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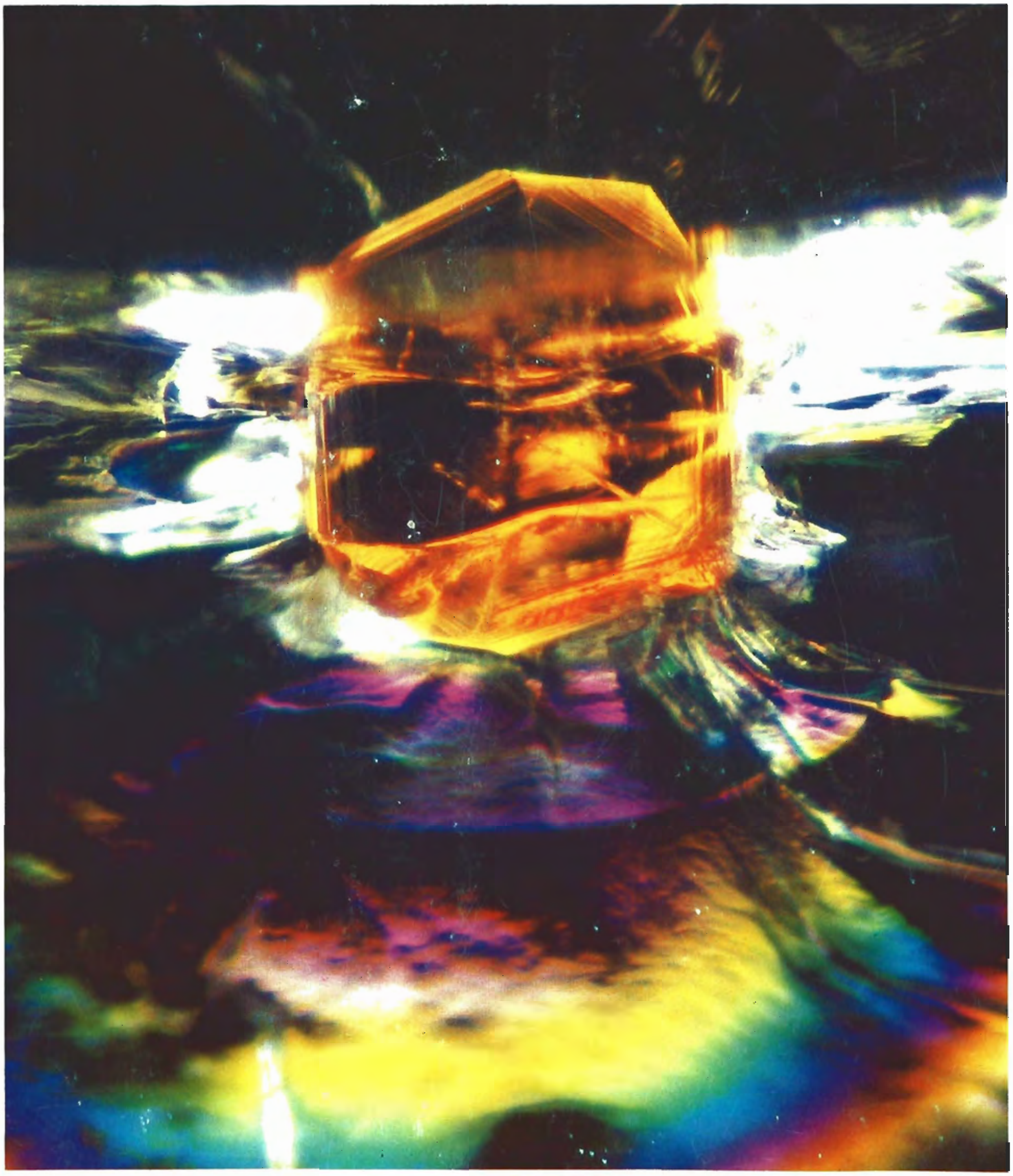

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ABOUT THE COVER: As many of the illustrations in this issue demonstrate, inclusions often provide significant, if not unique, clues to the identity of a gemstone and the origins of its color and other characteristics. Inclusion photography, therefore, can also play an important role in gemology—and, as is evident in this cover photograph, an aesthetically pleasing one as well. Included in quartz, framed by iridescent stress fractures, this euhedral spessartine garnet crystal testifies to the pegmatitic origin of its host. Magnified 60x. Photograph by John I. Koivula.

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HEAT TREATING RUBY AND SAPPHIRE: TECHNICAL ASPECTS

By Kurt Nassau

***Ruby** and sapphire of natural or synthetic origin can be heat treated to improve asterism; to remove asterism or silk; to improve, add, or remove color; and even to alter imperfections. At least nine distinct processes can be identified, although several may occur simultaneously. Some of these treatment methods correspond to natural processes and may not leave any evidence of their use; others do not correspond to natural processes and are readily identifiable.*

ABOUT THE AUTHOR

Dr. Nassau is a research scientist residing in Bernardsville, NJ. He does not wish to be contacted on any aspect of this article.

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In recent months, a variety of heat-treated sapphires and rubies with gemological characteristics different from any previously seen have appeared on the market. Contradictory rumors abound regarding the different manners and methods of treatment.

Examples of heat treatment methods that have been used to improve the appearance of gemstones include the conversion of green aquamarine to blue; the "pinking" of brown chromium-containing topaz; the "crackling" of quartz; the reddening of yellow agate, carnelian, and tiger's-eye; the development of the blue color of tanzanite; and the conversion of amethyst to citrine or to "greened amethyst." Such processes may be termed heating, burning, annealing, firing, high-temperature soaking, and so on. The use of these types of heat treatment is usually not specified.

The reaction of synthetic corundum (Nassau, 1980a) to various types of heat treatment has been studied widely, and the results are equally applicable to the natural material. Although most of the treatment methods described here have been known for some time, their use to improve rubies and sapphires has become widespread only recently.

The important parameters in any type of heat treatment are:

1. The temperature-time relationship
2. The oxidation-reduction conditions
3. The presence of chemical substances that can interact with the gemstone

Heat treatment of corundum can affect the presence of milkiness and asterism, the color, and even the internal structure (inclusions as well) of the material. A number of separate processes have been distinguished, although several may be performed simultaneously. The exact temperature, duration of treatment, and chemicals used for each process will depend on the specific material being heated; considerable variation must be expected with corundum from different localities.

Nine possible treatment modes are summarized in table 1 and examined in turn below. Identifying characteristics of such treatment methods have been discussed in detail by Crowningshield and Nassau (1981); therefore, they will be touched on here only briefly.

It should be noted that no consensus has yet been reached as to whether any of these types of treatment need to be disclosed to the buyer. The parallel is sometimes drawn that since heat treatment is not customarily disclosed with other gemstones, such as heated blue aquamarine, why should such disclosure be necessary with sapphires and ruby? There may be validity in viewing some types of treatment in this way, especially those that mimic natural processes (as is the case with aquamarine). However, other treatment methods—diffusion in particular—do not have any parallel in nature. The results of diffusion treatment, for example, are readily recognized, and remind one more of Lechleitner synthetic emerald overgrowth on a natural beryl than of heated aquamarine.

PROCESS 1: DEVELOPMENT OF POTENTIAL ASTERISM

Some natural sapphire and ruby, as well as some synthetic material intended for star use, contains a significant amount of titanium oxide. If such corundum cools fairly rapidly from its growth conditions, the material remains clear; the titanium oxide is in "solid solution" in the form of Ti_2O_3 (titanium sesquioxide) replacing some of the Al_2O_3 (aluminum oxide).

If such material, which typically contains only a few tenths of a percent titanium oxide, is held at between 1100°C and 1500°C for some time (say, 1300°C for 24 hours), particularly under mildly oxidizing conditions, the Ti_2O_3 converts to TiO_2 (titanium dioxide) as follows:

$$2Ti_2O_3 + O_2 \rightarrow 4TiO_2 \qquad (1)$$

In most cases, the TiO_2 will then form needles of rutile within the corundum and thus produce asterism. This process, which was patented for Linde Air Products Company by Burdick and Glenn (1949), is used to create all synthetic stars in corundum (Nassau, 1980a), and the analogous process also occurs in nature. In fact, if a piece of

TABLE 1. Heat treatment processes used on sapphires and rubies.

Treatment group	Specific process[a]	Result
Heating only	1. Moderate temperature (1300°C)	Develops potential asterism
	2. High temperature (1600°C), rapid cooling	Removes silk and asterism
	3. Reductive heating (1600°C)	Develops potential blue color
	4. Oxidative heating (1600°C)	Diminishes blue color
	5. Extended heating (1800°C)	Diminishes Verneuil banding and strain
Heating under unknown conditions	6. ?	Introduces fingerprint inclusions[b]
Diffusion of impurities into the material (extended heating at 1800°C)	7. Add TiO_2	Produces asterism[b]
	8. Add TiO_2 and/or Fe_2O_3	Produces blue color[b]
	9. Add Cr_2O_3, NiO, etc.	Produces other colors[b]

[a] *Treatments 1 through 4 correspond to processes that also occur in nature; treatments 5 and 6 are used on synthetic material; treatments 7 through 9 do not correspond to natural processes. The temperatures given are representative only and will depend on the nature of the material and the length of time they are used.*

[b] *Effect is limited to a region near the surface.*

Figure 1. Left, milky white "geuda" corundum from Sri Lanka; photograph by Tino Hammid. Right, intense blue color induced in Sri Lanka "geuda" by the heating method described in process 3; *photograph by Michael Havstad.*

natural corundum contains sufficient titanium oxide but was not heated sufficiently in nature to develop a good star, perhaps showing only fine "silk," asterism can be developed by means of such heat treatment. Thus far, however, this process appears to have been used on natural corundum on an experimental basis only.

If rutile needles in natural corundum are too coarse to provide a good star, *process 2* can be used to return the titanium oxide to solid solution by the reverse of equation (1), and *process 1* can be used subsequently to form star-causing needles as described above. The heating conditions of *process 1* are relatively mild and often leave no evidence by which this treatment may be recognized with certainty.

It should be noted that the Al_2O_3–TiO_2 phase diagrams of Lang et al. (1952) and Lejus et al. (1966) show an intermediate compound Al_2TiO_5, and that this and other compounds have been suggested as representing the needles (e.g., Phillips et al., 1976). However, detailed examinations always have pointed to the rutile form of titanium oxide as the principal component of the needles (e.g., Nassau, 1968; Phillips et al., 1980). Neither of the phase diagrams cited considers the solid solubility of TiO_2 or Ti_2O_3 in Al_2O_3, which must, on theoretical grounds, be present (see also, for example, Bratton, 1971).

PROCESS 2: REMOVAL OF SILK OR ASTERISM

If corundum containing silk or asterism caused by rutile needles is heated to a sufficiently high temperature, typically between 1500°C and 1700°C, the rutile will dissolve in the corundum by the reverse of *process 1:*

$$4TiO_2 \rightarrow 2Ti_2O_3 + O_2 \tag{2}$$

When all the silk has disappeared, the corundum is cooled fairly rapidly, perhaps 30° per minute (Falkenberg, 1978), so that rutile needles do not re-form as in *process 1.* Asterism may be removed in a similar manner.

The suggestion by Sasaki (1980) that this form of heat treatment might be conducted successfully at 1000°F (538°C) implies a temperature that is as unreasonably low as the 4000°C reported by Tombs (1980) is unreasonably high (it is above the melting point!). Tombs also proposes that the silk may originate from substances other than titanium oxide, for example, from α-corundum present in β-corundum. But ordinary corundum is α-corundum. Such unsupported suggestions must be discounted unless and until concrete evidence becomes available. Nevertheless, it is possible that heat treatment may cause other inclusions or defects to disappear by a process of solid solution similar to that involving titanium oxide. Oughton (1971) quotes another unusual suggestion, namely that liquid may be used to fill the hollow tubes that cause silk, with the effect wearing off after about 12 months. This might work if only there were hollow tubes!

Process 2 appears to be used widely on silky Australian sapphire and on milky white to pale blue "geuda" corundum from Sri Lanka, which is turned blue by the simultaneous use of *process 3* (see figure 1). Gunaratne (1981) refers to this pro-

Figure 2. The stress fractures surrounding inclusions in this ruby were produced by a heat treatment method similar to the one discussed in process 2. *Magnified 27×. Photomicrograph by Robert E. Kane.*

cess, but most of his discussion of the genetic history of geuda material and of the treatment used must be taken as purely speculative, since it is in great part inconsistent with known data. Cloudy Burma rubies, too, are said to be improved in this way, with the color also benefiting from the removal of the silk.

In many cases, this form of heat treatment may be identified by a dull, chalky green fluorescence and the absence of an iron line at 4500 Å in blue sapphire, and by internal stress fractures (figures 2 and 3). Pockmarked facets and abnormal girdles (figure 4) may also be seen if the stone has not been properly repolished (Crowningshield and Nassau, 1981). However, none of these characteristics may be present in a given treated stone, or some may be present in stones that have not been treated.

PROCESS 3: DEVELOPMENT OF COLOR IN A STONE WITH A POTENTIAL FOR BLUE

The color in blue sapphire is explained by a "charge transfer" process (Nassau, 1980a, 1980b). This is widely accepted to originate from the iron-titanium combination (Townsend, 1968; Leh-

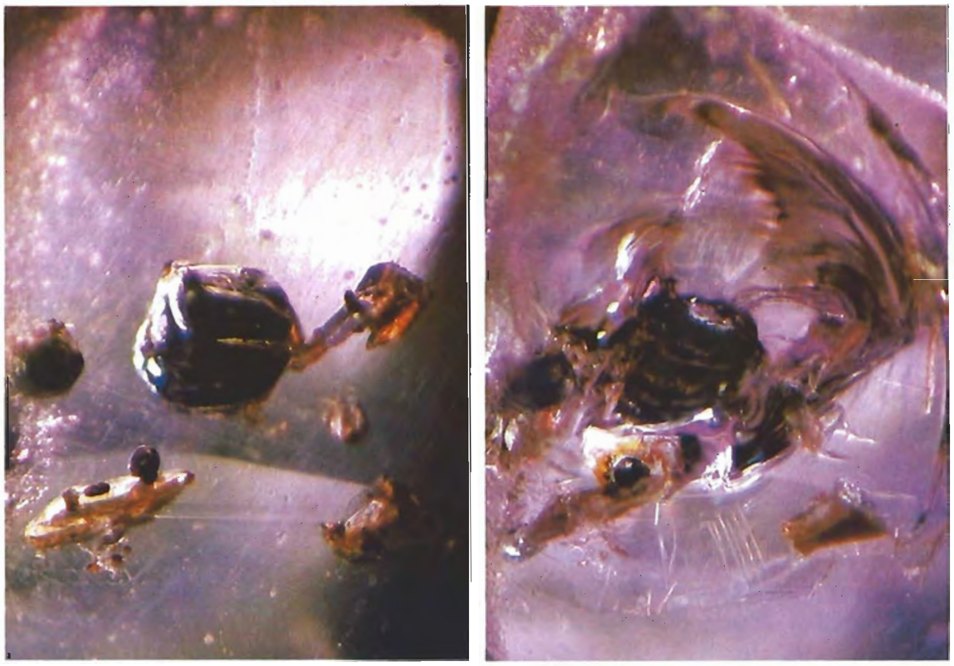


Figure 3. Left, phlogopite mica in a pink sapphire from Sri Lanka. Right, the same stone after heating to approximately 1000°C produced stress fractures surrounding the inclusions. Magnified 55×. Heat treatment and photomicrographs by John I. Koivula.

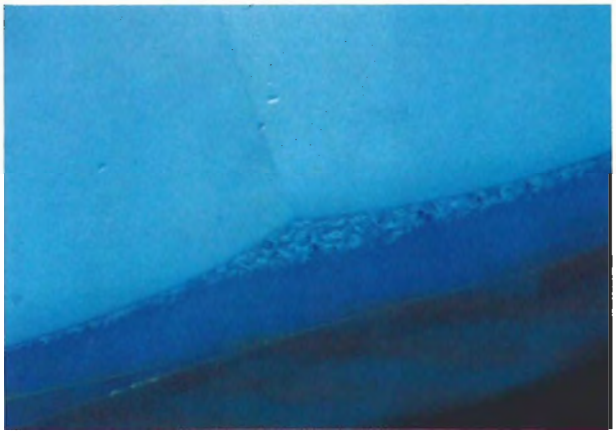


Figure 4. "Double girdle," where part of the original girdle was missed during repolishing. This indicates how the surface of a stone may become pockmarked during a high-temperature treatment. Magnified 25×. Photomicrograph by Robert E. Kane.

mann and Harder, 1970; Ferguson and Fielding, 1972; Eigenmann et al., 1972; Schmetzer and Bank, 1980). Recently, iron–iron charge transfer has been suggested as an alternative (Nikolskaya et al., 1978), though it is highly improbable; titanium is still essential, since the blue color never develops without it. Therefore, the process involved in these charge transfers is either

$$Fe^{2+} + Ti^{4+} \leftrightharpoons Fe^{3+} + Ti^{3+} \qquad (3)$$

or

$$Fe_a^{3+} + Fe_b^{2+} + Ti^{4+} \leftrightharpoons Fe_a^{2+} + Fe_b^{3+} + Ti^{4+} \qquad (4)$$

where *a* and *b* refer to different sites in the crystal. In each instance, a single electron is transferred from one atom to another atom and back again.

