of natural coral remains unknown, it would obviously be most difficult to find an exact duplicate! And if the color of a man-made coral does not originate from the same causes as does the color of natural coral, then it would not pass all the criteria for a "synthetic" gem material, as they have been recently detailed by the author[2], however close a duplicate it might be in all other respects.

B. The New Gilson "Coral"

Mr. Pierre Gilson of Switzerland

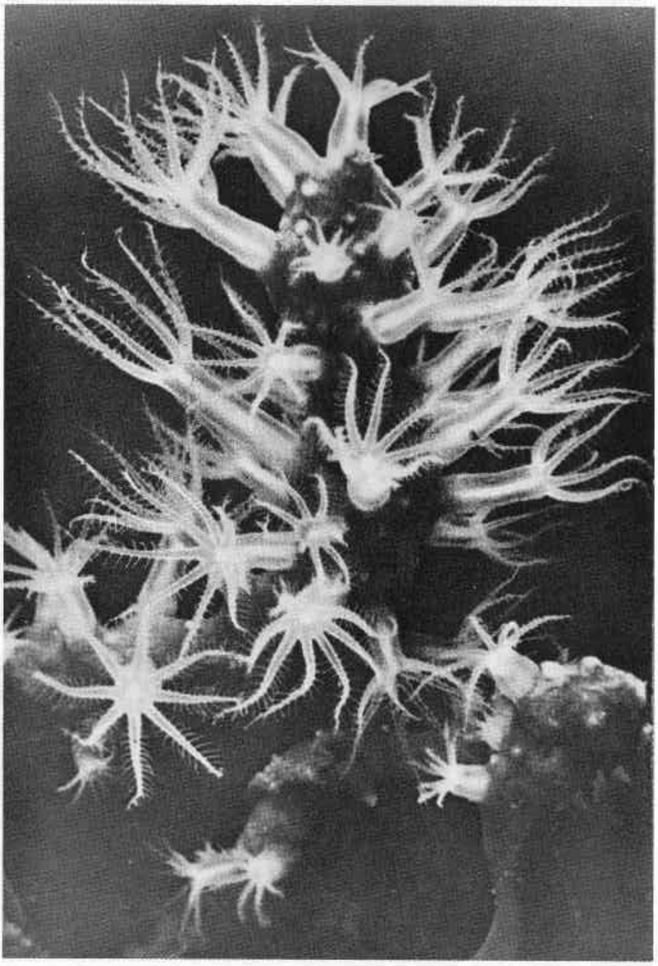

Figure 1. Polyps of corallium rubrum and the coral branches they are building (magnified) (courtesy of P. Gilson).

and France is well known for his superb synthetic emerald[3] and synthetic opal[2] as well as for his synthetic turquoise[4,2] and his recent lapis lazuli[2]. Most recently he has also announced "GILSON created CORAL."

According to Mr. Gilson, this "coral" is made from a natural calcite from a new mine in France, plus added pigment, by a process employing high pressure and some temperature. The specific gravity is stated to be 2.60 to 2.70 and the refractive indexes 1.468 to 1.658.

Material is manufactured in pieces weighing up to 700 grams (over 1 lb.) and is said to be available in the trade in rough pieces as well as in round (6 to 16 mm) and oval (6x8 to 16x20 mm) cabochons and drilled beads (5 to 16 mm). A wide range of colors with three shades of "angel skin," one of "salmon," two of "bright rose," one of "red," and two shades of "oxblood" are available at a cost said to be "about seven times cheaper than natural coral of the same quality and beauty."

C. Examination of the Gilson "Coral"

Four 14-mm cubes and one oval cab of various colors were studied. These are shown in *Fig. 2* together with a natural coral cameo and two natural coral necklaces. As can be seen from this photograph. the colors and general appearance are an excellent match for natural coral; other colors

Figure 2. Four 14-mm cubes and one 10x14-mm cabochon of the Gilson "coral" with a natural coral cameo and two natural coral necklaces.

were also seen but not studied.

