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Gems & Gemology

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IN THIS ISSUE

Part 1

The Origins of Color In Gems and Minerals

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Abstract

Twelve distinct causes of color in gems and minerals are described together with brief outlines of the four theories involved, namely crystal field theory, molecular orbital theory, band theory, and physical optics theory. The organization is as follows:

PART I

A. Introduction

The most prominent characteristic of the majority of gems and minerals, the aspect most striking to the eye, is their color. Surprisingly enough, the cause of the color in many of these materials is frequently either not known or only poorly understood. The conventional wisdom which tries to attribute blue-green colors to copper, deep blue to cobalt, red to chromium, and so on, often misleads. For example, chromium compounds can be red, orange, yellow, green or even lilac! Again, for a deep blue color the cause may be cobalt (as in spinel), iron plus titanium (as in sapphire), or a color center without any transition metal impurity (as in Maxixe-type beryl). A detailed study using a variety of tools such as spectroscopy, chemical analysis, irradiation, and even crystal synthesis may be required to solve the problem. In some instances, such as smoky quartz, the exact details have not yet been fully established even after more than 20 years' work by many investigators.

In mineralogy, color is often classified as belonging to one of three types: idiochromatic ("self-colored") originating from a major ingredient, e.g., copper in malachite, which is $Cu_2(OH)_2CO_3$; allochromatic ("other-colored") originating from an impurity, e.g., chromium in ruby which is Al_2O_3 + Cr; and pseudochromatic ("false-colored") originating from physicial causes such as the diffraction grating effect in opal, which is $SiO_2 \bullet xH_2O$. While useful in itself, such a classification is much too superficial to give any helpful insight into the causes of color. In Section E below, no less than twelve distinct types of color-causing mechanisms will be described, and there may well be others! Yet this apparent complexity should not be discouraging, since these mechanisms have much in common and need not be studied in full detail to obtain a significant understanding of the general principles.

There are in fact only four distinct theories which cover the whole range of colors in gems and minerals:

i) *Crystal field theory* which covers both idiochromatic and allochromatic color caused by transition metal ions as well as color centers; examples are rhodochrosite, emerald, and amethyst;

ii) *Molecular orbital theory* which explains charge transfer colors such as blue sapphire, magnetite and pyrite, the color of organic dyes (organic coloration occurs in amber, coral, etc.) and of graphite;

iii) *Band theory* which explains the color of metals (gold, copper), semiconductors (galena, proustite) and doped semiconductors (blue diamond);

iv) *Physical optics theory* which explains the color in pseudochromatic materials such as labradorite and moonstone.

In all but the last group it is the behavior of unpaired electrons interacting with light as controlled by quantum theory restraints which is the key to the understanding of color. Before the four theories are taken up in turn, it will be necessary to examine a few fundamental concepts: light, energy levels of unpaired electrons, and quantum transitions.

Following this, the color and fluorescence of ruby and emerald will be explained in detail as examples of crystal field theory. With this background the majority of colors in gems and minerals as caused by transition metals and color centers will be explained in Part 2 of this series. Next comes a discussion of the important charge transfer colors and brief consideration of organic coloration. In the last section of Part 2 the results of treatments used to change the color of gemstones follow simply from the previously discussed concepts.

In Part 3 band theory is discussed as it applies to the color of metals such as copper, semiconductors such as greenockite and proustite, and doped semiconductors such as blue diamond. Finally, a brief dip into physical optics will serve to explain the color of materials such as opal and moonstone.

The approach here is tutorial, and general references only are given at the end of each section. The specific examples given are those where the assignment of the exact cause of color is reasonably well established. In the majority of the many known mineral substances, the specific causes of color are in fact not known (and the author cannot answer inquiries).

B. Light, Energy, and Quantum Considerations

The visually observed color of light depends on the wavelength, e.g. 6000 Angstroms (0.6 micron) corresponds to yellow. We can also assign an energy to each wavelength in spectrally pure colors, as is done in *Figure 1*, in terms of "electron volts" (abbreviated eV; yellow is about 2.15 eV).

A well-known analogy shows that energy increases in going through the spectrum from red to blue: when an object is heated it becomes first "red-hot," then orange, yellow and, if hot enough as in the very hot stars, it becomes "blue-hot." At even higher energies the ultraviolet region is reached as shown in *Figure 1*.

In everyday experience we think of energy as being continuous; for example, when we accelerate an automobile there is a smooth increase of velocity (energy) and we do not notice any "energy gaps." When we look at very small particles, such as the electrons which are involved in color-causing ions, it is found that the quantum theory permits only certain "energy levels." The electron can be "excited" from one energy level to a higher energy level by absorbing energy, or it can relax from a higher to a lower energy level by emitting light or heat energy. It cannot, however, exist at intermediate energy levels as shown in *Figure 2*, where the energy of a ball increases or decreases as it is raised up or falls down the steps shown; in the earth's gravitational field this corresponds to an increase or decrease in energy. In a quantized situation it cannot ever exist half-way between two steps.

The exact position of the energy levels depends on the environment: specifically what atom, ion, or group of atoms the electron is located on; what other atoms or ions surround it or are connected to it, at what distances, and in what geometrical arrangement. In addition to the limitation on possible energy levels, quantum theory also controls the probability of occurrence of the various possible changes between energy levels which can exist and thus explains the intensity with which these changes occur (the "selection rules").

The result of such a quantum treatment is a specification of various possible transitions between energy levels. When such a transition is produced by