It is important to note that both processes require that some of the iron be in the divalent ferrous, Fe^{2+}, state. Also, sufficient quantities of iron and titanium must be present in the original stone to produce a deep blue.

A sapphire that contains adequate amounts of iron and titanium oxides but is too highly oxidized, so that not enough ferrous iron is present, may be pale blue, green, yellow, or colorless in its original state. Such material may be heated in a strongly reducing environment to convert some Fe^{3+} to Fe^{2+}, as follows:

$$Fe_2O_3 + H_2 \rightarrow 2FeO + H_2O \qquad (5)$$

or

$$Fe_2O_3 + CO \rightarrow 2FeO + CO_2 \qquad (6)$$

This change can be achieved by an extended heating of the stone in a hydrogen atmosphere for equation (5) or by packing the material in charcoal, graphite, or another substance that produces carbon (such as mineral oil, sugar, and the like), so that combustion with only a small amount of air produces carbon monoxide

$$2C + O_2 \rightarrow 2CO \qquad (7)$$

which then participates in equation (6).

The maximum color possible given the iron and titanium content of the stone can be achieved via equation (5) or (6). With sufficiently extended heating (hours to days?) at a high enough temperature (perhaps 1500°C to 1700°C), the reduction will penetrate throughout the stone and produce a uniform color (aside from any inherent banding due to uneven distribution of impurities). The reductive heatings of Schmetzer and Bank (1980) did not show this type of reaction, undoubtedly because the temperatures employed were too low (they heated in the hydrogen atmosphere at 1000°C and in the carbon monoxide environment at 1200°C). Eigenmann and Gunthard (1972) were successful with hydrogen at 1600°C.

As in the case of *process 2,* this treatment method appears to be used commonly on silky Australian sapphire and on milky white to pale blue corundum from Sri Lanka. Possible identifying characteristics include chalky green fluorescence, no iron line at 4500 Å, internal stress fractures (figure 5), pockmarked facets and/or abnormal girdles, and blotchy color banding or zoning within the stone. This treatment can be reversed by means of *process 4.*

PROCESS 4: LIGHTENING OF BLUE SAPPHIRE

If blue sapphire is heated for an extended period (hours to a day or so) in an oxidizing atmosphere (air or pure oxygen), all of the iron may be converted gradually to Fe^{3+}:

$$4FeO + O_2 \rightarrow 2Fe_2O_3 \qquad (8)$$

The result is the slow removal of one of the essential coloring ingredients, Fe^{2+}, on the left side of equations 3 and 4, thus lightening the blue color. If the process is continued long enough, a virtually colorless stone may result. This treatment has been described by Jobbins (1971), Eigen-

Figure 5. The stress fractures in this sapphire from Sri Lanka resulted from a heat treatment method like the one described in process 3. *Photomicrograph by Robert E. Kane.*

mann and Gunthard (1972), Harder (1980), and Schmetzer and Bank (1980). If an underlying yellow is also present, the final color may be green or yellow; a purple sapphire that also contains some chromium could lose the blue color entirely and end up as ruby (the oxidation has no effect on the red chromium coloration); and so on. Temperatures in the 1000°C to 1700°C range may be used, and this treatment can be reversed by using *process 3;* identifying characteristics are similar to those for *process 3* (figure 6).

Process 4 is used to lighten dark blue, "inky" Australian sapphires (Gunaratne, 1981), sometimes producing a pronounced green dichroic direction in the stone. Undoubtedly, it has also been applied extensively to purplish and brownish Thai rubies, which were so common at one time but now are seldom seen (Crowningshield and Nassau, 1981). This process as used in Sri Lanka has been described by Gunaratne (1981); the reported difficulties in obtaining consistent results probably derive from the use of charcoal,

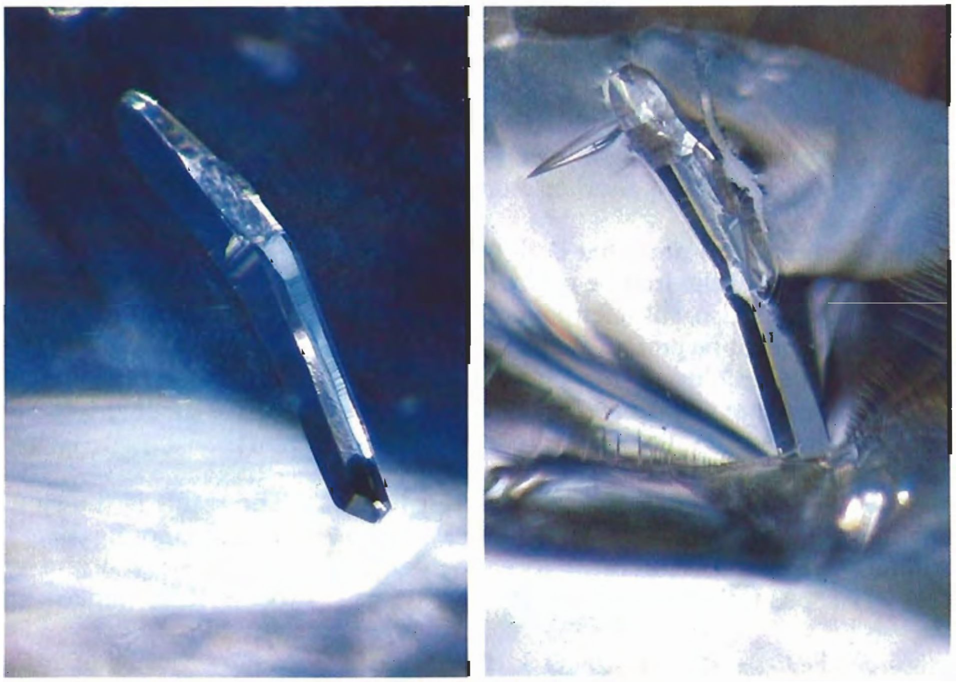


Figure 6. Left, fluid inclusion, probably carbon dioxide (CO_2), in a sapphire from Sri Lanka. Right, the same stone after heating to approximately 1000°C in air resulted in the almost total dissipation of color and the appearance of a large stress fracture around the inclusion. Magnified 45×. Heat treatment and photomicrographs by John I. Koivula.

which can lead to reduction rather than the desired oxidation if not performed carefully.

PROCESS 5: DIMINISHING VERNEUIL BANDING AND STRAIN

Extended heatings (for many days) at sufficiently high temperatures (1600°C and up), such as those associated with many of the processes discussed here, will result in a reduction of strain and will permit some smoothing of color irregularities. The curved striations typical of Verneuil-grown synthetic corundum originate from irregularities in the growth process; their main feature is a variation in the concentration of the impurities (Nassau, 1980a). Heating for an extended period permits a very slow diffusion to even out some of this variation, with the degree of improvement depending on the duration of the heating process.

This lengthy, high-temperature process is said to be performed in Bangkok on synthetic Verneuil blue sapphire. When used in conjunction with *process 6* (below), it results in improved color and less prominent curved growth lines. It is also more difficult to observe a positive Plato test in stones treated in this manner (Crowningshield and Nassau, 1981). A similar procedure should be possible in ruby and other colored corundum. The small gas bubbles associated with the Verneuil technique probably cannot be removed in this manner.

PROCESS 6: INTRODUCING FINGERPRINT INCLUSIONS

As reported by Crowningshield and Nassau (1981), some samples of "heat-treated natural blue sapphire" obtained from Bangkok turned out to be Verneuil synthetic sapphire with induced fingerprint inclusions. Both Verneuil synthetic ruby and pink sapphire showing fingerprints were also reported by Crowningshield (1980). Judging from the characteristics of these stones, it is clear that an extended heat treatment similar to that of *process 5* was involved.

At present, nothing definite is known about the treatment used with synthetic stones to mimic the fingerprint inclusions of their natural counterparts. The simultaneous occurrence of fingerprints, curved but weakened Verneuil banding, and occasional gas bubbles is clear evidence of such a treatment. According to some unsubstantiated reports, a flux-type chemical such as sodium carbonate or borax may assist in this process. It should be noted that the formation of inclusions seems to be limited to a region close to the surface of the stone.

THE DIFFUSION MECHANISM

Diffusion in solids is a mechanism by which atoms may be moved from one region to another. The amount of movement increases with both the temperature and the length of the heating. Atoms of oxygen or hydrogen can move very rapidly in corundum, which explains why the effects of *processes 3* and *4* will penetrate fully throughout a stone in as little as a few hours in some cases (and no more than a day or so in others). The formation or removal of the rutile needles of silk and asterism in titanium-containing corundum is also diffusion controlled. Although titanium diffuses very slowly, the distances involved are so small, only a few micrometers, that *processes 1* and *2* as well require only a day or so to be effective. The banding in Verneuil-grown corundum is much coarser; this explains why extremely long heating would be required for the near-total removal of the banding by *process 5*, which involves the movement of the slowly diffusing color-causing transition metals such as chromium, iron, titanium, and nickel. It is not known if a total removal of the banding is possible, since other factors (the dislocation structure, for example) may prevent this from occurring.

The movement of color- and star-forming atoms into and within corundum is a very slow process; as a result, the effects of *processes 7, 8,* and *9*, discussed below, are limited to a relatively thin skin on and just below the surface, typically to a depth of a few tenths of a millimeter. Very high temperatures must be used to obtain significant penetration in a reasonable time, since the fuel costs for these forms of heat treatment are considerable. As a consequence of the high temperatures required and the thin film that results, these treatment methods cannot be performed on rough material but must be applied to a preform or a cut stone; even so, only the lightest of polishing (or repolishing, since the surface is roughened by the treatment) can be used or the affected skin will be completely removed.

It is the localization of the effect of these treatment methods just below the surface of the stone,

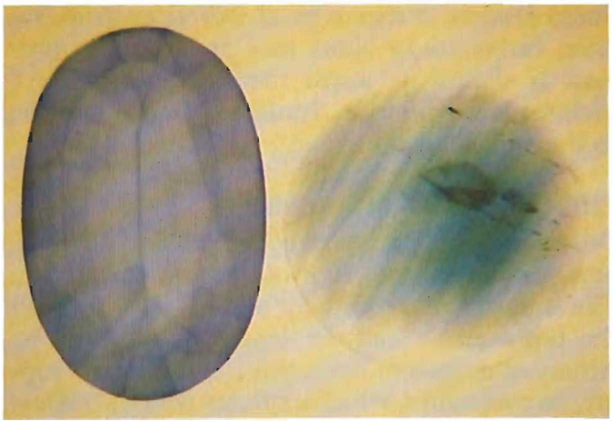


Figure 7. A diffusion-treated sapphire (left) lies next to a sapphire treated by a method like the one described in process 3 *(right), both immersed in methylene iodide. Immersion reveals that the diffusion-treated stone has much greater relief, as exemplified by a blue outlining of facet junctions. The stone on the right has low relief and does not show any facet junctions except near the girdle where some areas are slightly abraded. Magnified 10×. Photomicrograph by Robert E. Kane.*

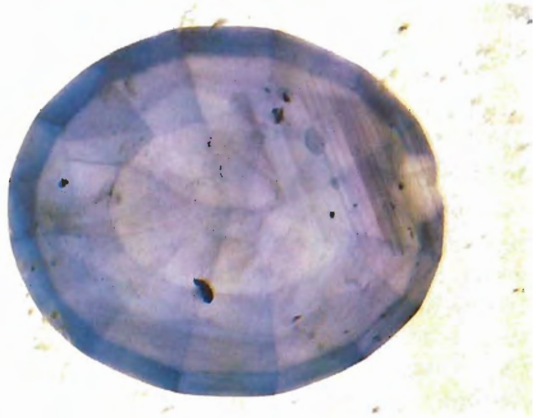
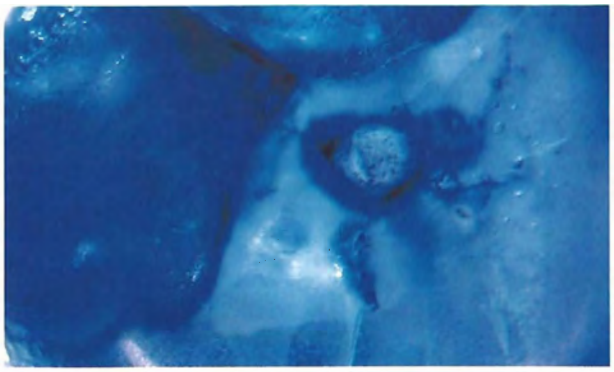


Figure 8. Diffusion-treated sapphire immersed in methylene iodide. Note the chip on the center right of the stone, which reveals the color of the untreated portion (both the blue color and the color in the chip area are much lighter than they would appear without immersion and under normal lighting conditions). Magnified 10×. Photomicrograph by John I. Koivula.

the restrictions on polishing, and the high temperatures required that provide the clues to identifying that these processes have been used. Viewing such stones while they are immersed in methylene iodide reveals both the localized effect and a blotchiness from the combination of uneven diffusion and light repolishing (figures 7 and 8). Other signs are stress fractures, pockmarked faces, and abnormal girdles as discussed under *processes 2, 3,* and *4,* and shown in figures 2 through 6 above, as well as a "bleeding" of color around pits and fractures (figure 9), as described by Crowningshield and Nassau (1981).

Figure 9. "Bleeding" of color around cavities and fractures in a diffusion-treated sapphire. Magnified 15×. Photomicrograph by Robert E. Kane.



PROCESS 7: ADDING ASTERISM BY DIFFUSION

If the corundum does not contain any titanium oxide, or at least not enough to form good asterism, it is possible to diffuse some *into* the gemstone in the form of a thin layer at and just below the surface. This process was first described in a U.S. patent by Eversole and Burdick (1954), intended for the manufacture or improvement of synthetic Verneuil stars; a similar description appeared later in a patent by Carr and Nisevich (1975). Both patents were assigned to the Union Carbide (and Carbon) Corporation (Linde). Typically, to produce the desired effect, a slurry of aluminum titanate in water is painted onto the stone and then fired at about 1750°C for several days. The stone is cooled and a subsequent heat treatment, as in *process 1,* develops the asterism. The depth of penetration may be only one tenth of one millimeter.

Natural sapphires with added asterism, as well as those with added color from *process 8,* have been described by Crowningshield and Nassau (1981). The process appears to be applied primarily to fractured material that is unsuitable for fac-

Figure 10. Immersion in methylene iodide reveals the localization and blotchiness of diffusion caused by the combination of uneven diffusion and heavy repolishing (which uncovered the color of the untreated portion) of an orange-red diffused sapphire. Magnified 8×. Photomicrograph by John I. Koivula.

eting; it can be recognized in stones by the unnaturally sharp stars caused by very fine rutile needles, by uneven color, by "bleeding" of the color at pits and fractures, and by other evidence of high-temperature treatment such as stress fractures and pockmarked surfaces.

PROCESS 8: ADDING BLUE BY DIFFUSION

If insufficient iron oxide or titanium oxide is present in a colorless, yellow, green, or pale blue sapphire, it is possible to add either or both of the missing ingredients by diffusion. A reducing atmosphere as in *process 3* is required, or a separate reductive heating step must follow oxidative diffusion. This type of diffusion is extremely slow, so that even with extended heating the penetration will be shallow. The result is a relatively thin skin of dark blue. This process was described in detail by Carr and Nisevich (Linde patent) in 1975 for the combination with *process 7*, and subsequently as a separate process (Carr and Nisevich, 1976, 1977). It appears to be in wide use (Crowningshield, 1980; Fryer, 1981), both on faceted stones and on cabochons. Identification includes immersion in methylene iodide as well as the other clues described above for *process 7*.

When Linde stopped producing synthetic gems about 1975, these U.S. patents were assigned to the Astrid Corporation Ltd. of Hong Kong, a firm set up to take over Linde's star corundum stock. Accordingly, it would appear that any corundum diffusion treatment in this country (or the importation of such stones from abroad) could be performed legally only by Astrid or with their express permission.

PROCESS 9: ADDING COLORS OTHER THAN BLUE BY DIFFUSION

Just as diffusion of iron and titanium oxide can produce a blue skin, so can other color-causing impurities also be diffused, again as described by Carr and Nisevich (1975, 1976, 1977). Thus, the diffusion of chromium produces a red skin, nickel gives yellow, chromium plus nickel creates the pinkish orange "padparadscha," and so on; the colors that will be produced by the diffusion of different substances are well known from sapphire synthesis (Nassau, 1980a). Orange-red diffused stones (figure 10) were examined in detail by Crowningshield in 1979. There may be problems associated with oxidation/reduction conditions if variable valence ions such as iron are involved; the identifying characteristics are the same as those given for *processes 7* and *8*.