Major examination was confined to the lightest and darkest cubes of *Fig. 2* and color-matched pieces of almost white and red-brown natural coral. Visually the appearances matched very well, including the high polish, luster, and a slight translucence. (An even more translucent form is said to be on the way.) The growth features described in the introduction are visible in the natural material even in *Fig. 2*, but the Gilson product appears quite uniform. Under 100x magnification a fine grain structure is visible with milky grains less than 1/100 mm in size with much smaller pigment grains distributed among them. The appearance could be likened to a brecciated or terrazo-like structure.

The hardness at 3½ matched the natural coral perfectly, with both materials just scratching each other. The resistance to breaking and powdering (toughness), however, was significantly less than that of the natural coral. The effervescence produced by dilute hydrochloric acid closely matched that of natural coral, but the color of the wipe from this test as well as the color of the streak depended on the color of the material, while natural coral is colorless or white in both instances. The fluorescence was variable, ranging from inert via a mottled orange to a quite strong purplish red.

The specific gravity of the darkest cube was measured by Archimedes' technique at room temperature. It was found to be 2.438, significantly less than the 2.60 to 2.70 listed by Gilson. A slow gain in weight was noted, and after 24 hours the specific gravity had risen to 2.504. At this point a slightly mottled appearance was noted. The weight gain was 2.94%, and the volume porosity was calculated at 6.98%, although the actual porosity may be somewhat higher since the water was not necessarily able to penetrate into all voids. After some days in the room atmosphere, essentially all the absorbed water was again lost but some of the mottled appearance remained.

A refractive index text by Mr. Crowningshield of the Gemological Institute of New York City proved difficult because some of the fluid seemed to be absorbed. A reading of about 1.55 showed only weak double refraction as distinct from natural coral, where the 1.49 and 1.65 of calcite can usually be seen. The gemological test data is summarized in *Table 1.*

A semi-quantitative emission spectrochemical analysis, given in *Table 2*, indicates the presence of one to several percent silicon in the Gilson product; it is likely that this is in the form of one of the calcium silicates. Interestingly enough there was no iron detected in the natural coral at the 0.001% level, indicating that essentially all of its color derives from organic pigment. The 0.01% to 0.1% iron present in the Gilson product could account for its color, which under the microscope can be seen to be concentrated in small deeply colored grains.

X-ray powder diffraction spectra were taken on a Rigaku Mini-flex Diffractometer using filtered copper

TABLE 1: Gemological Constants
Comparison of Natural Coral and Gilson "Coral"

	Natural Coral	Gilson "Coral"
Hardness	3½	3½
Specific Gravity	2.6 to 2.7	2.44*
Refractive Index	1.49 and 1.65	1.55
Acid Reaction	effervesces	effervesces #
Streak	white	variable
Structure	wood-grain	brecciated
Fluorescence	dull purple-red	variable*

*See text for details.

#Color may show in the wipe from the acid reaction.

radiation. The two natural corals gave patterns identical with each other and with the data for the pure calcite X-ray diffraction standard on JCPDS 24-27[4]; one of these natural coral patterns is shown at the bottom of *Fig. 3* and the numbers give the *d*-spacings in Angstrom units and the relative intensity in parentheses from JCPDS 24-27. Both Gilson "coral" specimens tested gave the pattern shown at the top in *Fig. 3*. It is clear that an extra phase is present from the occurrence of the extra lines marked x (possibly a calcium silicate), but no effort was made to identify this extra phase.