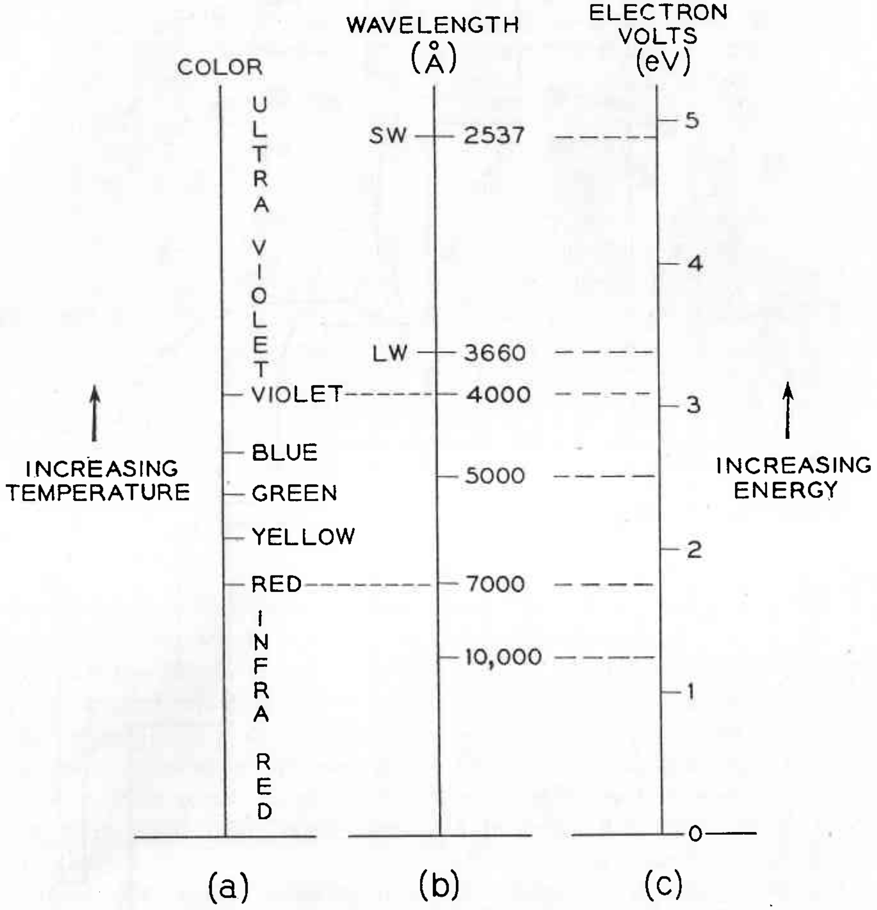

Figure 1. The colors, wavelengths in Angstroms, and energy in electron volts (eV) of spectrally pure light.

light passing through a material, this results in absorption of that part of the light having the energy needed to produce the transition. The light not absorbed passes through the crystal, giving it color. The visually perceived color of the crystal is complementary to the colors absorbed; for example, emerald absorbs red and violet and therefore transmits green.

For further reading on the subjects of this section, including crystal field theory, see: recent inorganic texts, such as "Advanced Inorganic Chemistry" by F. A. Cotton and G. Wilkinson, Interscience (3rd Ed. 1972). Intermediate treatments are found in "Geochemistry of Solids" by W. S.

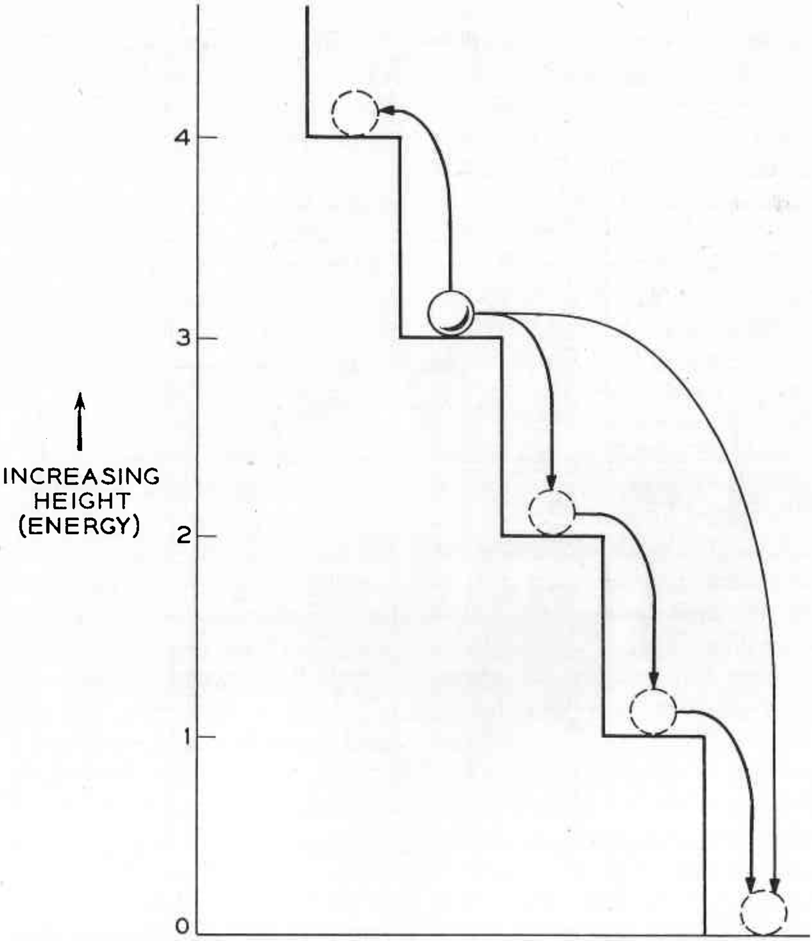

Figure 2. A ball on a set of steps, illustrating a set of "quantized" energy levels.

Fyfe, McGraw Hill, 1964, and "Modern Mineralogy" by K. Frye, Prentice Hall, 1974. Unfortunately I do not know of any good introductory treatments of these subjects.

C. The Color and Fluorescence of Ruby and Emerald

Ruby consists of corundum (single crystal Al_2O_3) which contains a small amount of chromium oxide (Cr_2O_3), typically less than 1% to give a deep red color. The trivalent chromium ions replace trivalent aluminum ions in the corundum structure.

In chromium metal each atom has 24 electrons, six of which are not paired off. In a trivalent chromium compound three of these six are used in forming chemical bonds, and the

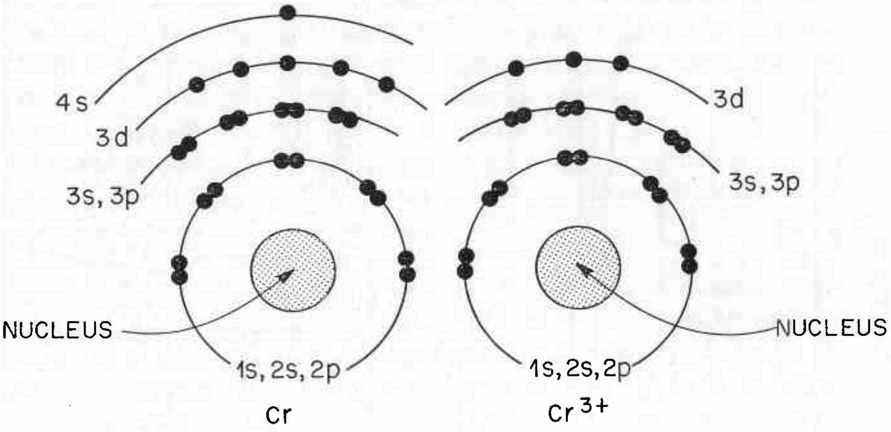

Figure 3. Arrangement of the 24 electrons (schematic) on a chromium atom (Cr) and the 21 electrons on a chromium ion (Cr^{3+} as in ruby, emerald, or alexandrite); each electron is a unit negative charge.

other three remain unpaired and cause the color, as shown in *Figure 3.* In ruby each chromium ion is surrounded by six oxygen ions in a distorted octahedral arrangement at distances and in a geometry dictated by the corundum structure. This results in an electric field, the crystal field, at the chromium ion.