The colors produced by these diffusion processes are just as stable as the natural and synthetic colors produced by the same impurities. This contrasts with the yellow to orange color produced by irradiating sapphire, which is unstable and will fade on exposure to light.

COMBINATION TREATMENTS

As suggested above, several of these processes can be combined. Removal of silk and intensification of color can be achieved in a pale sapphire by heating the stone in a reducing atmosphere and then cooling it rapidly, in a combination of *processes 2* and *3*. The removal of silk will produce an improvement in color even in the absence of any other changes, since scattered white light no longer dilutes the color. Among the chemicals employed in this process as used on milky white to pale blue "geuda" Sri Lanka sapphires are a red liquid reported by Crowningshield (1980) and since shown to be mineral oil (its role is described under *process 3*), the soda (sodium [bi-]carbonate?) reported by Harder (1980) which is said to prevent cracking of the stone and possibly to remove some iron preferentially (?), and the "thick coating of local paste" used in oil, gas, or electric furnaces as mentioned by Gunaratne (1981).

Diffusion of iron and titanium oxides and a simultaneous reduction (as in *process 3*) can be performed, according to Carr and Nisevich (1975, 1976, 1977), by embedding pale or nonuniform star sapphire in a mixture of 0.25 weight percent ferric oxide and 13 weight percent titanium oxide, with the balance being aluminum oxide, and heating the material in a reducing atmosphere at 1750°C for 30 hours to produce a uniform-appearing dark blue sapphire; this is a combination of *processes 2, 3,* and *8.* The dominant effect is, however, limited to a thin skin at the surface of the stone.

DISCUSSION AND SUMMARY

Silk, asterism, various colors, and even imperfections in ruby and sapphire can be intensified or diminished by appropriate heat and diffusion treatments, as summarized in table 1. One must sympathize with the gemologist in his attempt to establish whether any of these many treatment methods have been used on a given ruby or sapphire.

Processes 1 through *4* can intensify or remove silk, asterism, or the blue color of sapphire. These processes involve heating in oxidizing or reducing environments only and mimic processes that occur in nature. The development of potential asterism by heat treatment, for example, is successful only if this step was omitted in nature. It is this parallel behavior that renders ineffective most tests commonly used to establish whether a stone has been heat treated by man. Oughton (1971) cites one such test (of which he himself states that "the wisdom . . . is doubtful") in which the least valuable stone from a parcel is heated to observe the behavior. Unfortunately, even this rather risky procedure gives no definite answer in view of the many different types of heat treatment that could have been used previously, the analogous variety of ways in which the test could be performed, as well as the possibility of variation within the parcel. In the absence of reliable tests to identify such treated material, the report and disclosure situation is not clear-cut.

Processes 5 and *6* are used on synthetic material only, so the question of identification is most important but that of disclosure of treatment becomes irrelevant.

The diffusion *processes 7, 8* and *9* do not have a parallel in nature and their use can be identified. Accordingly, it would seem that disclosure of color or stars synthetically enhanced by diffusion is essential.

Finally, it must again be emphasized that the reaction of a material to a given treatment method may produce a variety of results, depending on the exact composition of the stone as well as on its previous treatment history, both in nature and by man.

REFERENCES

Bratton R.J. (1971) Precipitation and hardening behavior of Czochralski star sapphire. *Journal of Applied Physics,* Vol. 42, pp. 211–216.

Burdick J.N., Glenn J.W. (1949) Developing asterism in star corundum. *United States Patent 2,488,507,* filed December 11, 1948, issued November 15, 1949.

Carr R.R., Nisevich S.D. (1975) Altering the appearance of sapphire crystals. *United States Patent 3,897,529,* filed December 15, 1969, issued July 29, 1975.

Carr R.R., Nisevich S.D. (1976) Altering the appearance of corundum crystals. *United States Patent 3,950,596,* filed December 20, 1971, issued April 13, 1976.

Carr R.R., Nisevich S.D. (1977) Altering the appearance of corundum crystals. *United States Patent 4,039,726,* filed December 20, 1970, issued August 2, 1977.

Crowningshield R. (1979) Developments and highlights at GIA's lab in New York. *Gems & Gemology,* Vol. 16, pp. 194–202.

Crowningshield R. (1980) Developments and highlights at GIA's lab in New York. *Gems & Gemology,* Vol. 16, pp. 315–323.

Crowningshield R., Nassau K. (1981). *Journal of Gemology,* in press.

Eigenmann K., Günthard H.H. (1972) Valence states, redox reactions, and biparticle formation of Fe and Ti doped sapphire. *Chemical Physics Letters,* Vol. 139, pp. 58–61.

Eversole W.G., Burdick J.N. (1954) Producing asteriated corundum crystals. *United States Patent 2,690,630,* filed December 28, 1951, issued October 5, 1954.

Falkenberg R. (1978) The Verneuil process. In C.H.L. Goodman, Ed., *Crystal Growth,* Vol. 2, Plenum Press, New York.

Ferguson J., Fielding P.E. (1972) Origins of the colors of natural yellow, blue, and green sapphires. *Australian Journal of Chemistry,* Vol. 25, pp. 1371–1385.

Fryer C. Ed. (1981) Gem Trade Lab notes. *Gems & Gemology,* Vol. 17, pp. 40–46.

Gunaratne H.S. (1981) 'Geuda sapphires'—their colouring elements and their reaction to heat. *Journal of Gemmology,* Vol. 17, pp. 292–300.

Harder H. (1980) Edelsteine durch Brennen von Korunden. *Fortschritte der Mineralogie,* Vol. 58, pp. 45–46.

Jobbins E.A. (1971) Heat-treatment of pale blue sapphire from Malawi. *Journal of Gemmology,* Vol. 12, pp. 342–343.

Lang S.M., Fillmore C.L., Maxwell L.H. (1952) *Journal of Research of the U.S. National Bureau of Standards,* Vol. 48, pp. 298–312.

Lehmann G., Harder H. (1970) Optical spectra of di- and trivalent iron in corundum. *American Mineralogist,* Vol. 55, pp. 98–105.

Lejus A.M., Goldberg D., Revcolevschi A. (1966) New compounds formed between rutile, TiO_2, and oxides of trivalent and quadrivalent metals. *Comptes rendus, Academie des Sciences, Paris,* Series C, Vol. 263, pp. 1223–1226.

Nassau K. (1968) On the cause of asterism in star corundum. *American Mineralogist,* Vol. 53, pp. 300–305.

Nassau K. (1980a) *Gems Made By Man.* Chilton Book Co., Radnor PA.

Nassau K. (1980b) The causes of color. *Scientific American,* Vol. 243, pp. 124–154.

Nikolskaya L.V., Terekhova M., Samoilovich M.I. (1978) On the origin of natural sapphire color. *Physics and Chemistry of Minerals,* Vol. 3, pp. 213–224.

Oughton J.H. (1971) Fakes and frauds—caveat emptor. *Australian Gemmologist,* Vol. 11, pp. 17–22.

Phillips D.S., Heuer A.H., Mitchell T.E. (1980) Precipitation in star sapphire. I. Identification of the precipitate. *Philosophical Magazine,* Series A, Vol. 42, pp. 385–404.

Phillips D.S., Pletka B.J., Mitchell T.E., Heuer A.H. (1976) Precipitation in star sapphire. In J.H. Venables, Ed., *Developments in Electron Microscopy and Analysis,* Academic Press, New York.

Sasaki I. (1980) Treatment of sapphires. *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 29, p. 66.

Schmetzer K., Bank H. (1980) Explanations of the absorption spectra of natural and synthetic Fe- and Ti-containing corundums. *Neues Jahrbuch der Mineralogie, Abhandlungen,* Vol. 139, pp. 216–225.

Tombs G. (1980) Further thoughts and questions on Australian sapphires, their composition and treatment. *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 29, pp. 79–81.

Townsend M.G. (1968) Visible charge transfer band in blue sapphire. *Solid State Communications,* Vol. 6, pp. 81–83.

PHOTOGRAPHING INCLUSIONS

By John I. Koivula

Although the general principles of photomicrography are easily learned and applied, high-quality photomicrography is an art that is mastered only with time and great patience. The microscope must be kept scrupulously clean, and the effects of light on the subject inclusion must be fully understood in order to determine what method(s) of illumination will yield the most useful photographic image. Specialized techniques that can save film and time, while producing top-quality photomicrographs, are usually learned only through long hours of experience. This article discusses some of these techniques, such as the importance of a properly prepared microscope and photographic subject, as well as the control of vibrations and exposure time. In addition, the various methods of illumination that are adaptable to a standard binocular gemological microscope are introduced.

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Photomicrography of inclusions in gems requires the combined techniques of gemological microscopy, photomicrography, and the various specialized methods of illumination that aid in capturing images of a gem's interior on film. It is a simple matter to load film and place a camera body with a microscope adapter over a microscope eye piece, put a gem in the microscope's gem holder, focus on the inclusions within, and start snapping pictures one after the other by pushing the button on the cable release. These, however, are only the first small steps toward good photomicrography.

A sound working knowledge of inclusions in gems and how they react to various forms of illumination is vitally important. This knowledge is the first major step toward outstanding photomicrography. Along this road of learning there are a number of stumbling blocks. How should exposure time be controlled? What about long exposures? How can vibration be reduced? What illumination techniques are available and how can they best be used? And so on.

It is my intent in this article to introduce some important considerations for photographing inclusions through a microscope and to help remove many of these stumbling blocks for the interested gemologist. This article does not attempt to reiterate the "how to" of photomicrography, which has been presented in numerous other articles (some excellent references, for example, are Gander, 1969; Lawson, 1960; Loveland, 1970; Webster, 1966; and Eastman Kodak Co., 1974). Rather, it reports the specific application of these techniques to, and in many cases their refinement for, photographing inclusions.

WHY PHOTOMICROGRAPHY?

Not only are inclusion photographs often quite beautiful, but they can be highly informative as well. Properly identified and catalogued, photomicrographs can serve as a visual reference library that greatly aids the gemologist both in the routine identification of gemstones and in the determination of their origins, especially whether natural or synthetic. It is neither economical nor feasible for one individual to own every gem with interesting inclusions that has ever been encountered, and it is impossible to remember the internal characteristics of every major gem species. With photomicrographs, however, important inclusion characteristics are always available for quick reference.

Photomicrography also affords the jeweler-gemologist a permanent record of the internal characteristics of a specific gemstone. Inasmuch as no two inclusion images are ever exactly alike, the jeweler-gemologist, aided by photomicrographs, can identify beyond reasonable doubt a specific previously photographed stone. Even if a gem is recut, as long as the inclusions are deep within the stone rather than right on the surface, the stone can be identified through previous photomicrographs.

GETTING A CLEAN START

A good microscope should be treated as you would treat any precision instrument. When not in use, it should always be covered. Never smoke around optical equipment, and avoid eating while taking photomicrographs. Although these precautions should slow the process, oculars, objectives, and phototube lenses will eventually become dirty. Accordingly, when lens cleaning is needed, a can of compressed air should be used first to blow off all loose dirt particles. Then a soft camel's hair brush can be employed to lightly loosen any stubborn dust so that another dose of compressed air will blow it away. Oily or greasy smudges can be cleaned with either distilled water (easily produced by breathing on the lens surface) or any of the standard quick-evaporating lens cleaners and a lint-free lens tissue. Never dry-wipe a lens, as this will damage the coating and almost always guarantees a scratched surface. Dirty lenses produce fuzzy, blurred photomicrographs, making it virtually impossible to obtain a critical focus on the subject.

A clean photographic subject is almost as important as clean lenses on the microscope. Tiny dust particles appear as bright hot spots on the developed film, and oily smudges and fingerprints will distort the view of the gem's inclusions. If the subject is very oily, a standard lens cleaner and lens tissue can be used to clean the surface. Normally, though, just wiping the stone off with a clean, lint-free gem cloth is sufficient. Canned air, a blower brush, and a fine-point needle probe can be used to remove small dust particles that are attracted to the surface after the initial cleaning. A useful collection of items for the routine cleaning of microscope lenses and subjects, as shown in figure 1, should be kept close at hand.

Pyroelectric species such as tourmaline are often troublesome dust gatherers when they are slightly warmed by the microscope illuminators commonly used. Therefore, a cool, fiber-optic light source is recommended for the illumination of such materials.

THE TIME FACTOR

Many gemologists rush their preparation for a photomicrograph, and a poor end product almost invariably results. The beginner in a hurry will end up with a far higher incidence of failure than of success. Speed will come only with experience. Whenever possible, as much time as is necessary should be invested to clean the subject thoroughly and adjust the lighting to adequately illuminate the desired features. A few extra moments taken in the initial set up will not only save film, but will also eliminate the necessity of a reshoot in most cases. It should be remembered that the number of mistakes made increases as the time spent decreases, so if you want good inclusion photomicrographs, be prepared to spend the time.

Figure 1. A collection of items useful in cleaning microscope and gem alike. These are, from left to right: lens paper, lint-free gem cloth, lens cleaner (two brands displayed here), needle probe, small camel's hair brush, can of compressed air, and camel's hair blower brush.

CONTROLLING VIBRATIONS

Common vibration is often responsible for many a ruined photomicrograph. As exposure time and magnification increase, vibration problems also increase. The problem is how to isolate the photomicrographic unit from unavoidable room vibrations during the entire exposure cycle. Optical isolation benches and air flotation tables have been designed for this specific purpose, but their costs are prohibitive for most photomicrographers. Making your own vibration control stage is the logical alternative, and this is easily done.

Start with a hard, thick-surfaced, sturdy table as a primary base. Place a rubber cushion (such as a typewriter pad) on the table. Then put a ¼- to ½-inch-thick steel plate on the rubber cushion. Next, position another rubber cushion over the steel plate. On this cushion, place a 1- to 3-inch-thick granite (or similar rock) slab. Flat, preshaped, and finished rock slabs can be obtained from a local stone mason. The photomicrographic unit will rest on the rock slab. The rubber cushions effectively eliminate short, sharp vibrations while the table top, steel plate, and rock slab reduce rolling vibrations of longer wavelengths. This method eliminates vibrations for virtually all magnifications less than about 150×.

Even when an anti-vibration base is used, care must be taken to avoid touching the microscope itself, the table, or any miscellaneous equipment on the table during the actual exposure.

EXPOSURE TIME

Long exposure times are one of the inclusion photomicrographer's worst enemies because of the potential for color shifts in the film and vibration problems. The speed of the film used and the amount of light reaching the film dictate the length of exposure. In attempting to reduce exposure time, usually it is better to apply additional light to the subject than to use a faster film. In general, the higher the film speed is, the greater the graininess of the film will be. If the recorded image is to be enlarged, this should be considered. Also, as the film speed increases, the quality of the colors obtained decreases. There is an obvious difference in color saturation and richness between photographs taken with 50 ASA film and those taken with high-speed 400 ASA film.

ILLUMINATION TECHNIQUES

Dark-field Illumination. Through the microscope, the routine observation and photography of inclusions in gem materials is greatly aided by the use of dark-field illumination. In the dark-field technique, the direct transmission of light

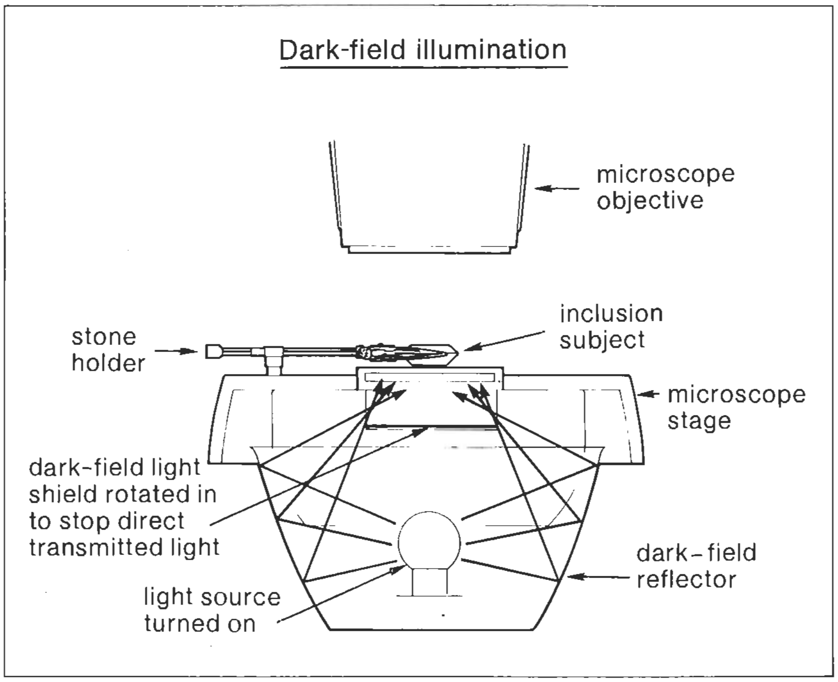


Figure 2. In dark-field illumination, the direct transmission of light from below the stone is blocked so that only indirect side light reflected from below reaches the subject.