Professor A.P. VanHook of the College of the Holy Cross, Worcester, Mass., has performed a solution experiment using a 10% solution of ethylene diamine tetra-acetic acid (EDTA) in water adjusted to a pH = 10 with a caustic soda solution, at room temperature as well as at 70°C. This is a solution which dissolves calcite very slowly and gently. The red Gilson material was barely attacked (even

TABLE 2: Spectrochemical Analysis of some Corals*

Level Present	Gilson almost white	Gilson red-brown	Natural Coral red-brown
10% +	Ca	Ca	Ca
1% to 10%	Si, Mg	Si, Mg	Mg, Sr
0.1% to 1%	Sr	Ba, Sr	—
0.01% to 0.1%	Fe, Al, Ba, Na	Fe, Al, Cd, Na	Na
0.001% to 0.01%	—	—	Ba

*All other detectable elements less than 0.001%.

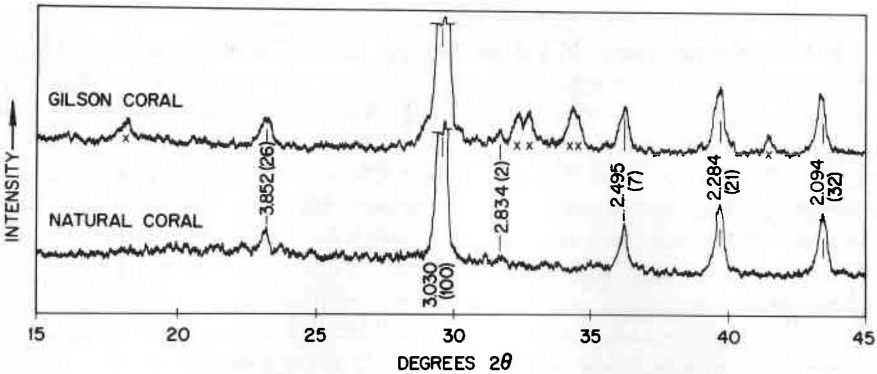

Figure 3. Powder X-ray diffraction data of natural coral and Gilson "coral."

after two weeks at 70°C), but the red natural coral was dissolved at room temperature, with its diaphanous skeletal structure being thereby revealed as seen in *Fig. 4.*

The behavior on heating as revealed in the differential thermal analysis curves of *Fig. 5* showed significant differences. These were taken on a Dupont 990 Thermal Analyser in flowing nitrogen at a heating rate of 20°C per minute. The natural coral showed the decomposition endotherm of calcite near 900°C at A, while the Gilson product showed this plus an additional endotherm near 475°C at B, presumably belonging to the extra phase showing the X lines in *Figure 3.* This could be either a decomposition or a phase change, but this was not further investigated.

In view of these results, it was felt that further technical examination, e.g. by the scanning electron microscope or by thermal decomposition (to determine if organic material either as a binder or as a coloring agent was present) were not necessary.

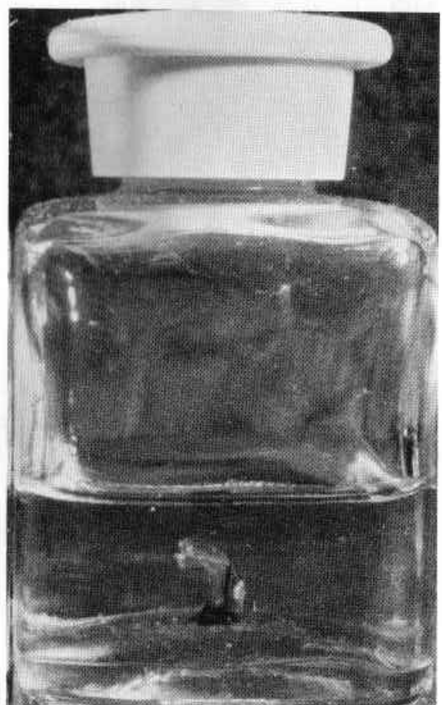

Figure 4. Skeletal structure of natural coral revealed after three weeks in a 10% EDTA solution.