Whenever possible, electrons pair off (spin pairing) and such paired electrons do not absorb light in the visible region of the optical spectrum and therefore do not cause color. The three electrons in the chromium ion are unpaired and in the crystal field environment of ruby the result is the energy level scheme shown in *Figure 4a* in a simplified schematic form. This scheme shows that, depending on the energy available, the state of the electrons on one of the chromium ions in ruby can be in energy levels A, B, C, or D as shown in *Figure 4a.* There are also higher levels, not relevant to the present discussion.

When not excited, the state will be the lowest or "ground state" A. Transition from A to B is forbidden by the selection rules mentioned above, but C or D can be reached from A. Since the A to C and A to D transitions correspond to the energy of green and violet light, respectively, these two colors are absorbed from white light when it passes through ruby. The remaining light is mostly red – one of the two causes of the color of ruby.

After absorbing violet or green light the system will now be in states C or D as shown in *Figure 4b.* Since the selection rules favor the transitions from C to B and D to B over C to A and D to A, the former will dominate as shown in *Figure 4c*. Relaxation from level B to the ground state A now occurs with the emission of red light as in *Figure 4d.* This is a red fluo-

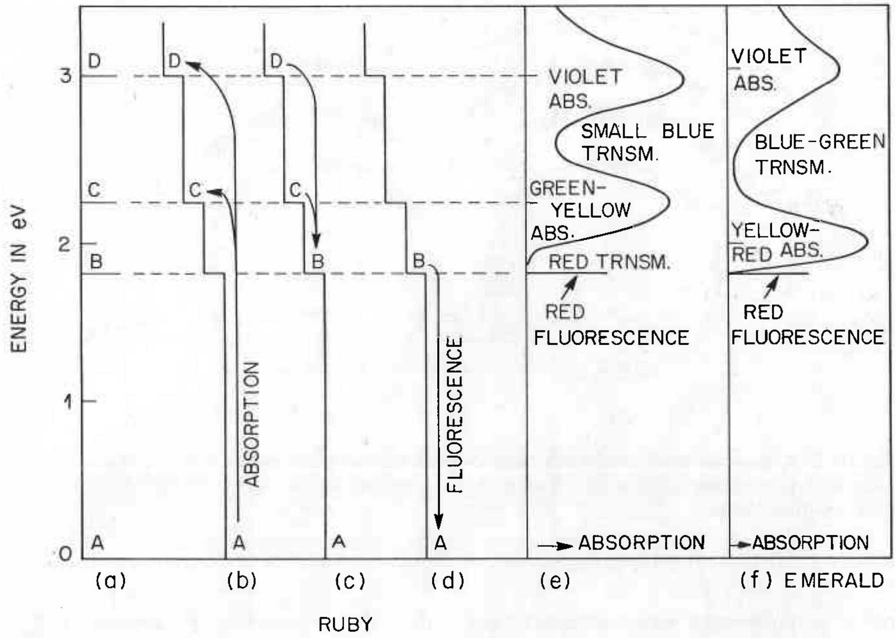

Figure 4. Energy levels, transitions, and color absorptions in ruby (a) to (e) and in emerald (f); (e) and (f) show the absorption bands, transmission regions, and fluorescence levels.

rescence, and occurs when ruby is illuminated with green light, or violet light, or ultraviolet, etc. It is this red daylight-caused fluorescence, added to the inherent absorption-caused red color, which gives ruby its exceptionally beautiful glowing color.

The way this energy level scheme results in the absorption spectrum is shown in *Figure 4e.* Here it can be seen how the broad peaks corresponding to levels C and D (technically the quartet T_2 and quartet T_1, respectively) result in the absorption of the violet and green-yellow regions of the visible spectrum. However, all of the red and some blue pass through the ruby, giving it the red color with purple tint; there is also some red fluorescence from the B level (the doublet E).

Emerald is $Be_3Al_2Si_6O_{18}$ containing a small amount of Cr_2O_3 (just as in ruby) again substituting for Al_2O_3. Here also the symmetry is the same as in ruby (D_3), but the crystal field is somewhat weaker (1630 cm^{-1} instead of 1800 cm^{-1}). This produces a small lowering of the C level (from 2.25 eV to 2.0 eV). The resulting change is dramatic: essentially all of the red light is now absorbed, but almost all of the blue-green is transmitted as shown in *Figure 4f;* the result is the beautiful color of emerald.

These energy level schemes have

been discussed by D. L. Wood, "Spectra of Ions in Crystals," in "Optical Properties of Solids," Plenum Press, 1969, p. 571.

D. Pleochroism

Since the environment around the coloring ion, the crystal field, is not necessarily spherically symmetrical, neither is the color, thus producing pleochroism. In the case of ruby the symmetry of the environment produces dichroism, the color being violet-red (ordinary ray) and orange-red (extra-ordinary ray). In alexandrite the color is also caused by chromium. Here the crystal field is even less symmetrical than in ruby and the result is trichroism (yellow, purple-red, and blue-green). Visually the color depends on the illumination, being bluish green in daylight and purplish red in incandescent light.

E. Specific Causes of Color

In *Table 1* are listed twelve causes of color in gems and minerals. These fall into four general approaches or theories which will be discussed in Parts 2 and 3 of this series with examples of each type. It should be noted that in most minerals the specific causes of color are not known; in many cases a plausible cause can be suggested, but detailed, painstaking work is needed for each individual color in each material to confirm the details.

Many gems and minerals occur in a wide variety of colors. It is always necessary to establish the color of the pure substance – this is frequently the lightest color ever observed. The streak (color of the powdered substances) can be a good guide. As examples, quartz and sphalerite occur in many colors, but the pure material is perfectly colorless in both minerals. On the other hand, peridot is pale green and greenockite is yellow even when perfectly pure, although impurities can produce a variety of darker shades in both materials. So both the intrinsic color as well as the impurity-caused colors need to be explained separately.

Part 2 will appear in the next issue.

TABLE 1

Twelve Types of Color in Gems and Minerals

Typical Materials	Color Cause	Theory
1. Malachite, almandite	Transition metal compounds	Crystal Field Theory
2. Emerald, citrine, jade	Transition metal impurities	
3. Amethyst, Maxixe-beryl	Color centers	
4. Blue sapphire, pyrite	Charge transfer	Molecular Orbital Theory
5. Amber, coral, bitumen	Organic coloration	
6. Copper, silver, iron	Good conductors	Band Theory
7. Galena, proustite	Semiconductors	
8. Blue and yellow diamond	Doped semiconductors	
9. "Fire" in diamond, rutile	Dispersion	Physical Optics Theory
10. Moonstone, stars and eyes	Scattering	
11. Iridescent chalcopyrite	Interference	
12. Opal, iris agate	Diffraction	

Developments and Highlights at GIA's Lab in New York

By ROBERT CROWNINGSHIELD

Opal, Opal

Some months ago Mr. John Slocum of Rochester, Michigan, made a special trip to New York to show us an amazing selection of imitation opals which he had manufactured. (Many years ago he experimented with making actual synthetic opal with very limited success.) Numerous specimens looked convincing, and there were lookalikes of most opal types. Some, however, were very fanciful with metallic orange, bronze, and yellow flashes. At that time he stated that although some were set into rings and other jewelry, he had never sold any and had not yet decided to market the material. When asked what name he would suggest be used if he ever decided to commercialize, he said, "Fake opal!" At the time of his visit we were unable to secure the properties of his product but assumed that it is a type of glass with colored reflecting platelets to give the imitation play of color. By coincidence, we received a visit from Mr. Michael Costello, opal dealer of Sydney, Australia, the day Mr. Slocum was here so that he was really able to see what black opals should look like.