Figure 3. Reminiscent of the Pailin, Cambodia, urano-pyrochlors, these two tiny, intergrown, orange-red garnets, surrounded by a residual liquid halo, seem to streak through their Thai sapphire host. The "comet tail" is the result of directional growth disturbance caused by the garnets. Dark-field illumination, magnified 45×.

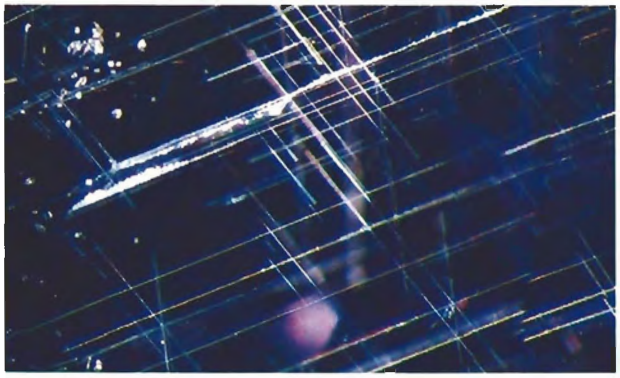


Figure 4. Often mistaken for rutile, this latticework of boehmite, AlO(OH), in an African sapphire is the result of stress along repeated twin junctions. Dark-field illumination, magnified 60×.

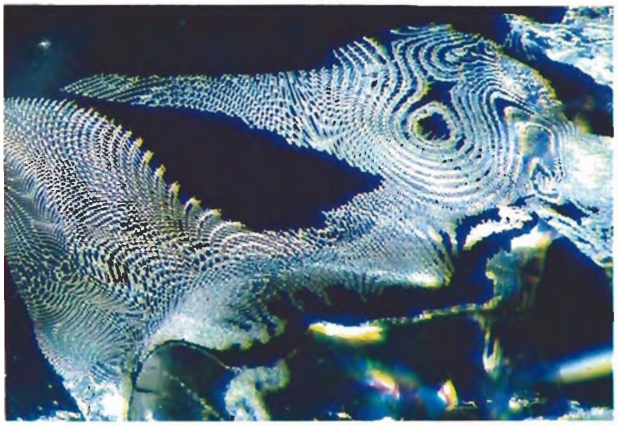


Figure 5. The descriptive term fingerprint *readily applies to partially healed fractures such as this one in rock crystal quartz from Brazil. Dark-field illumination, magnified 50×.*

from below through the inclusion host is blocked by a dark-colored (preferably black), opaque light-shield. The only light to reach the subject is indirect side light reflected from below around the sides of the opaque light shield by a hemispherical or circular mirror-like reflector (figure 2).

With this technique, only light that is scattered or reflected by the inclusions enters the microscope objectives and passes to the film plane. The inclusion subjects are seen very brightly against a dark background. Even tiny inclusions stand out in high relief, and a tremendous amount of detail may be photographed. Dark-field lighting is most applicable to the study of included crystals (figures 3 and 4), some small fluid inclusions, healing fractures (figure 5), and cleavages.

For dark-field photomicrography, the subject must be very clean, since dust on the surface of the host readily stands out as tiny hot spots, while grease and finger smudges become highly visible surface swirls that tend to dim or fog the internal features.

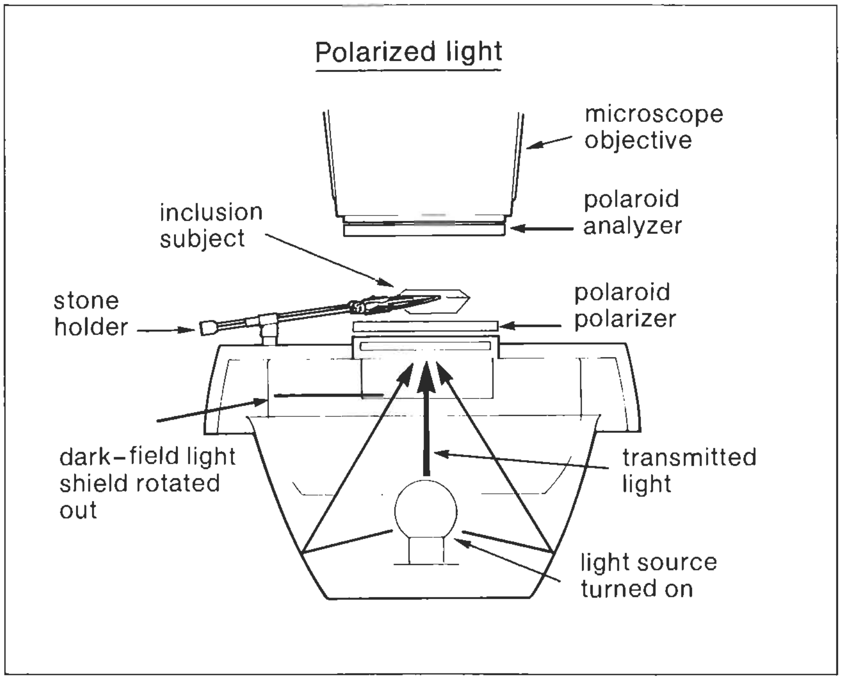
Polarized Light. Polarized light microscopy is often thought of as a mineralogist's tool and has long been neglected by gemologists. Any gemological microscope with transmitted light capabilities can be easily converted, temporarily, to a polarizing microscope. Two polaroid plates are the only requirement. One polaroid, called the polarizer, is placed over the transmitted light port under the gem subject. The other polaroid, called the analyzer, is placed over the gem subject in front of the microscope objective (as shown in figure 6). Normally, the analyzer is rotated and the polarizer remains fixed, but in this set-up both can be rotated. In routine examinations, unprotected plastic sheet polaroids with their fine scratches and slightly warped surfaces are adequate, but for photomicrography camera-type polaroid filters of good optical quality are needed.

In color and variety, the world of polarized light microscopy can be both startling and beautiful, especially if one is using this technique for the first time. Internal strain around included crystals, crystal-intergrowth induced strain, and twinning (as illustrated in figures 7, 8, and 9) all become visible under polarized light. Included crystals of very low relief, if doubly refractive, will stand out readily when polarized light is used and optic figures in gems can be located and photographed. If the polarizer is removed, the photographer can easily capture an inclusion in a strongly birefringent gem, such as peridot or zircon, by rotating the analyzer and clearing the otherwise strongly doubled image.

In polarized-light photomicrography, light levels are usually low and exposure times are correspondingly long; if vibrations are controlled, though, the photographic results can be quite spectacular.

Figure 7. Under polarized light, a crystal of apatite included in an almandine garnet from Sri Lanka shows the strain it is causing in its host. Magnified 70×.

Figure 6. Polarized light microscopy requires the addition of only two polaroid plates, the polaroid polarizer and the polaroid analyzer, to convert a gemological microscope with transmitted light capabilities to a polarizing microscope.



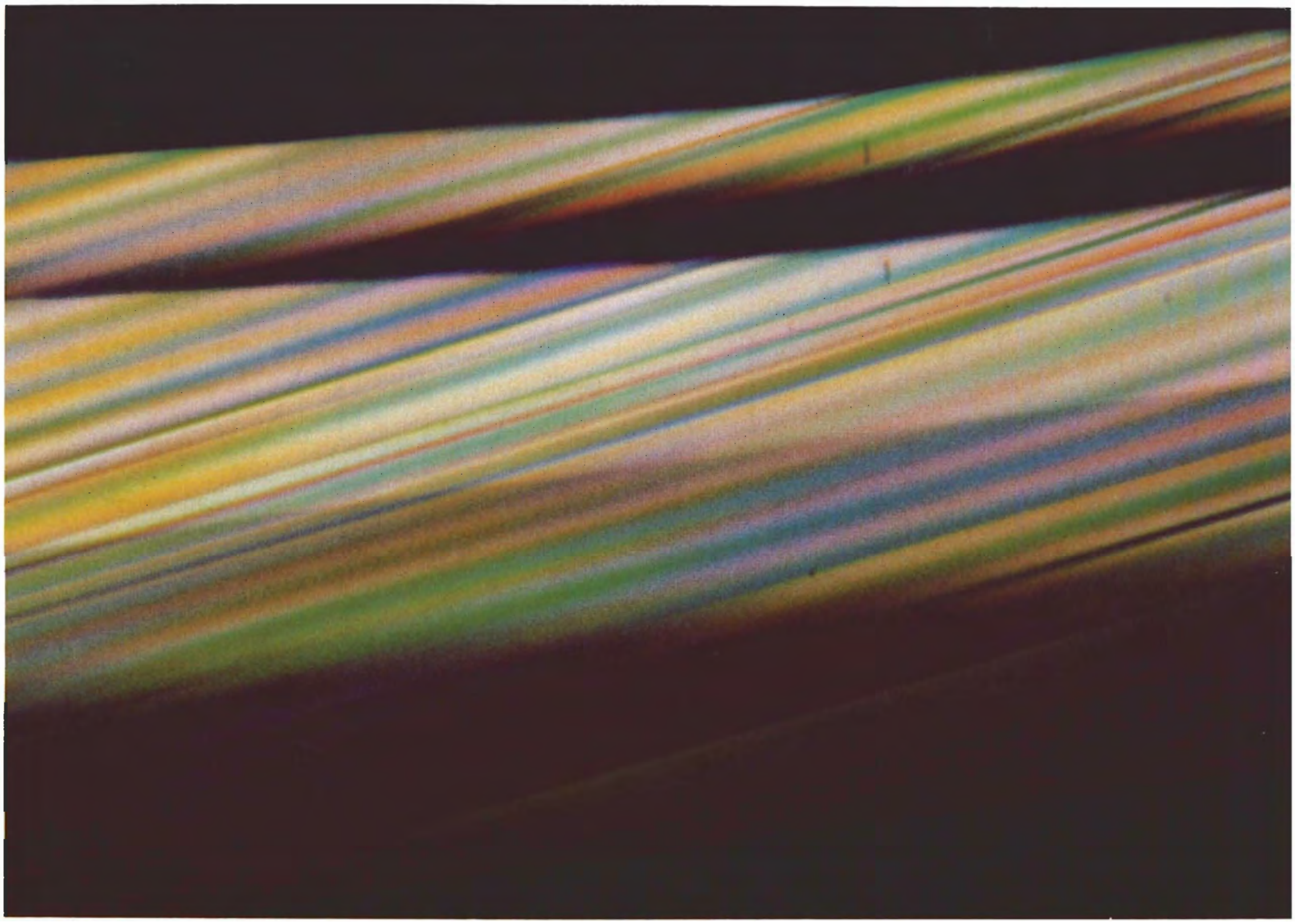


Figure 8. This brightly colored pattern is produced by the effect of polarized light on a twinned orthoclase feldspar from Itrongahy, Madagascar. Magnified 50×.

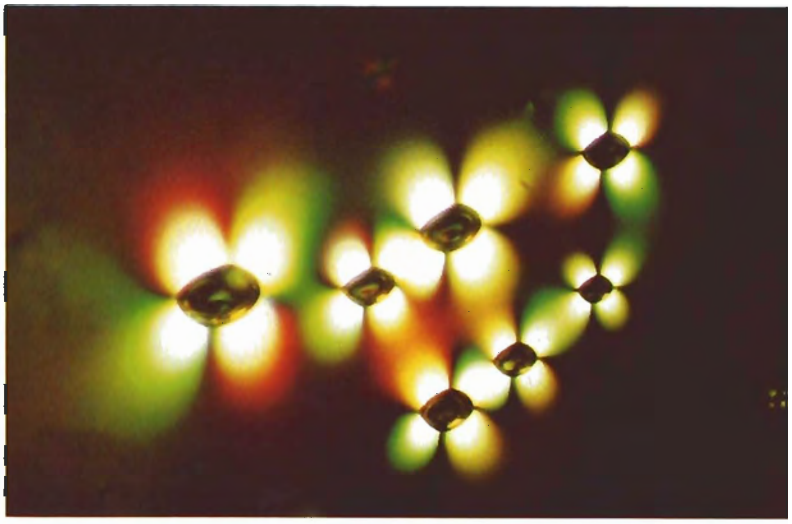


Figure 9. These seven gas bubbles in a piece of amber from the Dominican Republic reveal themselves to be strain centers under polarized light. Magnified 30×.

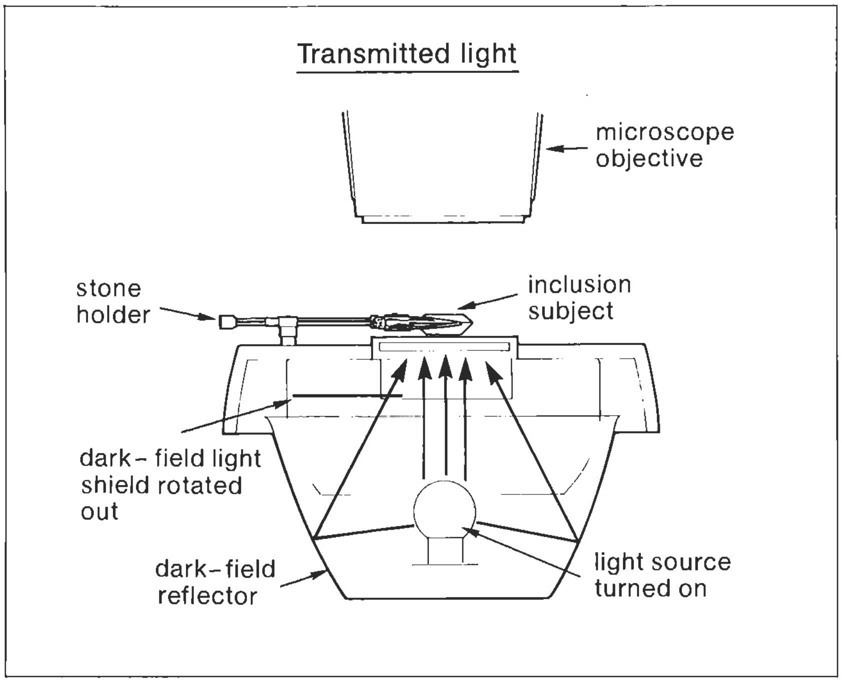


Figure 10. To produce transmitted light, the dark-field light shield is removed and light is allowed to pass from directly below the gem, through the stone itself, upward into the microscope system.

Transmitted Light. Transmitted light is produced by removing the dark-field light shield and allowing the passage of light from directly below the gem, through the gem itself, upward into the microscope system (see figure 10). A great deal of the detail normally seen with dark-field illumination is lost in transmitted light. Darkly colored or opaque included crystals and fine growth features are virtually washed out. Large fluid inclusions such as those shown in figure 11, however, are very easily examined in transmitted light. Details in these fluid chambers that were invisible under dark-field conditions stand out readily in a beam of transmitted light. Color zoning is also easily observed and photographed.

When transmitted light is used, exposure times are at their shortest. Small dust particles on the surface of the host gem are no problem, since the quantity of direct bright light washing around them tends to cancel their ability to interfere with light transmission.

Oblique Illumination. Between the 0° angle of horizontal lighting and the 90° angle of vertical illumination lies a range of angles that is known as the *arc of oblique illumination* (see figure 12).

Oblique illumination is seldom used in gemology except in the examination of opaque materials; when it is applied to transparent gems, however, the results can be both beautiful and fascinating. Behaving like thin films, fractures and ultra-thin liquid fingerprints (such as those shown in figures 13, 14, and 15) spring to life, dec-

Figure 11. This secondary healing plane of tiny negative crystal fluid inclusions in a spessartine garnet from Virginia is well detailed by transmitted light. Magnified 75×.

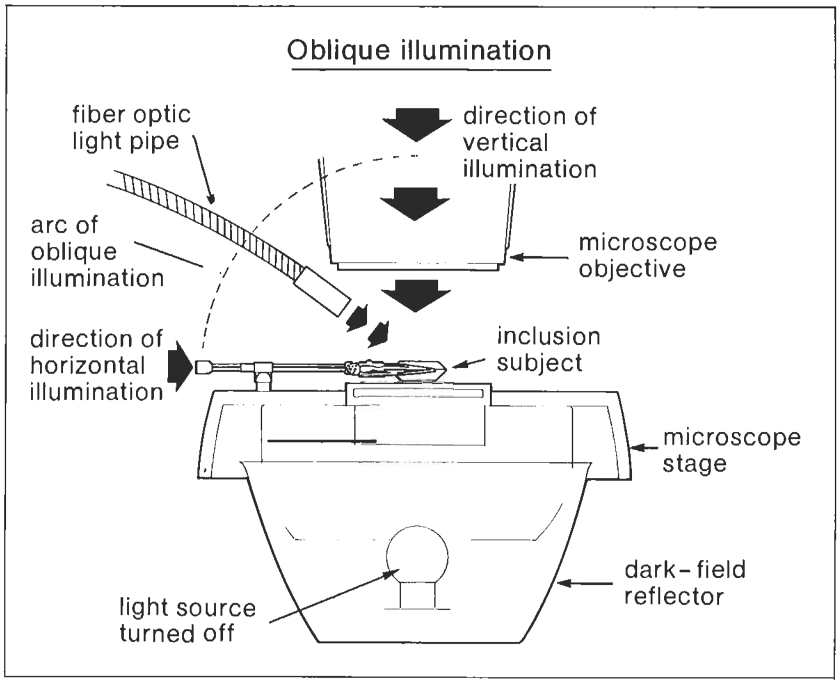


Figure 12. Oblique illumination involves the transmission of light from an outside source along the range of angles between the 0° angle of horizontal lighting and the 90° angle of vertical illumination.