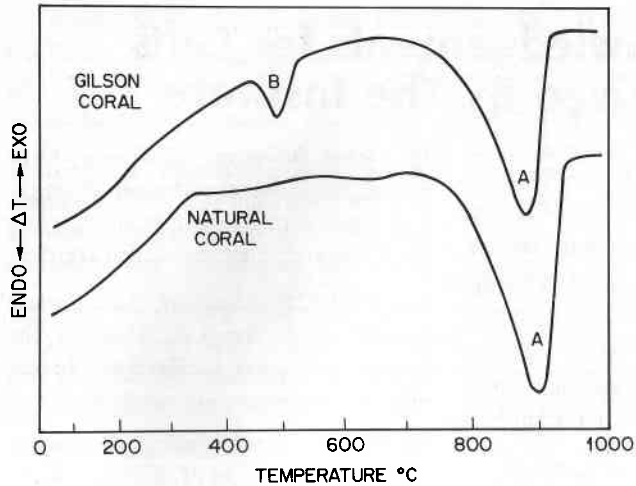

Figure 5. Differential Thermal Analysis curves of natural coral and Gilson "coral."

D. Conclusion

The Gilson "coral" product presents a very excellent coral-like appearance to the eye, differing most obviously from natural coral in the absence of the natural growth features (rings and stripes with a grainy substructure).

It is clear from the many differences, including specific gravity, porosity, chemical analysis, X-ray diffraction, differential thermal analysis, etc., that the composition of Gilson "coral" differs in a significant manner from the composition of natural coral. Accordingly, the author believes that it should not be designated "synthetic coral," "man-made coral," or "created coral," but would more correctly be designated "imitation coral."

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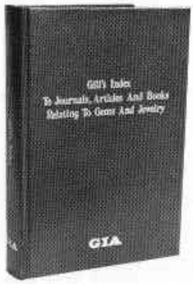

GIA Publishes An Essential Gem Book

GILL'S INDEX TO JOURNALS, ARTICLES, AND BOOKS RELATING TO GEMS AND JEWELRY, by Joseph O. Gill, B.Sc., G.G., F.G.A.; 420 pages; 6x8½' Gemological Institute of America; $24.50; First Edition, 1979.

Have you ever needed additional information on color treated diamonds or a certain synthetic or natural gem material and not known where to look? A source of sources is now available to aid all interested in the science of gemology.

The Gemological Institute of America has just published the long awaited *Gill's Index to Journals, Articles and Books Relating to Gems and Jewelry.* It is a total subject index to the literature of gems and jewelry.

This 420-page book provides a cumulative index for quick reference to the world's eighteen leading journals and books on gemology, mineralogy, jewelry and lapidary. The easy-to-read format is an all inclusive index, with each entry annotated for quick evaluation of content. The amateur to the professional will find it an invaluable source for gem information from actinolite to zoisite and Afghanistan to Zambia. Each subject of this index has been broken down by individual journal, thus eliminating time wasting hours researching a particular subject of interest. Considering most people have only one or two journal sets to work from, the range of uses are innumerable for a book of this format.

This book will be used by the worldwide gemological associations, students of gemology, jewelers, mineralogists, lapidaries, museums, libraries, writers and anyone planning gemological field trips throughout the world.

Gill's Index will be updated every few years so valuable and pertinent information will be available right at your finger tips for use in your business or hobby.

The author, Mr. Joseph O. Gill, B.Sc., G.G., F.G.A., Gemologist for J. & S.S. De Young of Boston, Massachusetts, is an authority on gem and jewelry literature in the English language. His articles have been published in *Gems & Gemology, Jeweler's Circular Keystone* and *Lapidary Journal.*

The GIA is proud to announce the publication of *Gill's Index* as part of our continuing effort to keep the jewelry and gem industry informed. All inquiries about *Gill's Index* should be sent to the GIA Bookstore at 1735 Stewart Street, Santa Monica, California 90404.