A few weeks ago, Mr. Slocum called to say his home had been burglarized and the entire collection of stones stolen. With the exception of a few rejects, he had nothing left. The burglar might be able to palm off the stones because to the uninitiated and to those unfamiliar with Gilson's synthetic opal, his product resembles opal better than any imitation seen to date. Consequently, he volunteered to send a selection of the remaining stones to us for study and to publish information in order to warn the trade. At this writing, however, the mystery may be about to be solved. A Midwestern jeweler was offered some suspicious "opals" and called opal enthusiast Dr. William E. Kelley, who in turn called us in New York. Meanwhile we have had a chance to secure the properties and some photos – although not of the more striking examples. *Figure 1* shows the range of types. The long oval at lower left resembles some clear Brazilian opal we have seen. The stone next to it appears to be a fine black opal. *Figure 2* gives a vague idea of the color patches, while *Figure 3* shows the finely divided reflective metallic (?) inclusions under magnification. We

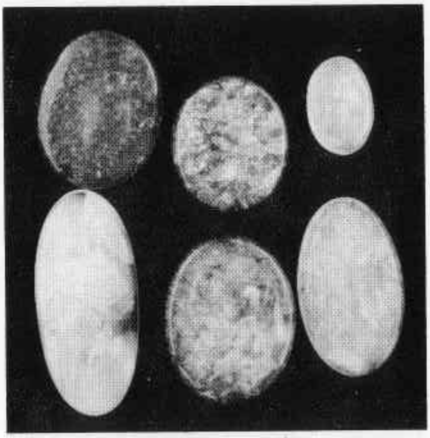

Figure 1.

Figure 2.

found the specific gravity to vary from approximately 2.41 for the white stones to approximately 2.50 for the stones resembling Australian blacks. The refractive index varied slightly from 1.50 to 1.52. Mohs hardness tested to be about 5.

By coincidence while studying Mr. Slocum's "opals" we received a welcome visit from Mr. Pierre Gilson, who gave us a fine example of his latest black synthetic opals. It was amazing how much one of Mr. Slocum's imitations resembled the stone. *Figure 4* was an attempt to show this. Under magnification this latest Gilson product exemplifies yet another appearance unlike any illustrated to date. The unusual "can of worms" appearance when a strong pinpoint light is passed through the stone is gone (page 343 of the Fall 1974 issue of *Gems & Gemology*). Instead, very little light passed, and the color was mainly green with the exception of one bright red patch. When admired from above, this red patch was a clear blue in most positions. *Figure 5* indicates a honeycomb or "chicken wire" structure which seemed present throughout the stone, though in certain areas the hexagons were highly distorted.

Figure 3.

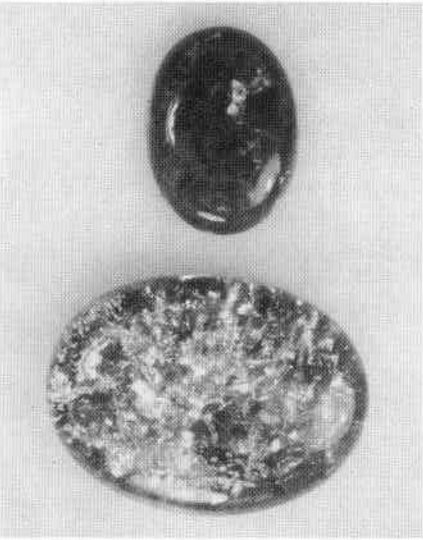

Figure 4.

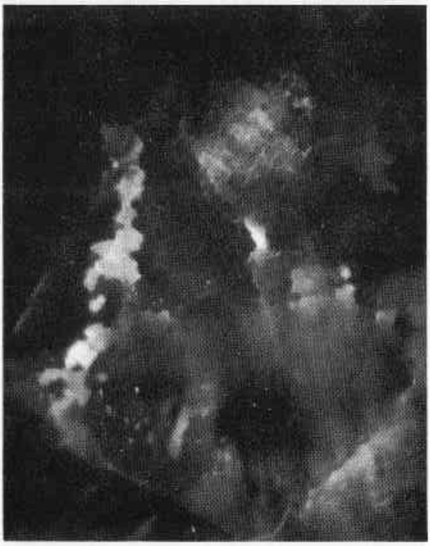

Figure 5.

More About Opal

We have illustrated in recent issues a type of imitation opal consisting of white opal top with irregular back painted black and jointed with a thick layer of cement to natural ironstone matrix. The cement seems to be an epoxy with ground-up ironstone particles. In *Figure 6* gas bubbles can be seen in the slightly darker cement layer. In a full bezel setting, this type of assembled stone (a quadruplet?) could be mistaken for a Queensland boulder opal. A similar assemblage is pictured in *Figures 7* and *8,* although here we have a carved white opal painted black on back and a mixture of dark particles and ground-up opal as a backing. *Figure 9* shows the backing. In this brooch no attempt was made to hide the joining plane (*Figure 10),* although the piece had worried a prospective purchaser enough to have it tested.

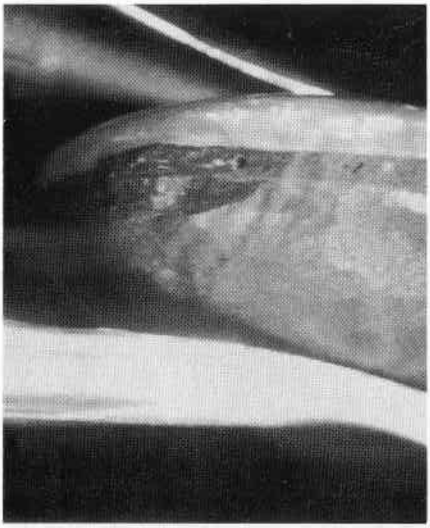

Figure 6.