Figure 13. This conchoidal fracture in a Brazilian beryl shows its every detail in vividly reflected colors. Oblique illumination, magnified 55×.

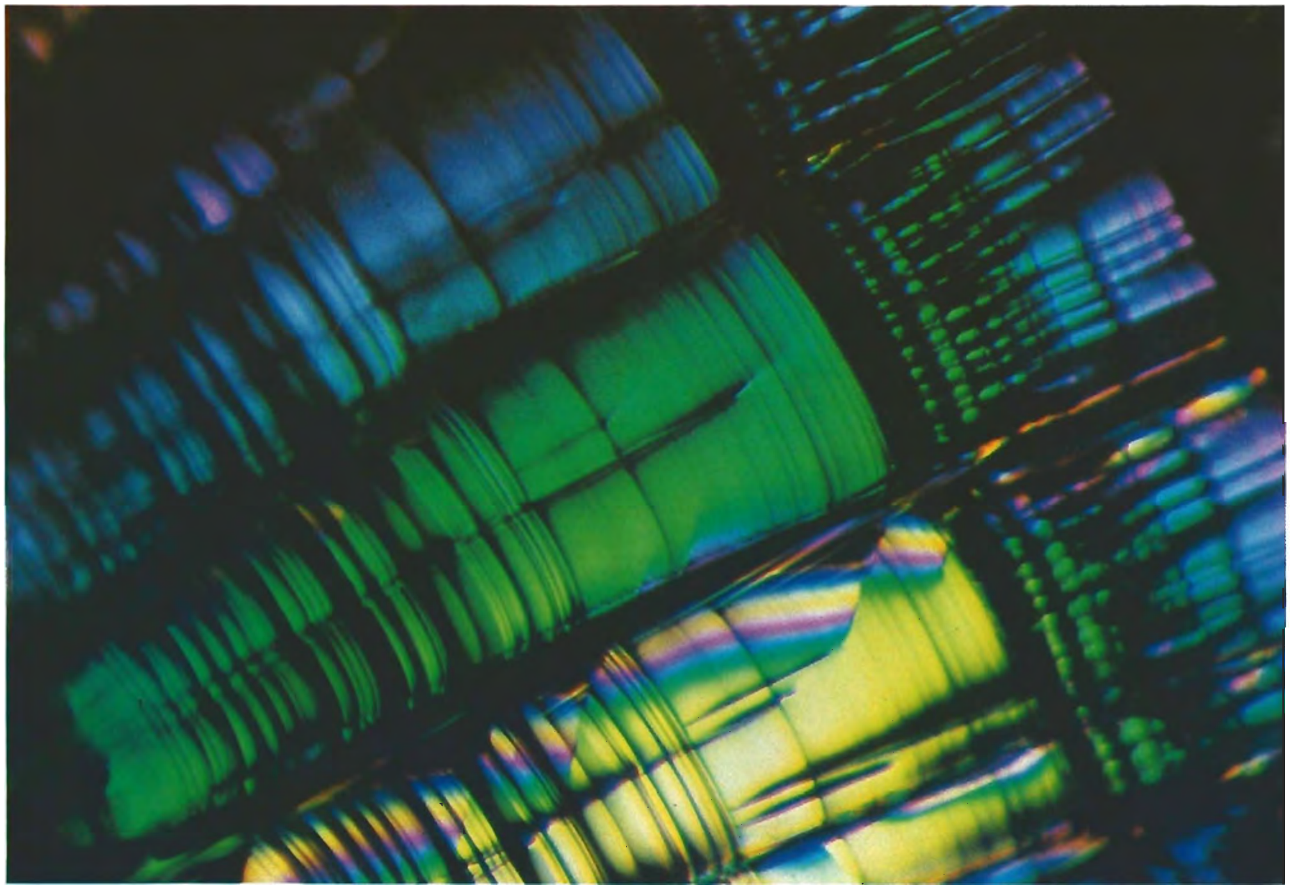


Figure 14. This partially healed pseudo-secondary fracture was photographed in a high zircon from Sri Lanka. The color-reflecting veins are areas of separation, while the black represents areas that have healed. Oblique illumination, magnified 40×.

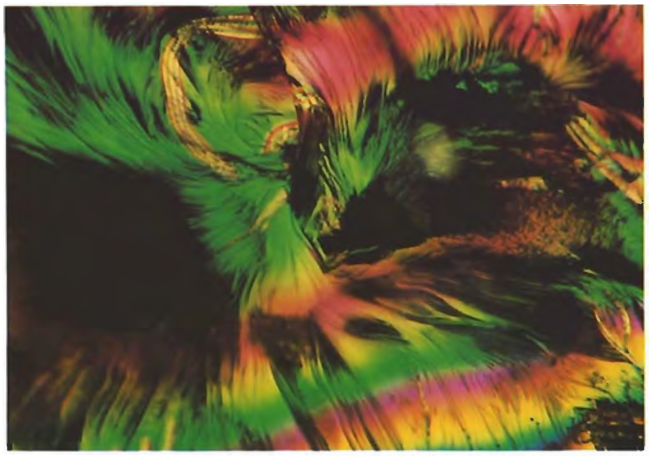


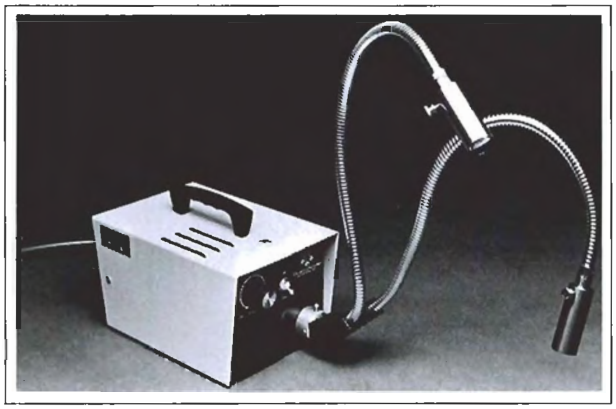
Figure 15. This cleavage in a fluorite from Colombia shows only small areas of nonseparation or healing (i.e., very little black). Oblique illumination, magnified 85×.

orated by vibrant interference colors. Interfaces surrounding included crystals show details of growth on the crystals that otherwise elude observation. Reflecting facets return the oblique light rays to the observer's eye, seemingly magnifying their intensity and the richness of color.

A variety of lighting sources can be used for oblique illumination. One of the most efficient is a fiber optic illuminator, such as the one shown in figure 16.

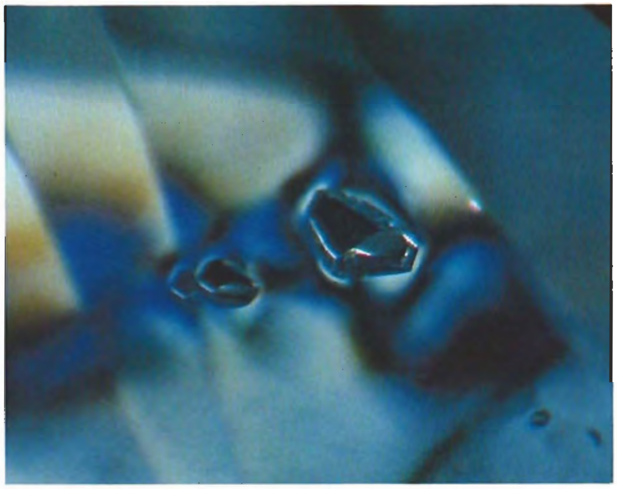
Oblique illumination may also be used in combination with other methods of illumination, such as dark-field or polarized lighting, to add color highlights and additional light where needed, thus revealing more detail, adding desirable reflections, and reducing the exposure time required. Figures 17, 18, and 19 illustrate the results that may be obtained when oblique illumination is used with another lighting source.

Figure 16. A fiber optic illuminator, such as the one shown here, is an excellent source of oblique lighting. It can also be used to direct additional light where it is most needed, effectively reducing the exposure time in most cases.



Ultraviolet Illumination. The use of ultraviolet light in photomicrography and inclusion research

Figure 17. Under combined polarized and oblique illumination, these garnets in a diamond from Africa show the strain produced in the host gem as a direct result of their presence. Magnified 40×.



is somewhat limited. If the host gem material, such as quartz or flourite, is transparent to ultraviolet wavelengths, then certain included organic fluids (such as those in figure 20) and fluorescing solids will be seen to glow under the influence of the ultraviolet illumination. The low light levels of ultraviolet photomicrography often require excessively long exposure times, so slight vibrations in the equipment may become a problem.

WHY NOT IMMERSION?

Immersion techniques have their place in gemology; but not, at least in this writer's opinion, in photomicrography. A general rule of thumb is that the more lenses and other optically dense media that lie between the film plane and the subject, the lower the image quality will be. The common immersion liquids are dense, poisonous organic compounds that are typically colored. They generally are difficult to work with and sensitive to the bright lights that are needed for inclusion photography. Their colors tend to darken

Figure 18. As nucleating growth from their apatite centers, these stars of rutile in a red African garnet stand suspended above a plane of facet junctions. Dark-field and oblique illumination, magnified 30×.

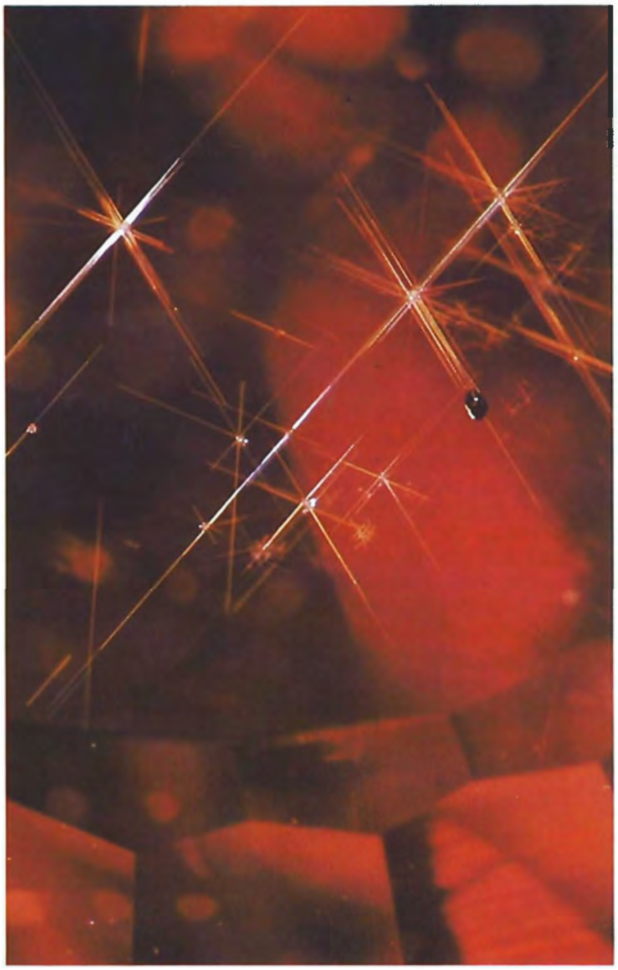
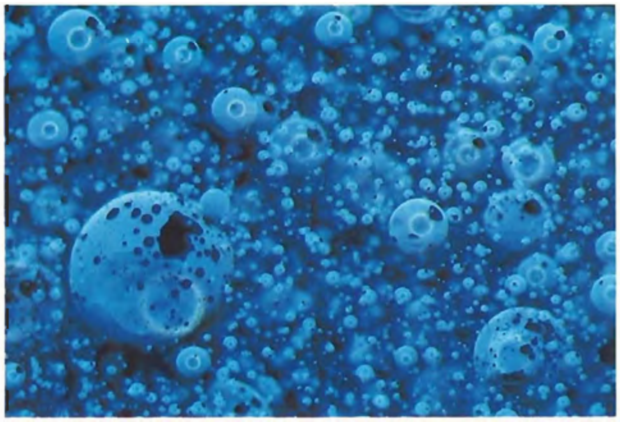


Figure 19. Under combined transmitted and oblique illumination, these negative crystals show not only their detailed form but also the amethystine coloration of their Brazilian quartz host. Magnified 70×.

Figure 20. Under long-wave ultraviolet illumination these spherical voids, filled with liquid petroleum—a solid tar-like substance—and a bubble of methane gas, cause the interior of their Illinois fluorite host to glow. Magnified 35×.



after only short exposure to these lights. In addition, they must be filtered continually to remove the microscopic dust particles that readily contaminate them. If they are not filtered, the suspended dirt will appear through the microscope as a milkiness composed of hundreds, or even thousands, of "floaters" in continuous motion, some in focus and some just out. The convection currents in these dense liquids are often seen as heat wave–like swirls that can distort a photographed image, especially if the exposure time is long.

Although, to the beginner, facet reflections are often very irritating and seemingly uncontrollable, with experience the photomicrographer will find that these reflections can become welcome sources of additional lighting and can add both color and desirable highlights to photomicrographs. It is important to work with the light by manipulating both the gem being photographed and the source(s) of illumination. The use of immersion to control facet reflections, although somewhat tempting to the novice, only adds an additional thickness of optically dense material between the subject and the film, thus reducing the quality of the image.

PHOTOGRAPHING SCRATCHED GEMS AND ROUGH CRYSTALS

Occasionally a gem is encountered with unique internal patterns that beg to be photographed, but the surface of the stone is so badly scratched that obtaining a clear image is virtually impossible. In such situations, a modified immersion technique can work very effectively. This technique employs a small droplet of an index of refraction liquid, such as a Cargille liquid, with a refractive index very close to that of the gem being photographed. The droplet is placed on the scratched stone and, as it wets the gem's surface, all of the abrasions seem to disappear, effectively eliminating the image obstructions and allowing a clear view of the gem's interior.

This technique has several advantages over total immersion. The liquid layer is very thin, so the effects of liquid color and density currents on image quality are negated. So little liquid is used that clean-up is very easy, and the strong odors that are so prevalent during total immersion are practically nonexistent. In addition, back reflecting facets can still be used to highlight the inclusion. This method is especially useful on soft, easily scratched gem materials such as amber.

This technique is also very helpful when studying the interiors of natural crystals through their rough crystal faces or waterworn surfaces. And it can be a tremendous aid in locating optic figures in anisotropic gemstones without having to resort to total immersion.

CONCLUSION

Inclusion photomicrography is a gemological skill that is well worth mastering. The knowledge necessary to obtain high-quality photomicrographs goes far beyond the mere mechanics of the marriage of microscope to camera, and into the nature and very origins of the inclusions themselves.

Photomicrography adds yet another dimension to gemological microscopy and further aids the gemologist in recording and identifying stones and in appreciating the complex nature and striking beauty of inclusions in gems.

REFERENCES

Eastman Kodak Co. (1974) *Photography through the Microscope.* Kodak Publication No. P-2, Rochester, NY.

Gander R. (1969) *Photomicrographic Techniques.* Hafner Publishing Co., New York and London.

Lawson D.F. (1960) *The Technique of Photomicrography.* MacMillan Co., New York.

Loveland R.P. (1970) *Photomicrography. A Comprehensive Treatise,* Vols. 1 and 2. John Wiley & Sons, New York.

Webster R. (1966) Photographic techniques used in gem testing. *Journal of Gemmology,* Vol. 1, pp. 13–17.

CRYOGENICS, AN AID TO GEMSTONE TESTING

By Stephen C. Hofer and D. Vincent Manson

Cooling of gemstones to low temperatures provides for enhanced detail in the absorption spectra. This article identifies some simple techniques for cooling gems that are available to the jeweler-gemologist and offers a detailed description of the procedures used in the research laboratory for automatic recording of spectra at low temperatures. Examples of the differences observed between spectra recorded on stones held at room temperature and those recorded for the same stones at significantly lower temperatures are presented for diamond, emerald, and synthetic alexandrite.

The ability to measure the detailed transmission or absorption spectra of gemstones in the ultraviolet, visible, and infrared portions of the electromagnetic spectrum is a necessity for the modern gemological research laboratory. Accurate data on the occurrence of absorption lines can be invaluable in the identification of some gemstones. When used by the informed gemologist, spectra can also aid in distinguishing natural from synthetic, treated, or imitation gemstones as well as in determining the cause of the color in certain gemstones (Liddicoat, 1977).

In recent years, technological advances in spectroscopy have provided the gemologist with new and interesting possibilities. The specially designed optical spectroscopy equipment assembled in the Department of Research of the Gemological Institute of America has proved invaluable in applying some of these advances, enabling the research gemologist to record, file, photograph, display, manipulate, and store spectral data for comparison in future identifications.