Book Reviews

FABERGÉ: IMPERIAL EGGS AND OTHER FANTASIES, by Hermione Waterfield and Christopher Forbes. Published by Thames and Hudson, London, Great Britain, 1978. 123 color plates, 143 pages. Hard Cover. $19.95.

Few of us will ever be allowed to hold a Fabergé creation. However, the color photographs in this collection almost make this dream a reality. After seeing many of these "fantasies" on exhibition, I can testify that the photographic reproduction is of unusually high quality. Even the minute guilloche patterns are clearly visible through the enamel. Each objet d'art is lovingly described, with previous owners and exhibitions also listed. An unusual appendix shows details such as the hidden pencil on the nephrite desk pad (number 108). Miniature portraits and scenes from several eggs are also reproduced. The appendices also include biographies of the workmen, and a year-by-year list of the Easter Eggs. Through the photographs of this collection, we can all appreciate the creativity and genius of Peter Carl Fabergé.

By Betsy Barker

GEMMOLOGICAL INSTRUMENTS by Peter G. Read. Published by Newnes-Butterworth, London 1978, 227 pages plus 7 unnumbered pages of advertisements. Hard bound with numerous drawings and black and white photographs.

The author has brought together descriptions, and in most cases photographs, of the various gem testing instruments produced by the leading manufacturers of the world. The features of each instrument are presented impartially without making any comment about the advantage or disadvantages of one instrument versus another manufacturer's version of the same type of instrument.

The table of contents is very good, as is the index at the back. Chapter one has a good introduction to the basic procedures of gem testing along with simple definitions of the terms used in gemology. The printing, although slightly small in size, is still easily readable. The quality of the reproductions of photos and drawings is excellent.

There are a few inconsistencies in the text. For example, on page 39 the R.I. of Methylene iodide is correctly listed as 1.74, yet on page 154 it is listed incorrectly as 1.66. It is also incorrectly stated on pages 37 and 38 that if the eyepiece is changed from 10X to 20X, the working distance changes from 40 mm. to 20 mm. Changing the eyepiece power has no effect at all on the working distance. It only changes the size of the field of view and the overall magnification.

Table 12.1 on page 173 does not

correctly show the relationship between GIA and AGS color grades. For example, the high end of AGS color grade 1 could be called an E on the GIA system. The lowest end of AGS color grade 1 could be a GIA color grade of F, not G as shown on the chart. Furthermore, GIA master stones do not correspond to the center of each color grade as stated on page 173.

Although there are a few other minor discrepancies in the gemological data presented, the objective of the book is well fulfilled in that it does give adequate coverage to the various instruments available for Gem Testing. It should be a useful book to anyone looking for information about the instrumentation necessary for a gem testing laboratory.

By Chuck Fryer

CATALOGUE OF THE ENGRAVED GEMS AND FINGER RINGS, Volume I, Greek and Etruscan, by John Boardman and Marie-Louise Vollenweider. Published by the Oxford University Press, Oxford, England, 1978. 122 pages of text plus 64 pages of photographs. Hardbound, $65.00

Engraved gems provide an unusual historical record that can be appreciated by anyone. For the serious student of ancient gems, this study provides a detailed chronology of gem use. Each piece is discussed completely, from the type of carving material to the dating of the artistic style. Although only the Greek and Etruscan periods are covered in this volume, later works in the series will cover gems of the Roman and Minoan civilizations. While this text provides a detailed study of these individual artifacts, John Boardman's previous work, *"Engraved Gems – The Ionides Collection,"* supplies background information. Marie-Louise Vollenweider's expertise is clearly demonstrated in the section on Hellenistic gems. She also includes a complete table of ancient gem names and sources for carving material. Among the gems used were agate, ruby, opal, emerald, and garnet, gems that are still familiar today.

Although this book is primarily intended for the serious student of glyptics (gemstone engraving), anyone with an interest in the history of gems will find this study illuminating. The wealth of photographs illustrates clearly that gems were as highly prized centuries ago as they are today.

By Betsy Barker