Acknowledgements

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

To the firm of *Fortunoff's,* West-

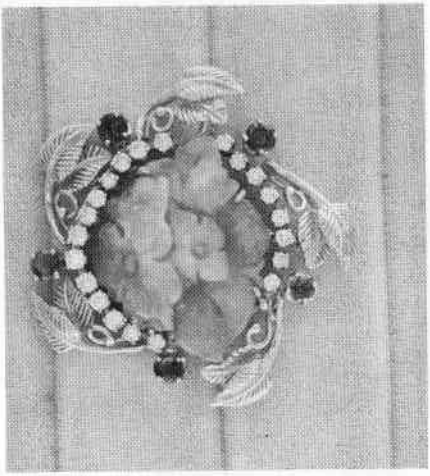

Figure 7.

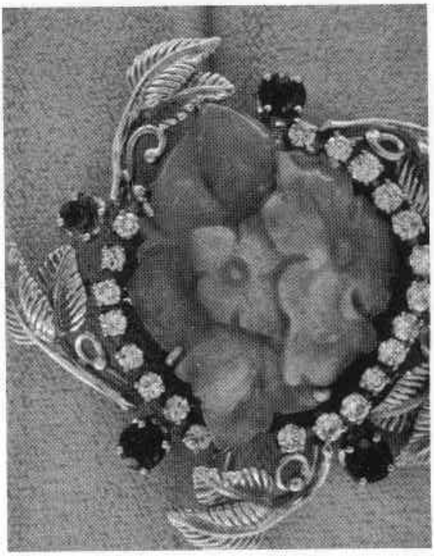

Figure 8.

bury, Long Island, for a wide selection of many types of natural and synthetic stones for use in gem identification classes.

To *Mr. Peter Blank,* Henry Blank and Co., Newark, New Jersey, for a nice group of early synthetic rubies of the type that at one time were mistakenly thought to be "reconstructed."

To GIA Graduate *Leon Trecker* of Laguna Hills, Calif., and host for a week to this columnist, for specimens of hydro-grossular and idocrase which were thought to be jadeite, a nice intarsia from Afghanistan in which the artist used native stones on a black

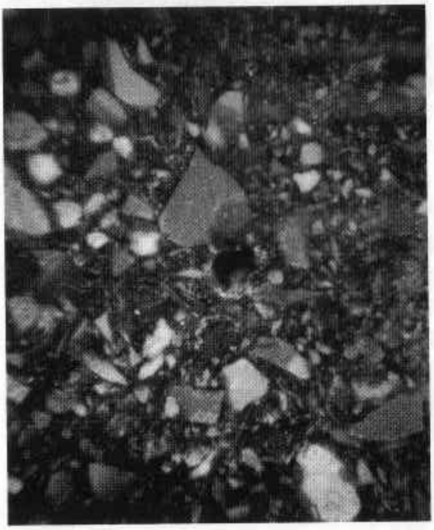

Figure 9.

Figure 10.

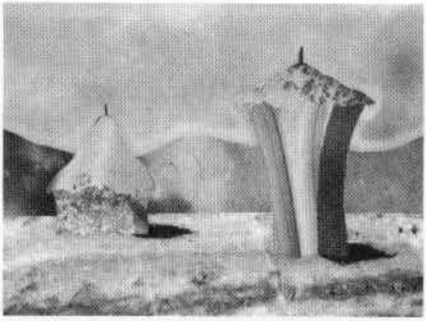

Figure 11.

slate back *(Figure 11)*, and a most unusual slab of chert which shows definite slippage after formation *(Figure 12)* resembling crustal movement associated with faults in earthquake zones.

To Mr. *Bill Larsen* of Pala Properties International, Fallbrook, California, who was most gracious in receiving the writer at his shop and lovely home and for a selection of rough minerals the sources of which read like a world atlas – baryte from South Dakota, bustamite and rhodonite from Australia, blue zoisite and alexandrite from Tanzania, etc., etc. We are most appreciative and look forward to having time to record the absorption spectra of some of these we have not studied before.

To *Mr. Marvin Bankoff* of M. Landis Co. of New York, Inc., for a very well-made round brilliant of gadolinium gallium garnet (GGG). It will shortly be set in a ring for the writer to test its wearability. Mr. Bankoff states that his associates in the manufacturing of this high specific gravity diamond imitation (7.05 S.G.) have succeeded in eliminating an unfortunate tendency to turn brownish upon exposure to ultraviolet, including daylight. It is our feeling that this material comes closest to resembling a diamond together with acceptable hardness of any diamond simulant yet announced. Hardness stated to be 6½.

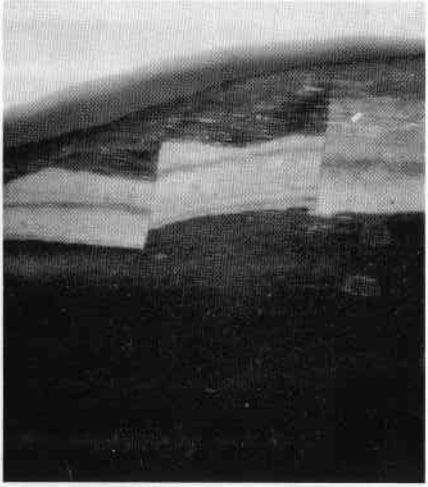

Figure 12.

To *Mr. "Mack" McMacken* of Craftstones, Ramona, California, for receiving the writer on an unexpected visit to Ramona and giving specimens of nephrite rough in which the outer "bark" appears to be chatoyant actinolite (?) gradually grading into the central tough nephrite. "Mack" mentioned that currently the most popular tumbled stone of the many manufactured by this, the largest firm specializing in tumbled materials, is dyed howlite imitating turquoise. The writer hereby retracts his statement on page 330 of the Fall 1974 issue of *Gems & Gemology* in which it is implied that turquoise-colored howlite is not a successful material.

Developments and Highlights at GIA's Lab in Los Angeles

By RICHARD T. LIDDICOAT, JR.

In the period since the last report we have seen some especially interesting items.

A New Synthetic Alexandrite by the Czochralski Method

While in New York recently, I saw an alexandrite with a very obvious synthetic look, but without the usual flux characteristics. Shortly thereafter, we were sent two examples of a new pulled synthetic alexandrite by Dr. Kurt Nassau. This material showed a strong color change but not much resemblance to natural alexandrite. The colors were somewhat more reminiscent of synthetic alexandritelike sapphire than of alexandrite. The stones were exceedingly transparent and in daylight the color appeared bluish-green to greenish-blue, and under incandescent light the color was purple to almost violet. The samples were very transparent and slightly pale in color. Refractive indices were 1.740-1.749, ±.001; birefringence .009. The material was biaxial positive with a specific gravity of 3.715 ±.005. To short- and long-wave ultraviolet and x-ray, it showed a strong red fluorescence. Charles Fryer tried short-wave and long-wave ultraviolet transparency tests on two flux-grown synthetic alexandrites, the two pulled synthetics and a natural alexandrite for two- and three-second exposures. *Figure 1* is a three-second exposure to long-wave ultraviolet, the two flux-grown synthetics on top, the natural alexandrite in the center, and the two pulled, or Czochralski, synthetics at the bottom of the picture. These were three-second exposures with the tube nine inches from the film. *Figure 2* is a short-wave exposure with otherwise the same distance and exposure. *Figure 3* is taken under long-wave with a two-second exposure, and *Figure 4*, under short-wave with a two-second exposure.