Recently the application of cryogenics (i.e., the use of very low temperatures) to the system has played an important role in extending the usefulness of spectroscopy in gem testing. The chapter on atomic motion in Holden (1965) describes the phenomenon whereby the thermal vibrations of atoms modify the transmission characteristics of light passing through a material. Essentially, atomic vibrations in the crystalline lattice "diffuse" the energies at which absorption occurs and make the absorption lines broad and elusive at room temperature. Cooling the gems to low temperatures enhances the detail with which the absorption lines appear by slowing down the atomic vibrations in the crystalline lattice.

This article discusses some techniques of cooling gemstones that are accessible to the jeweler-gemologist who is familiar with a hand spectroscope, as well as

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The authors thank Peter Johnston, of the Gem Media Department of GIA, for the illustrations in figures 1–5.

methods and equipment used in the more sophisticated research laboratory. To illustrate the usefulness of cryogenics in gemology, details of spectra recorded for diamond, emerald, and synthetic alexandrite are also given.

LOW-TEMPERATURE SPECTROSCOPY FOR THE JEWELER-GEMOLOGIST

There are several methods by which gems can be cooled to provide enhanced spectra for the gemologist using a hand spectroscope unit. Spectroscope units that provide a gemstone holder are preferred, since the holder minimizes the need for handling and thus prematurely warming the cold specimen. If the unit does not have a built-in heat filter, one should be added to protect the gemstone from lamp heat.

One useful cooling agent is refrigerant gas, which is commercially available in disposable cans. Refrigerant aerosol products are marketed under a variety of names (e.g., Quik-Freeze MS-240, manufactured by Miller-Stephenson Chemical Co.); all provide effective cooling of gemstones to temperatures of approximately −45°C/ −50°F. Such temperatures are usually recorded in the scientific literature on the Kelvin scale. See table 1 for temperature conversions between Fahrenheit, Celsius, and Kelvin.

An alternative coolant might be ice or, preferably, "dry ice" (solid carbon dioxide). A less satisfactory cooling method, but one that is still of value with some stones, is to leave the stone in a pair of tweezers in a food freezer for a short period of time (approximately 15 minutes) before examining it with the spectroscope.

With some practice, in most cases the gemologist will be able to see a sharpening of spectral lines on the cooled stone, and thus will observe more detailed spectra. Additional information on other spectroscopic techniques for improving spectral observations can be found in Webster (1975). An excellent series of articles on techniques useful to the spectroscopist have been published by Anderson (1953).

While there are some advantages to be gained with the methods of cooling described above, they are not entirely satisfactory. First, the gem will absorb heat rapidly from the surrounding air, so spectral examinations must be done quickly to ensure the most satisfactory results. Second, some gemstones, because of inclusions present, are susceptible to damage when subjected to abrupt temperature changes (Koivula, 1980). Great care should be taken not to "thermally shock" the stone. We recommend that cooling with refrigerant gas or dry ice be avoided when testing highly included gems.

TABLE 1. Temperature conversions for degrees Fahrenheit, degrees Celsius, and Kelvin units.

Degrees Fahrenheit (°F)	=	9/5 (°C) + 32
Degrees Celsius[a] (°C)	=	5/9 (°F − 32)
Kelvin (K)	=	°C + 273.16

[a] Previously Centigrade.

LOW-TEMPERATURE SPECTROSCOPY WITH LIQUID NITROGEN

In order to cool gems gradually and observe spectra at cryogenic temperatures on a routine basis, the GIA research department recently constructed an optical bench spectroscopy unit similar to the one described by Scarratt (1976). This design for an apparatus to lower the temperature of gems during a spectroscopic examination was proposed by Dr. A. T. Collins of King's College, London, for use in the London Chamber of Commerce Gem Testing Laboratory.

While the optical bench arrangement does not readily provide a permanent record of the observed spectrum, it is very practical and relatively inexpensive compared to the more sophisticated equipment used in the research laboratory. By boiling off liquid nitrogen (available from suppliers of industrial gases) and passing the vapor through a tube protected by an evacuated annular sleeve (see figure 1), the gemologist can easily achieve a temperature of 120 K and maintain it for an extended testing period relative to the abbreviated period available with the previously mentioned cooling methods. The windows in the tube are made of silica glass to extend the light transmission into the ultraviolet and near infrared regions of the spectrum.

A unique feature of the GIA system results from the design of the tube system to enable the testing of as many as seven stones during a single cooling cycle. The mounting plate has apertures to accommodate gemstones of various sizes, and is connected to a rod for positioning the gem in the focused light beam. This metal rod also serves as a thermocouple probe which provides for a display of the gemstone's temperature. The light

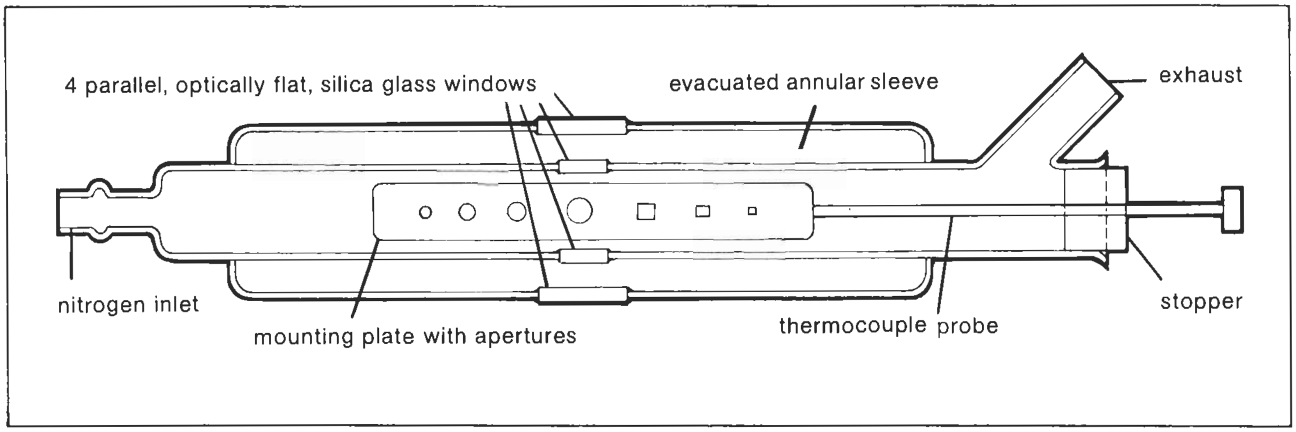


Figure 1. Diagram of a glass tube with evacuated annular sleeve and mounting plate for use with liquid nitrogen on an optical bench.

beam, after it passes through the cooled gem, is collimated and focused with lenses onto the slit of a direct-vision spectroscope for analysis. Cooling the gem for spectral analysis by this system has proved useful in the lab and provides a dramatic view of the sharpening effect that cooling has on spectra. For more detailed analysis of gem spectra, a recording capability is desirable.

THE RECORDING SPECTROPHOTOMETER

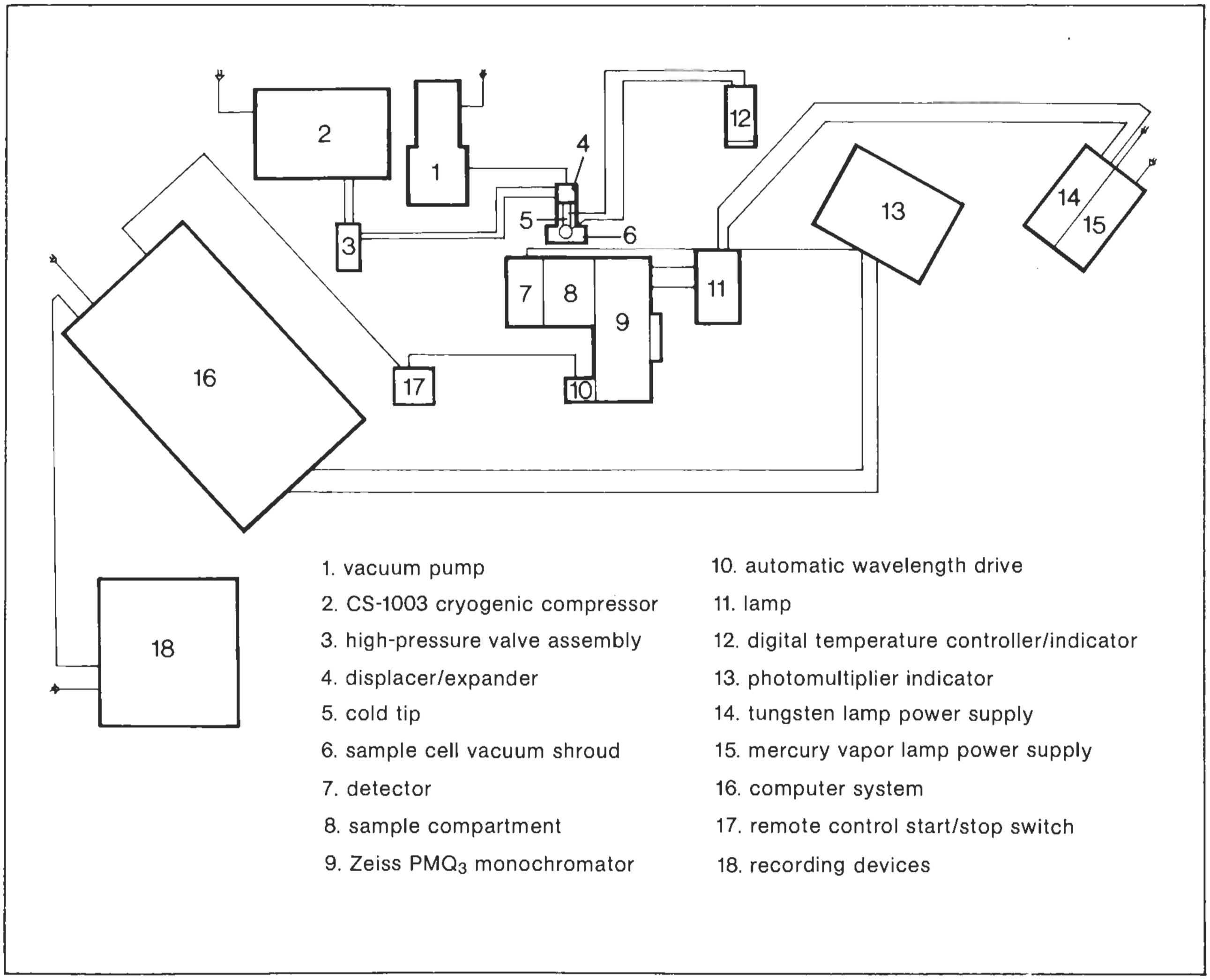
The Zeiss PMQ$_3$ spectrophotometer used at GIA is suitable for studying the absorption of radiation by gemstones in the ultraviolet, visible, and near infrared regions of the electromagnetic spectrum from 2000 Å (angstroms) to 25,000 Å. The essential equipment to complete such a spectrophotometry system includes a light source, a monochromator, a sample compartment, a detector, and recording devices (figure 2). The monochromator is used to select the electromagnetic radiation of a single frequency from a beam of radiation that covers a wide range. The Zeiss PMQ$_3$ single-beam monochromator is equipped with an automatic wavelength drive assembly, which makes a spectral scan between any two wavelengths in the ultraviolet, visible, and near infrared regions possible.

The wavelength drive is equipped with a remote-control start/stop switch operated by a computer that is programmed to record an absorption spectrum and store it in computer memory automatically. As many as 150 different spectra may be stored on one "floppy" data disc. Later comparison and manipulation of the stored spectra is possible with display of the spectral transmission curve on a cathode ray tube screen or on a chart recorder. These displays enable the operator to assess the character of the spectral scan rapidly and to measure the wavelength of the absorption bands precisely.

The absorption lines and bands may be measured directly at the wavelength at which they occur (in angstroms) or may be converted into units of electron volts that correspond to the energy associated with that wavelength, wavenumbers, or into any other desired unit (Nassau, 1976).

With the addition of the custom-designed cryogenic system to the spectrophotometer, transmission spectra may be collected on faceted gemstones held at temperatures as low as 50 K. The Air Products and Chemicals Corporation model CS-1003 cryogenic compressor is a closed-cycle cooling system with a cooling range to 40 K (−233°C). The unit consists of a compressor module that is connected to a high-pressure valve assembly which provides a flow of research-grade helium to the "cold tip," a displacer/expander cooling assembly. The system gives fast (less than 30 minutes) cool down and temperature stability at 40 K. The ease of operation and small size of the CS-1003 make it suitable for use with the Zeiss PMQ$_3$ spectrophotometer.

To control the transfer of convective heat and to provide a moisture-free environment for the stone, a high-vacuum sample cell was fabricated. The cell has optically flat silica glass windows for transmission of the light beam. With this apparatus, a vacuum of 1×10^{-3} torr is maintained for



1. vacuum pump
2. CS-1003 cryogenic compressor
3. high-pressure valve assembly
4. displacer/expander
5. cold tip
6. sample cell vacuum shroud
7. detector
8. sample compartment
9. Zeiss PMQ3 monochromator
10. automatic wavelength drive
11. lamp
12. digital temperature controller/indicator
13. photomultiplier indicator
14. tungsten lamp power supply
15. mercury vapor lamp power supply
16. computer system
17. remote control start/stop switch
18. recording devices

Figure 2. Schematic diagram of the automatic recording spectrophotometer and cryogenic system used at the Gemological Institute of America.

extended periods during a cryogenic spectroscopic examination.

Collecting the scattered transmittal light signal that results when the collimated light beam is passed through a small faceted gemstone poses a problem that has also been solved with this system. A set of truncated parabolic reflectors with known focal lengths are positioned back to back with the gemstone at the common focal point. This allows examination of gems of any shape from 0.5 mm to a maximum of approximately 20 mm in any dimension (figure 3).

With the addition of an ADP-B temperature indicator/controller, the system can monitor the temperature of samples to a stability of ±1 K over a range of 40 K to 300 K. The cool-down time is less than 30 minutes, and the addition of a heater circuit at the tip enables the rapid return of the cold head to room temperature. Two iron-doped gold vs. Chromel thermocouples are connected to the temperature indicator/controller, one for the cold tip and the second for the sample mount to determine the temperature gradient, if any, between the cold head and the actual sample.

The present arrangement of a single-stone sample cell has proved invaluable to linking the cryogenic capability with gemstone spectroscopy in the research laboratory. To extend these capabilities, a new sample cell has now been designed with a vacuum shroud that will accommodate up to five samples for examination during a one-hour cool-down period.

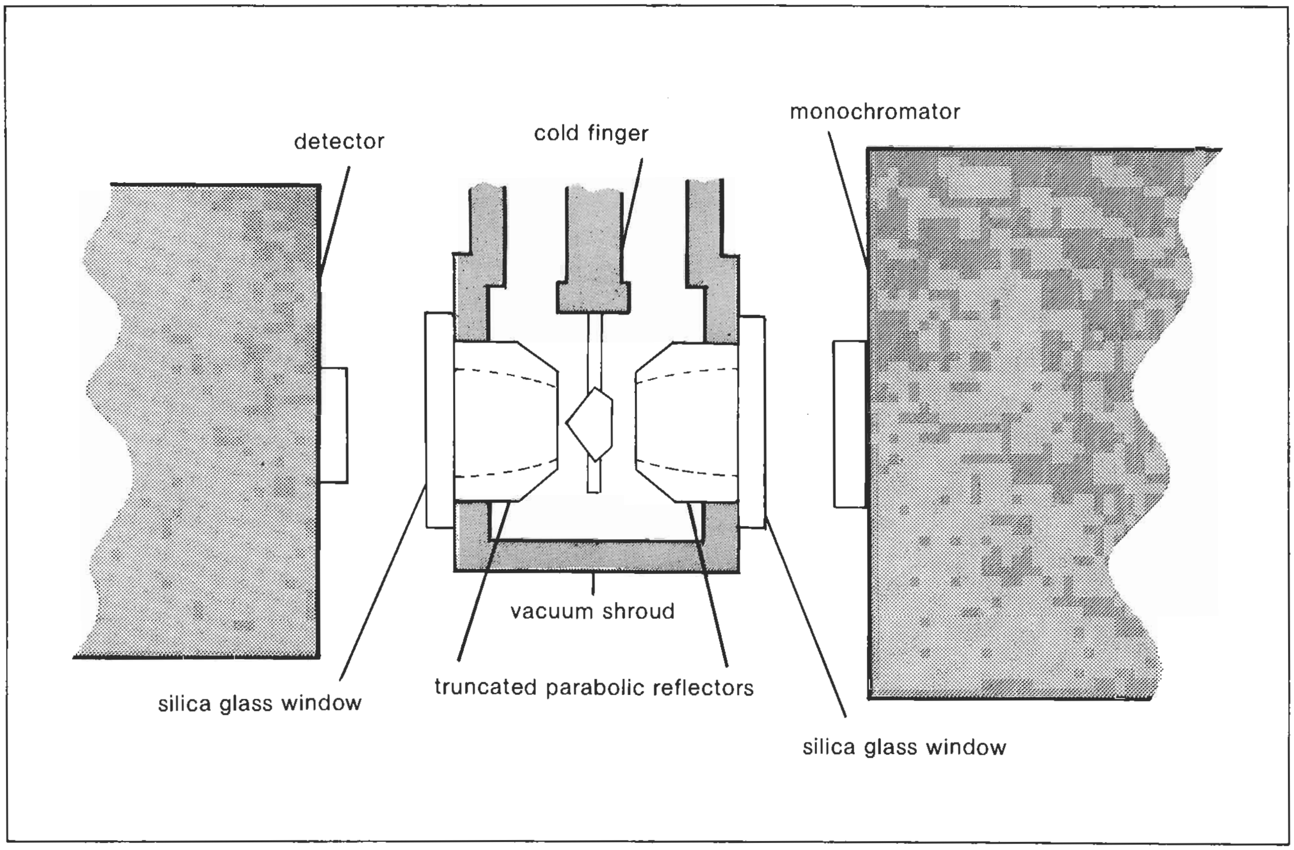


Figure 3. Schematic diagram illustrating the use of truncated parabolic reflectors in a cryogenic sample compartment.