It can be seen in all four shots that pulled synthetics are much more transparent to short-wave and long-wave and that the flux synthetics are more opaque, but not nearly as opaque as the natural alexandrite.

In each case, the flux are more

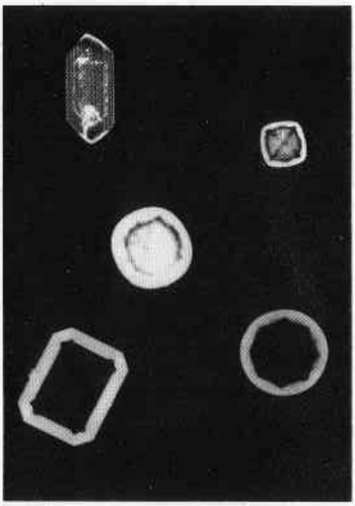

Figure 1.

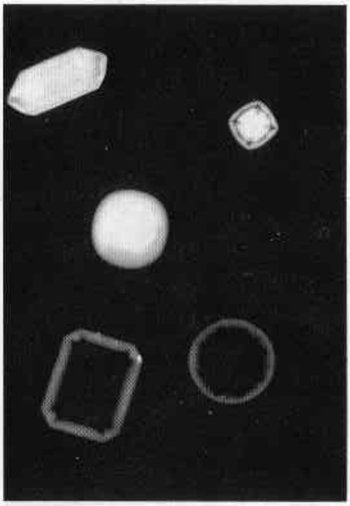

Figure 2.

transparent to the long-wave than to the short-wave. *Figure 5* shows curved striae in the pulled synthetic. *Figure 6* shows some lath-shaped included crystals in the new pulled synthetic alexandrite. *Figure 7* shows some randomly oriented needlelike inclusions also in the Czochralski synthetic alexandrite. Both *Figures 6* and *7* were taken at 63x.

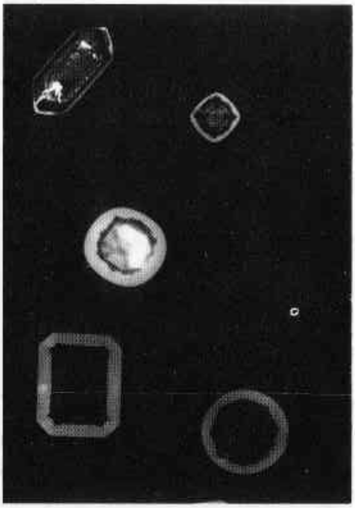

Figure 3.

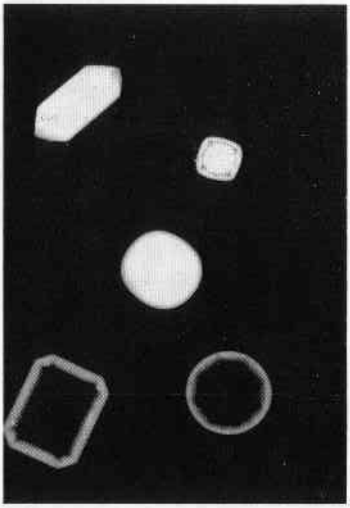

Figure 4.

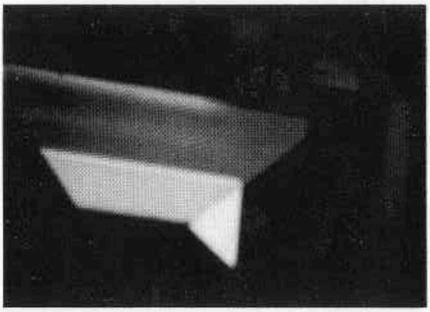

Figure 5.

Figure 6.

Figure 7.

Finally – An Example

Back in the dim dark ages, I remember when first studying the GIA Colored Stone Course, the coral assignment contained the statement that in addition to the garden variety of coral, there was black coral and a very rare blue coral. In the nearly 35 years since that reading, many types of coral have passed through the laboratory, but in 1975 we finally have seen a blue coral.

One might expect that this one would be somewhat similar to black coral in being noncalcareous, but such was not the case. This is a calcareous type. It had a peculiar structure with quite a number of large holes with a very conspicuous structure, plus a myriad of tiny indentations in the surface. Despite the indentations, the overall stone took a rather high polish.

Figure 8 shows the surface under 10x, with the small indentations or pits showing as white dots and the gearlike larger openings, partially filled, showing as dark spots. The dark spots are shown under 63x in *Figure 9,* where their peculiar structure becomes apparent. There are also, as can be seen in this second shot, some holes with light and dark rings surrounding them.

The structure is very interesting, and the stone was not unattractive. Our next hope is a second example of painite.

A Totally New Coral

While in New York at the Spring RJA Show in February, a man from

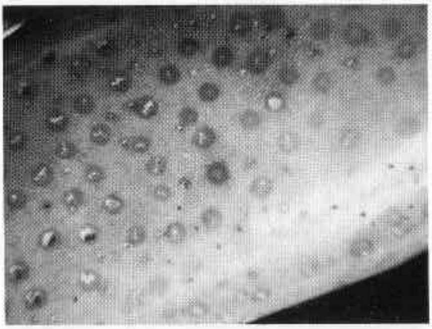

Figure 8.

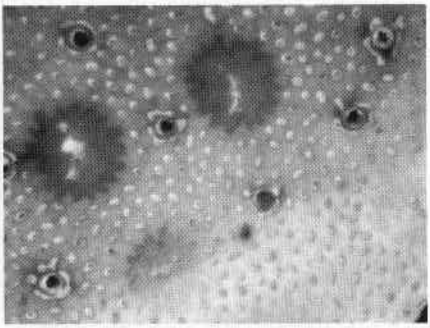

Figure 9.

Maui Divers in Hawaii showed me a ring set with a coral of the black coral family with what would best be described as a subsurface sheen. The bright reflection from beneath the fairly transparent surface had a golden color. This effect is shown in *Figure 10.* When magnified to 63x an unusual knobby appearance was evident, as shown in transmitted light in *Figure 11.* By reflected light the odd structure becomes more apparent and the reflecting surfaces also are more obvious, as seen in *Figure 12.*

Acknowledgements

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

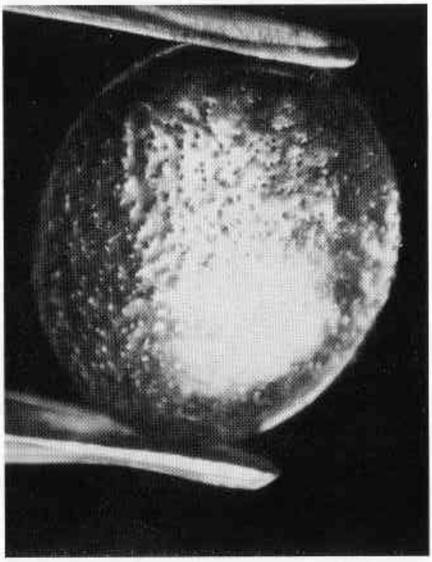

Figure 10.

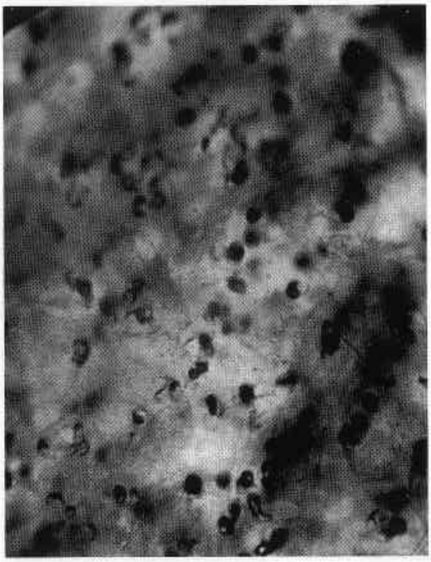

Figure 11.

To *Mrs. Spaulding Abell,* G.G., Louisville, Kentucky, for an interesting dendrite opal for student study use.

To *Davis S. Atlas,* C.G., of D. Atlas & Co., Inc., Philadelphia, Pennsylvania, for a large assortment of natural and imitation stones, including ruby, sapphire, amethyst, emerald, peridot, citrine, and demantoid garnet, which will be put to good use in our gem identification course.

To *Arnold Baron,* C.G., of Barton Distributing, Inc., Billings, Montana, for a natural blue sapphire and a natural emerald for classroom use.

To *Joe Best,* G.G., F.G.A., of Gilchrist Jewelers, Santa Barbara, California, for a miscellaneous collection of crystals and cut stones including apatite, quartz, corundum, amethyst, garnet, and two rose-cut diamonds.

To *Elizabeth Bruns,* AGS member, of Elizabeth Bruns, Inc., Charlotte, North Carolina, for a large assortment of garnet and glass doublets that will be used extensively in our gem identification course.

Figure 12.

To *Frank Faukoner* of Tri-City Lapidary & Jewelry Supply, Sacramento, California, for a much-needed donation of tektites for our reference and research collection.

To *GSI Gem Corporation,* Los Angeles, California, for an unusual 0.41-ct. round brilliant diamond with an included crystal protruding from a recess on the surface. This stone will be used in our diamond course.

To *Dick & Jack Industries, Inc.,* Los Angeles, California, for a welcome assortment of miscellaneous stones including opal, ruby, sapphire, emerald, quartz, and jadeite which will be used in our gem identification course.

To *Dorothy Norris,* GIA student, San Carlos, California, for a collection of opal baroques to be used in our colored stone classes.

To *Rick Shalberg,* GIA instructor in Jewelry Repair and Diamond Setting, for four mineral specimens which include sulfur, calcite, aragonite, and linarite for our reference collection.

To *Ron C. Stevens,* former GIA student, of Steven's Jewellers, Auckland, New Zealand for a much needed book on "New Zealand Jade," for use in our library.

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Book Reviews

By ROBERT GAAL, Ph.D.

THE DIAMOND MAGNATES, by Brian Roberts. Published by Charles Scribner's Sons, New York, 1972. 335 pages. Hardbound. Price: $8.95

Although today the sun does set on the British Empire, there was a time it didn't, when Britannia was off exploring, civilizing, and exploiting the far corners of the world. This book, "The Diamond Magnates," describes one powerful epic struggle for British control of the fabulous South African diamond fields. From the very beginning when the "Eureka" diamond was found in 1867, Englishmen dominated the diamond fields. The book is a well-researched, people-oriented history written in a popular style. It is centered entirely on the careers of a colorful group of men who became rich, their subsequent skyrocketing rise and later demise. The list of incredible and ruthless characters includes the famous colonizer Cecil Rhodes, the contentious and mean J. B. Robinson, the colorful and money-driven Barnato brothers, and the financial genius Alfred Beit.

"The Diamond Magnates" is a lively, exciting, and interesting story of what men will do for high stakes. It is sprinkled with rough politics, intrigue, scandal, sorrow, and base passions. The transformation of the quiet shanty mining town of Kimberley into the arena where the original giants of the diamond industry battled for control is truly a fascinating tale. It involved initially the merger of the small surface diggers into companies in order to mine at depth, followed by the amalgamation of these various companies by take-overs. Eventually, it led to the final struggle between the two giant companies, one owned by Rhodes, who in partnership with Beit controlled the De Beers Company, and their rival, Barney Barnato, who ruled the Central Company.

Their active competition ceased in 1889, when Rhodes won the last struggle for control of Kimberley and these two magnates joined forces. Consequently, the diamond monopoly as we know it began, controlled by one vast corporation, the De Beers Company. After the merger of the two giants, the diamond magnates, now very rich men, turned their aspirations elsewhere to find, surprisingly, new battles to fight in other fields of endeavor. Apparently only one character, Cecil Rhodes, was motivated beyond avarice by his desire to put wealth to the service of a grand imperialistic design. His story, development, reward, and the fates of the other characters can be found in this thoroughly enlightening book.

The book is highly recommended for jewelers, gemologists, and students of history who want an authoritative, highly readable history of the beginnings of the diamond industry and the men who made it possible. A collection of little-published photographs of the main characters further enhances the story. "The Diamond Magnates" will provide some new insights into an old, but always new and intriguing story about diamonds and the aspirations of men.

GEMSTONE & MINERAL DATA BOOK, by John Sinkankas. Published by Collier Books, New York, 1974. 346 pages. Paperback. Price: $4.95

This paperback reprint of a remarkable compilation of varied and valuable gemological data and information is a must for the serious gemologist and jeweler. John Sinkankas has written a concise, handy reference for various kinds of gem information, chemical data, optical and physical properties, conversion tables on weights and measurements, metals, cleaning mineral specimens, etc., offered for the extremely reasonable price of $4.95.

The reader is referred to *Gems & Gemology,* Summer, 1972, for a detailed review of this book. The book follows the same format as the earlier hardbound edition, first published in 1972, and unfortunately still maintains the earlier major drawback, namely the lack of an index. The usefulness of the book is, nevertheless, considerable. In the absence of an index, the reader has to rely on the Table of Contents, which gives a fairly detailed breakdown of subject headings and page numbers. Regardless, this is still an excellent reference book.

"Gemstone & Mineral Data Book" is highly recommended for anyone who is interested in jewelry making, lapidary, and gemology, and for those who maintain a gem library. Very nice at about half the price of the earlier edition.