EXAMPLES OF CRYOGENIC SPECTROSCOPY

Three examples of how the spectral absorption lines observed in gemstones cooled to very low temperatures can show more detail than those observed in the same stones at room temperature are presented here. Two visible-region spectra were recorded for an irradiated diamond, an emerald, and a synthetic alexandrite for the wavelength range from 4000 Å to 8000 Å, as shown in figure 4. In each section of this figure, the upper spectrum plot is recorded at room temperature, the lower at 55 K (−218°C), on the Zeiss PMQ_3 spectrophotometer. The absorption "lines" appear here as sharp depressions in the continuous transmission curve. In figure 5, the same spectra are shown as they would be observed on the hand spectroscope used by most gemologists.

Diamond. Some of the principal features of the optical absorption spectra of an irradiated diamond are displayed in section A of figure 4. A natural diamond containing nitrogen impurities (evident from the line at 4155 Å) has been irradiated and heat treated to enhance its color. The key to the history of this stone was found through spectral examination at a very low temperature. The 4960 Å/5040 Å pair is barely discernible at room temperature (upper plot), and the 5920 Å line is questionable because of its elusive nature. On the spectral absorption plot produced when the stone was cooled to 55 K, the enhancement of the 5920 Å and other absorption lines proves the irradiation history of this stone.

Emerald. Cooling of an emerald, as represented in section B of figure 4, provides the spectroscopist with a classic representation of the absorption pattern of emeralds. The sharp line at 4770 Å, which is not often seen in light-colored emeralds, is clearly evident at 55 K. The general appearance of the chromium lines in the red area improved after cooling. There are three main lines, at 6352 Å, 6593 Å, and 6830 Å; under close inspection, the 6830 Å line is seen to be a doublet of lines at 6802 Å and 6843 Å.

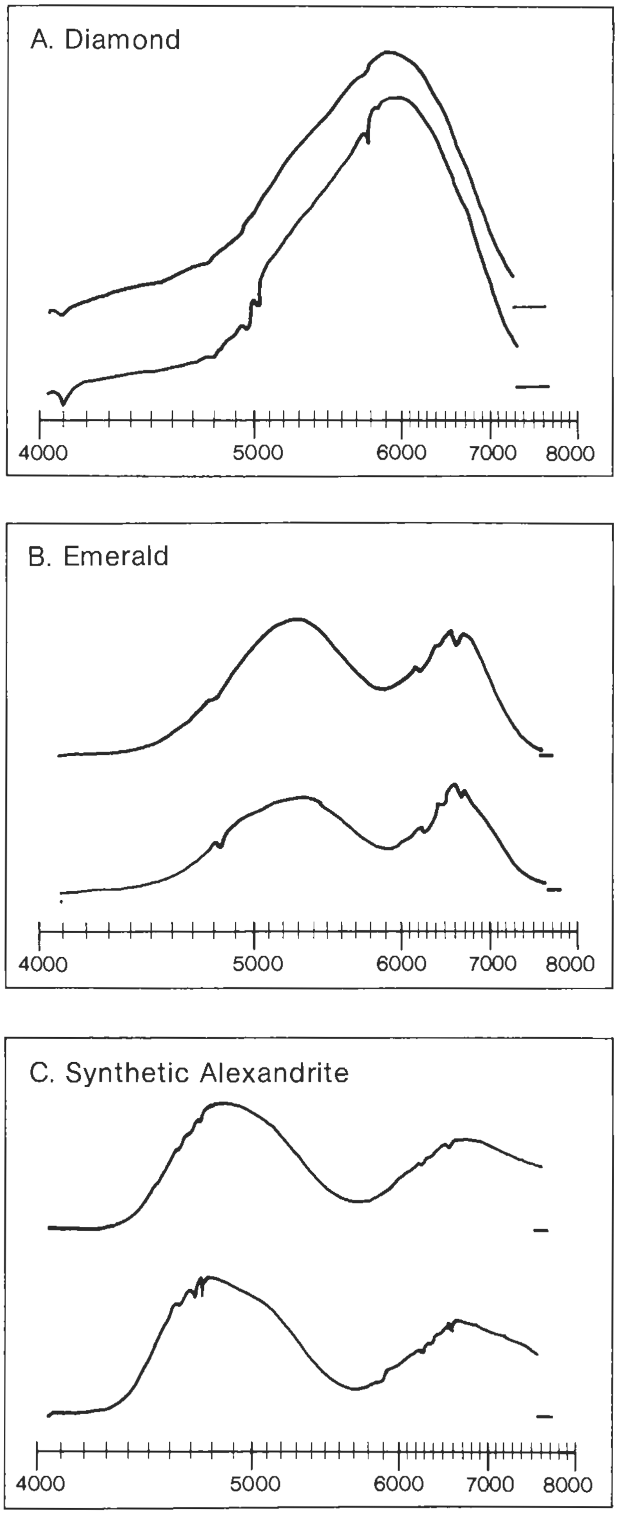


Figure 4. Visible-light spectral transmission curves for (A) diamond, (B) emerald, and (C) synthetic alexandrite, as documented by the automatic recording spectrophotometer at room temperature (upper curve) and at 55 K (lower curve).

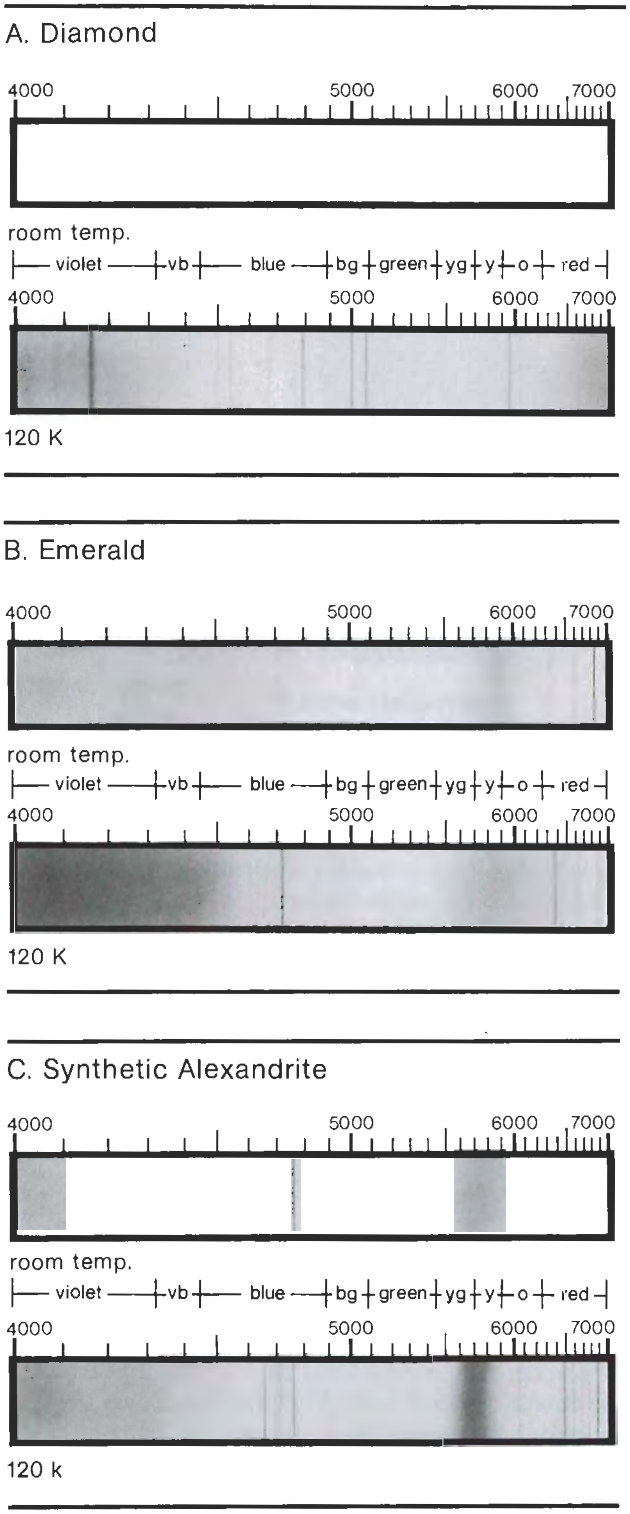


Figure 5. Drawings of absorption spectra for (A) diamond, (B) emerald, and (C) synthetic alexandrite, as observed on a direct-vision spectroscope before (at room temperature) and after the stones were cooled with liquid nitrogen.

Synthetic Alexandrite. Part C of figure 4 shows the spectra recorded for a synthetic, flux-grown alexandrite. Cooling to 55 K provided for a most interesting enhancement of the spectrum seen at room temperature. A fine structure of absorption lines extends from the 6830 Å line toward the green, and the two weak absorption lines in the blue region at room temperature resolve into four lines with separate energies at 55 K.

CONCLUSION

Cooling of gemstones to low temperatures during spectroscopic examination provides for enhanced detail in the spectra observed. The jeweler-gemologist who uses the simple methods for cooling gems described here will, with a little practice, find that he or she can obtain better spectral information on many gemstone species. The spectroscopist is advised, however, to exercise caution to avoid thermal shock and possible damage to the gemstones.

The use of more sophisticated equipment allows for the controlled and gradual change of temperature, which greatly reduces the danger of damage and provides for longer observation at low temperatures. Results obtained on the automatic recording instrumentation used in the GIA research laboratory have demonstrated the advantages of using cryogenic temperatures in the spectroscopic observation of gemstones.

REFERENCES

Anderson B.W. (1953) The spectroscope and its applications to gemmology. *The Gemmologist*, Vol. 22, No. 226, p. 153.

Holden A. (1965) *The Nature of Solids.* Columbia University Press, New York and London, p. 241.

Koivula J. (1980) Fluid inclusions. *Gems & Gemology*, Vol. 16, No. 8, pp. 273, 276.

Liddicoat R. T. Jr. (1981) *Handbook of Gem Identification.* Gemological Institute of America, Santa Monica, CA, p. 179.

Nassau K. (1976) Units used in spectroscopy. *Lapidary Journal*, Vol. 29, No. 7, p. 2116.

Scarratt K. (1976) Investigating the visible spectra of coloured diamonds. *Journal of Gemmology*, Vol. 16, No. 7, pp. 433–447.

Webster R. (1975) *Gems: Their Sources, Descriptions and Identification*, 3rd ed. Archon, Hamden, CT.

NOTES
· AND ·
NEW TECHNIQUES

REVOLUTION IN DIAMOND CUTTING: LASER SAWING OF DIAMOND CRYSTALS

By David M. Baker

Laser sawing of diamonds is beginning to revolutionize the diamond-cutting industry. Not only does the laser saw offer savings in time and money, but it also enables the cutting of material virtually unworkable by conventional methods and makes available an almost limitless assortment of fancy shapes. This article describes the components and operation of the laser saw, as well as the situations in which it has proved most useful.

The modern technology of the laser (*l*ight *a*mplification by the *s*timulated *e*mission of *r*adiation) has penetrated the ancient art of diamond cutting. The use of lasers represents one of the greatest technological advances for the diamond cutter since the advent of the conventional diamond saw in the 1930s. In the hands of a competent operator, the laser saw can save time and money, and can greatly reduce the risk associated with conventional cutting methods.

The art of laser sawing is, for the most part, a well-kept secret. Although the manufacturers of laser diamond-cutting equipment are careful about releasing statistics on the number of units currently in use in the diamond industry, unofficial sources estimate that there are approximately 15 units in the U.S. and a total of 50 units in operation worldwide. In many cases, diamond cutters with adjacent offices are not aware that their neighbors have laser facilities.

On the basis of information gathered from sources in the diamond-cutting industry and researchers involved with laser technology, this article describes the laser saw and explains how it is used to cut diamonds. The article also discusses those situations in which the laser saw has proved to be invaluable.

THE LASER SAW

The components of the laser saw are illustrated in figure 1. On the right, a large cabinet houses a power amplifier for the laser's flash lamps. These lamps surround the neodymium-doped yttrium aluminum garnet (Nd:YAG) rod, which is enclosed in the smaller metal cabinet that appears in the center of figure 1. Located off to the left outside the first figure are the focusing lens, the x-y platform on which the stone is mounted for passage through the laser beam, and a microscope and television monitor, both of which are used to observe the progress of the laser through the stone (see figure 2).

The laser beam is created as light from the flash lamp excites the neodymium atoms in the YAG crystal host, causing them to give off laser

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Figure 1. The laser saw unit consists of a large cabinet that houses the power amplifier for the flash lamps (on the right), a smaller cabinet that encloses the laser rod (center), and an x-y platform computer (off to the left).

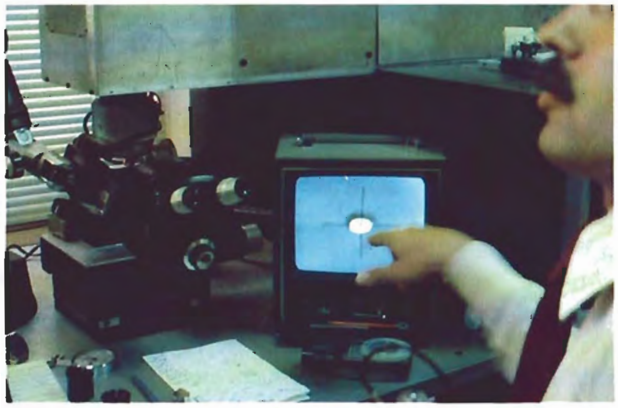

Figure 2. To complete the laser saw unit, this figure shows the x-y platform, the focusing lens, and the microscope and television monitor used to observe the progress of the laser through the stone.

light. This light is emitted from the rod as a parallel beam of a single color. (Actually, the light is invisible, with a wavelength of 10,640 Å in the near infrared region of the spectrum.) A procedure known as Q-switching is used in most diamond-cutting laser saws to increase the intensity of the light beam.

The beam that is emitted from the rod is 1.5 mm in diameter; it subsequently passes through a lens system that increases the diameter to 12 mm. A special mirror reflects the infrared laser light at 90° while allowing the visible light to pass. The reflected light then passes through another lens system that focuses the beam down to a spot 25 microns in diameter on the diamond to be cut.

In contrast to conventional cutting methods, in which the saw as well as the stone being cut move, the beam in laser sawing remains stationary; the cutter needs only to focus further into the stone as the sawing progresses. The diamond is mounted in a dop similar to those used in conventional cutting, and then placed on the x-y platform. The desired cut is preprogrammed into a computer linked to the platform; the platform then moves the diamond through the beam in a back-and-forth motion precisely as determined by the system operator.

Once the beam reaches the stone and the platform begins to move, the sawing starts. At the point where the laser beam strikes the diamond, the temperature is extremely high. As a result, the diamond's molecular structure at this point is converted to graphite on one pass of the beam, with the graphite build-up evaporated or "burned off" on the return pass. It is known that, in air, diamond combustion occurs at 690°C to 875°C. Inquiries made to determine the beam temperature at the point of laser contact remain unanswered.

The width of the cut produced is directly related to the size of the crystal being cut, as a consequence of the V-shaped nature of the beam. Weight loss, approximately 5%–7%, is slightly greater than when a stone is cut by conventional means, and depends on such variables as the size of the crystal and the expertise of the cutter. A representative cutting time would be approximately eight hours for a 10-ct. crystal.

Once the crystal has been completely sawed, the stone looks brackish and opaque. Cleaning by one of several recommended procedures returns the stone to its precut appearance. The saw plane (figure 3) shows minute parallel striations as a result of the movement of the platform.

WHY CUT WITH LASER?