GEMS AND MINERALS OF AMERICA, by Jay Ellis Ransom. Published by Harper & Row, Publishers, Inc., New York, 1975. 705 pages. Hardbound. 48 color and 24 black and white photographs. Price: $17.50

"Gems and Minerals of America" is primarily a book for the lapidary hobbyist. It contains a massive gazetteer of about 8500 gem and mineral locations in the United States, listed alphabetically by state. Where available, directions on how to find the collecting sites are given which will be of great assistance to the collector. Although very generalized, the book represents a respectable effort in bringing to the amateur hobbyist a reasonably documented guide as to where minerals come from, how they are used, and where to find them.

The book is divided into two major parts, and includes appendices and numerous tables. Part one is mostly geological, describing minerals, rocks, their types and associations; preparation for field collecting; geologic maps and how to use them; care, preservation, and organization of gem and mineral collections; agates, opals, and petrified wood; and cutting and polishing of gem materials. Each of these sections is a short elementary introduction to the subject listed. Although not necessarily accurate in some geologic terminology, and lacking in modern concepts, the book can be used with caution by the beginner as an introduction to the topics.

The second part of the book dedicates 423 pages to gem and mineral localities alphabetically listed and subdivided into counties. A major feature of the book is a list of reference libraries and mineral museums by states, which might be a handy reference for the serious collector. A useful bibliography is also a valuable attribute. The book may find its greatest use by the beginning collector, who is just starting his travels in the hobby.

HUNTING DIAMONDS IN CALIFORNIA, Revised Edition by Mary Hill, Naturegraph Publishers, Healdsburg, California, 1972. 80 pages with 21 black-and-white maps, photographs and illustrations. Paperback.

Price: $2.00

"Hunting Diamonds in California" appears to be a well-documented introduction to diamonds in California. The author, Mary Hill, stresses that one of the best places to look for diamonds is where they have already been found. This is repeatedly stated to be, " . . . in the beds of streams that now drain the mountain reaches of the State, or in the beds of ancestral streams that thousands of years ago flowed down the mountain fronts by different routes." In California, no diamond has been reported to have been found in the rock in which it was formed. All diamonds claimed to have been found in California to date have been alluvial stones.

The first diamond discovered in California was in 1853 in Butte County. In 1868, the largest stone reportedly ever found in California was from the Cherokee pit, Butte County, and weighed about 6 carats. Since then, numerous small diamonds have been found, all of which are associated with placer gold deposits. Nine counties in California have produced at least one or a few minute diamonds each.

The first part of the book describes the properties of diamonds, discusses the term "carat," the prices of diamonds in general (which are very much outdated), and covers simulants and synthetic diamonds. Following the first part is a chapter on where to look for diamonds and several sections on California placer diamond locations with much historical retrospect. Each major diamond-producing county in California is listed and pertinent information given. The book then turns to the subject of California diamonds in lode and the association of diamonds with kimberlite. Two short chapters on how to prospect and file a claim for diamonds conclude the book. An excellent bibliography provides valuable references for those wishing to delve deeper into the subject of diamonds in California.

Some inconsistencies which need mention occur in the revised edition. As stated on page 8, diamonds are not "chipped" into light-refracting facets, but rather, they are *polished.* Louis de Berquem is again incorrectly credited with placing the first symmetrical facet arrangement on diamonds on page 8.

Other very important diamond substitutes not listed under "may be confused with" on page 11 are strontium titanite, natural and synthetic sapphire, and synthetic spinel. The pricing information listed on page 17 is De Beers' 1959 guide for diamond prices. In today's market, the information is incredibly out of date. The listing of calcite as a diamond substitute, appearing on page 22, is indicative of the quality of the revision. On page 23, "the synthetic stone titania" is *not* a variety of the mineral titanite (sphene) as listed, but rather is synthetic rutile.

Everyone who has an interest in diamonds in California should find this non-technical book an interesting reading experience, if they disregard the portions that attempt to impart a general knowledge of diamond.

GEMS AND MINERALS IN COLOR, by Rudolph Metz. English translation of "Edle Steine." Published by Hippocrene Books, Inc., 1974, with numerous illustrations by A. E. Franck. 255 pages. Hardbound. Price: $6.95

"Gems and Minerals in Color" is a richly-illustrated and relatively informative introduction to minerals and gem materials. It was translated from the German by G. A. Wells and contains over 100 pages of superb color photographs. Besides the dramatic color illustrations, other features such as the relatively accurate text, pocketbook size, and reasonable price make this a very attractive handbook for amateurs and collectors.

The book is divided into two parts, including a section on gem materials in which the important gemstones are discussed and rough materials are illustrated in color. The first part of the book covers mineral characteristics, properties, and distribution in general. Where minerals are formed is the major topic of the second part of the book. The minerals illustrated in the colored plates are grouped according to their place of natural occurrence in the major realms of mineral formation, that is, in the magmatic, sedimentary, and metamorphic environments. This freshly-written environmental approach can be a stimulating way to arouse young people and novices to take an interest in science. This book stands in contrast to the stodgy, pedantic, classical approach of most mineralogical textbooks which use chemical composition and molecular structure to classify minerals. However, to fully understand the text, a preliminary knowledge of mineralogy and geology is required which, in itself, does not detract from the wealth of information that can be obtained from the book.

The book deserves to be read carefully by students seriously interested in the hobby of collecting minerals and gemstones. The color plates alone make the book worth the $6.95 and the text is just topping on the cake.

PEBBLE COLLECTING AND POLISHING, by Edward Fletcher. Published by Sterling Publishing Co., New York, 1973. 70 black and white illustrations and 20 color photographs. 96 pages. Hardbound. Price: $3.95

Although originally written for a British following, Joe Rothstein has done a quality job of editing and adapting this book for an American audience. "Pebble Collecting And Polishing" by Edward Fletcher is a fascinating new book on what you have always wanted to know about pebbles, tumbling and tumbled stones and were afraid to ask. The author explains the how-to and what-to-do with pebbles with step-by-step instructions. The reader is led through six well-written chapters which include where pebbles are found, their collection and selection for tumbling, and an excellent explanation of the tumbling machine and how it works. A complete chapter has been devoted to "perfect polishing," which carefully explains the basic tools and supplies needed to achieve a perfect polish on your specimens. After you have prepared your polished "gem," the author gingerly guides you through a chapter on jewelry making in order to make the end product an original piece of Baroque style jewelry. Once you have learned to collect, polish, and create a piece of original jewelry, the final chapter of the book orients you on the many phases of the hobby and where you go from there. A short list of accessible collecting areas, lapidary supplies, publications, and how to plan a trip concludes this delightful new book on tumbling.

"Pebble Collecting And Polishing" is written in a refreshing style and is a basic educational book from which anyone can learn. The full-color photographs and other excellent black and white illustrations greatly enhance the learning situation. The book is highly recommended for the beginner in lapidary and anyone interested in the tumbling hobby.

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