Many diamonds with distorted growth, such as graining or twinning, are virtually impossible to cut by conventional means because of the changes in cleavage and sawing planes they contain. One diamond cutter recently presented a piece of distorted rough in excess of 20 cts. that had been in his possession for over 15 years. It had been carefully sawed and cleaved four or five times over

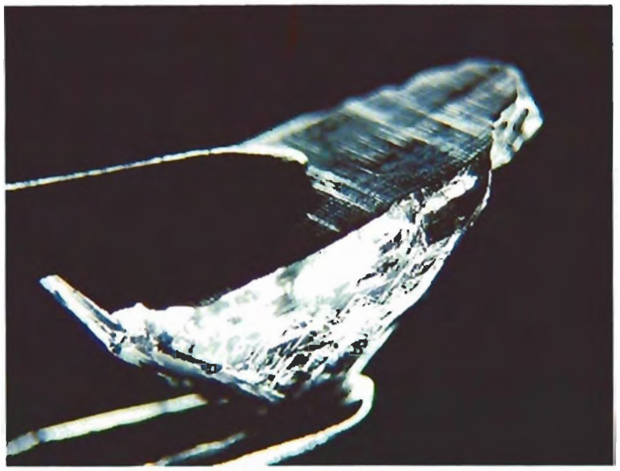

Figure 3. Striated appearance of the laser saw plane.

the years in an attempt to unlock the key to its structure that would allow production of the finest, largest stone possible. A stone such as this can now be sawed by laser without regard for the grain.

The laser saw can also be of help in those situations where the material has included crystals of diamond along the plane selected for sawing. Given our knowledge that diamond has conventional primary sawing directions parallel to the theoretical cube faces and secondary sawing directions parallel to the theoretical dodecahedral faces, and that the crystallographic orientation of the included crystals of diamond is random to the host crystal in most instances, it is evident that the different sawing planes make conventional sawing next to impossible. A diamond cutter using conventional equipment does not "saw" through an included crystal of diamond, he "worries" through it. The vibrations produced when the blade reaches the included crystal can cause the crystal to shatter. Even if the stone does not shatter, the cutting time may easily be twice or three times that of a normal stone, extending into many days or even weeks. With laser technology, this problem is tackled easily and efficiently in a matter of hours.

Other applications of the laser saw include the ability to produce many of the new fancy shapes on the market today—horseheads, oil wells, stars, butterflies, initials, and the like. In addition, there are many industrial applications for laser-cut diamonds: wire dies, surgical instruments, heat sinks, and many others for the electronics and aerospace industries. The potential for unusual cuts is limitless with this method, although it is still somewhat of a mystery how some of these special cuts are polished. The techniques used have remained firm trade secrets.

There are several manufacturers of laser sawing equipment in the U.S. and abroad. Many will provide the buyer with the training needed to become a competent laser saw operator. At this writing, an initial investment of approximately US$75,000 for the laser equipment is required before the first stone is cut. However, lasering services are available on a contract basis.

RUBY IN DIAMOND

By Henry O. A. Meyer and Edward Gübelin

The first substantiated identification of corundum (var. ruby) occurring as an inclusion in natural diamond is presented. The ruby is assigned to the eclogitic suite of inclusions in diamond, and the implications of its occurrence are discussed in relation to the genesis of "eclogitic" diamonds. It is concluded that diamond crystallizes from a melt over a long period of time with possible fluctuations in ambient temperature and geochemical environment.

Inclusions in gemstones can be fascinating for scientist and layman alike. Scientifically, they aid in deciphering the genesis of the mineral; gemologically, they are often distinctive and aid in identifying the host stone (Gübelin, 1953, 1974).

In 1645, John Evelyn, a diarist, reported seeing a "faire Rubie" inside a diamond that belonged to a Venetian nobleman (DeBeer, 1955). This identification, although historically interesting as one of the first recorded observations of a mineral included in a gemstone, has usually been considered incorrect. Harris (1968) suggested that the inclusion to which Evelyn referred was probably a garnet, since garnets have now long been recognized as inclusions in diamonds (see Futergendler, 1950, and Futergendler and Frank-Kamentsky, 1961). Early in 1967, Meyer (1967) used the electron microprobe to obtain the first chemical analyses of mineral inclusions in diamond and discovered that two chemically distinct types of garnet were present. One type consists primarily of magnesium- and chromium-rich, calcium-poor pyropes; whereas the second type is calcium and iron rich, and has virtually no chromium. This latter group of garnets is made up of almandine pyropes; its members are orange-red, whereas the chromium-rich garnets (*chrome-pyropes**, Meyer, 1968) of the first group are claret colored. Similar results were obtained by later studies (e.g., Sobolev and Lavrent'yev, 1969; Prinz et al., 1975; Meyer and Svisero, 1975).

It was also observed during the early microprobe analyses conducted by Meyer and Boyd (1968, 1969, 1972), and described by Sobolev (1974) and by Prinz et al. (1975), that not only did the garnets comprise two distinct groups, but most inclusions in diamond could be assigned to one of two suites as well: the *ultramafic** or the *eclogitic**. The members of these suites are listed in table 1. Reviews of the minerals in these suites are to be found in Meyer and Tsai (1976), Gübelin et al. (1978), and Harris and Gurney (1979). It should be noted that ruby does not appear on either list of inclusions in table 1.

RUBY INCLUSION IN DIAMOND

During endeavors to find diamonds with unusual, colored mineral inclusions, one of the authors received two diamonds of unknown origin with red crystal inclusions that, on the basis of previous knowledge, were first tentatively identified as chrome-pyrope garnets with a low Cr_2O_3 content. However, the difference in hue between the two inclusions, one of which was claret red while the other was a typical "ruby" red, was so great that additional research was pursued.

The claret-red inclusion, which we freed from its host diamond by breaking the latter, proved on analysis to be a chrome-rich pyrope garnet indeed. However, analysis with the electron microprobe showed that the other inclusion, which was exposed at the surface of one crown face of the 0.06-ct. brilliant-cut diamond (see figure 1), showed

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*Asterisk denotes terms defined in the glossary included with this article.

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TABLE 1. Minerals of the ultramafic and eclogitic inclusion suites.

Suite	Mineral	Chemical composition[a]
Ultramafic	Olivine	$(Mg,Fe)_2SiO_4$
	Enstatite	$(Mg,Fe)_2Si_2O_6$
	Diopside	$(Ca,Mg,Fe)_2Si_2O_6$
	Cr-pyrope garnet	$(Mg,Fe,Ca)_3(Al,Cr)_2Si_3O_{12}$
	Mg-chromite	$(Mg,Fe)_1(Cr,Al)_2O_4$
	Mg-ilmenite	$(Fe,Mg)_1TiO_3$
	Phlogopite	$K_2(Mg,Fe)_6Si_6Al_2O_{20}(OH)_4$
	Sulfides	Fe_7S_8; $CuFeS_2$; $(Fe,Ni)_9S_8$
Eclogitic	Almandine-pyrope garnet	$(Fe,Mg,Ca)_3Al_2Si_3O_{12}$
	"Omphacitic" clinopyroxene	$(Ca,Mg,Fe,Na)_1(Si,Al)_2O_6$
	Coesite	High-pressure form of SiO_2, quartz
	Rutile	TiO_2
	Kyanite	Al_2SiO_5
	Fe-chromite	$(Fe,Mg)_1(Cr,Al)_2O_4$
	Biotite	$K_2(Fe,Mg)_6(Al,Ti)_2Si_6Al_2O_{20}(OH)_4$
	Sulfides	Fe_7S_8; $CuFeS_2$; $(Fe,Ni)_9S_8$

[a] *The order of the elements indicates the order of importance. Thus, in olivine, Mg is more important than Fe.*

that it was in fact corundum (var. ruby). The analytical data for this inclusion, together with the data for a gem ruby from Burma, are presented in table 2.

Single-crystal X-ray diffraction studies further substantiated this identification of ruby as an inclusion in diamond. The diffraction pattern of the inclusion was identical to that of a reference ruby or corundum. Cell dimensions were $a_0 = 4.76$ Å, $C_0 = 13.22$ Å, compared to 4.758 Å and 12.991 Å, respectively, for a synthetic corundum.

From the X-ray photographs it was observed that the crystal orientation of the ruby did not line up precisely with that of the host diamond as it would in an epitaxial relationship. However, several crystallographic zones in the diamond were

GLOSSARY OF SPECIAL TERMS

Chrome-pyrope
A garnet that is composed mostly of pyrope ($Mg_3Al_2Si_3O_{12}$) in which some of the Al is replaced by Cr. The end member with no Al and all Cr ($Mg_3Cr_2Si_3O_{12}$) is referred to as knorringite.

Eclogite
A rock consisting predominantly of two minerals: a reddish iron-magnesium-calcium garnet and a pale green sodium-calcium rich pyroxene referred to as omphacite. Eclogites are believed to occur at depths in the earth, but they are not as common as the ultramafic rocks.

Grospydite
A rock consisting of the minerals grossular garnet, pyroxene, and disthene (kyanite).

Ultramafic
A term used to describe minerals that have a low silica content but are usually rich in magnesium, iron, and possibly alumina. Rocks in which these minerals occur (ultramafic rocks) are thought to be common in the upper mantle of the earth, i.e., deeper than 35 km. Peridotite, consisting of about 90% olivine, is a good example of an ultramafic rock.

Xenolith
A fragment of rock that is foreign to its host rock. Thus, in kimberlite one often finds fragments of rocks from the deeper parts of the earth that are chemically and mineralogically unrelated to kimberlite and were incorporated into the host kimberlite during its ascent from a depth of about 150 km.

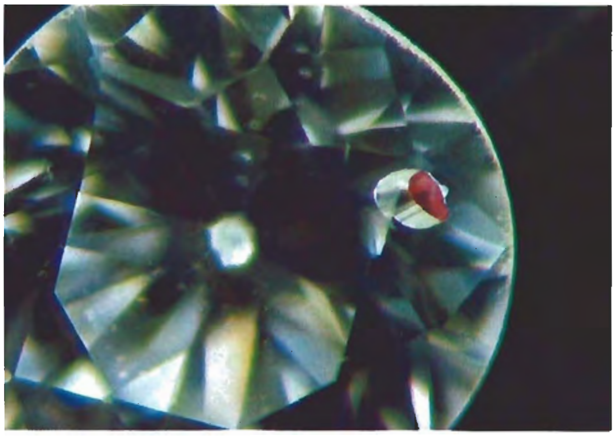

Figure 1. Ruby crystal included in a 0.06-ct. brilliant-cut diamond.

close to those of the inclusion, and possibly at the high temperatures and pressure in which the ruby-diamond couple formed, the crystallographic orientation of the two minerals was better. The inclusion is somewhat elongated and has rounded faces; the elongation may be subparallel to the c-crystallographic direction.

The small size of the ruby inclusion and the fact that it is partly contained in its host stone made determination of the ultraviolet fluorescence and absorption spectrum difficult. Nevertheless, in spite of the yellowish fluorescence displayed by the host diamond, a faint reddish fluorescence was obvious from the inclusion. Furthermore, a very faint absorption line was perceived at 6600 Å, and a slightly stronger one at 6935 Å. Admittedly, the absorption data are subject to some error, but they are compatible with the microprobe and X-ray determinations that the inclusion is a ruby.

DISCUSSION

This is the first substantiated identification of corundum (var. ruby) as an inclusion in natural diamond. The occurrence of this mineral as an inclusion is not unexpected, since both ruby and sapphire have been reported in South African kimberlite (Harger, 1911), and corundum-bearing eclogite and *grospydite* xenoliths** have been found in kimberlites in Siberia and Africa (Sobolev, 1964; Sobolev and Kuznetsova, 1965; Rickwood et al., 1968). More recently, Sobolev (1974) reported a diamond-bearing corundum eclogite from the Mir kimberlite pipe. Curiously, the corundum in this Mir eclogite is bluish, whereas that in non-diamondiferous eclogite from the Obnazhennaya kimberlite is violet-pink. The pinkish color is due to the presence of chromium, as is the case of the corundum inclusion reported here (table 2).

We have, therefore, assigned this ruby to the eclogitic suite of mineral inclusions in diamond. Interestingly, it is usual for the inclusions in the ultramafic group to show enrichment in chromium; this ruby is the first member of the eclogitic suite to have this feature. The fact that ruby has not previously been recognized in diamond is probably a consequence of its rarity as an inclusion. Evidence for this rarity is perhaps indicated by the rareness with which corundum eclogites occur in kimberlite.

If we confine the discussion to diamonds for which genesis is associated with the chemical environment in which eclogites are formed, the following conclusions are suggested.

First, the generally monomineralic nature of the inclusions, their lack of impurities and chemical zoning, and their smallness (usually less than 400 μm) suggest that the diamonds crystallized from a melt.

Second, the similarity in chemical composition of garnet and pyroxene inclusions with those of the host eclogite in which the diamond is embedded (Sobolev et al., 1972) suggests growth equivalent in time at least to that of the major mineral phases (garnet and pyroxene) in the eclogite.

Third, the zonal stratigraphy revealed by etching diamond, as well as the marked variation in

TABLE 2. Analysis of corundum (var. ruby) inclusion in diamond compared to a ruby from Burma.

Oxide	% present in the inclusion in diamond	% present in the Burmese ruby
SiO_2	0.29	0.18
TiO_2	0.09	0.00
Al_2O_3	97.4	99.3
Cr_2O_3	1.30	0.96
FeO	0.22	0.00
MgO	0.13	0.02
CaO	0.02	0.02
MnO	0.02	0.04
NiO	0.01	0.01
Na_2O	0.04	0.00
K_2O	0.00	0.01
Total	99.5	100.5

chemistry and morphology of diamond, suggest that throughout its growth period diamond has been subjected to fluctuating geochemical conditions or to changes in pressure and temperature. A combination of temperature and chemical variations is most likely.

Finally, the presence of ruby, kyanite, coesite, rutile, and other relatively rare or minor minerals as inclusions in diamond is evidence that the "eclogitic diamonds" must have formed in a variety of geochemically distinct, but similar, environments. For example, coesite-bearing diamonds (and coesite eclogites) obviously formed in a relatively silica saturated environment compared to the alumina-rich environment that would give rise to corundum eclogites (or ruby-bearing diamonds).

Much information has been obtained during the last several years regarding the chemical characteristics of inclusions in diamond. Unfortunately, much more information is lacking due to the minute nature of the inclusions and the reluctance with which they and the host diamond give up their secrets. Science will never really know whether Evelyn saw a ruby or a garnet in the Venetian nobleman's diamond; it will remain, like diamond, an enigma.

REFERENCES

DeBeer E.S. (1955) *The Diary of John Evelyn,* Vol. 2, 1620–1649. Oxford University Press, London.

Futergendler S.I. (1956) The study of solid inclusions in diamond by the method of X-ray structural analysis. *Zapiski Vsesoyuznyi Mineralogia Obshchestva,* Vol. 85, pp. 568–569.

Futergendler S.I., Frank-Kamentsky V.A. (1961) Oriented inclusions of olivine, garnet and chrome-spinellid in diamond. *Zapiski Vsesoyuznyi Mineralogia Obshchestva,* Vol. 90, pp. 230–236.

Gübelin E. (1953) *Inclusions as a Means of Gemstone Identification.* Gemological Institute of America, Los Angeles.

Gübelin E. (1974) *Internal World of Gemstones: Documents from Space and Time.* ABC Edition, Zurich.

Gübelin E., Meyer H.O.A., Tsai H.M. (1978) Natur und Bedeutung der Mineral-Einschlüsse im natürlichen Diamanten. Eine Übersicht. *Zeitschrift der Deutschen Gemmologischen Gessellschaft,* Vol. 27, pp. 61–101.

Harger H.S. (1911) Note on the occurrence of oriental ruby in kimberlite. *Transcript of the Geological Society of South Africa,* Vol. 14, pp. 64–70.

Harris J.W. (1968) The recognition of diamond inclusions. Part I: Syngenetic mineral inclusions. Part II: Epigenetic mineral inclusions. *Industrial Diamond Review,* pp. 402–410, 458–561.

Harris J.W., Gurney J.J. (1979) Inclusions in diamond. In J.E. Field, Ed., *Properties of Diamond,* Academic Press, London, pp. 555–591.

Meyer H.O.A. (1967) Inclusions in diamond. *Yearbook of the Carnegie Institute in Washington,* Vol. 66, pp. 446–450.

Meyer H.O.A. (1968) Chrome-pyrope: an inclusion in natural diamond. *Science,* Vol. 160, pp. 1446–1447.

Meyer H.O.A., Boyd F.R. (1968) Inclusion in diamond. *Yearbook of the Carnegie Institute in Washington,* Vol. 67, pp. 130–135.

Meyer H.O.A., Boyd F.R. (1969) Inclusion in diamond. *Yearbook of the Carnegie Institute in Washington,* Vol. 68, pp. 315–324.

Meyer H.O.A., Boyd F.R. (1972) Composition and origin of crystalline inclusions in natural diamond. *Geochimica et Cosmochimica Acta,* Vol. 36, pp. 1255–1273.

Meyer H.O.A., Svisero D.P. (1975) Mineral inclusions in Brazilian diamonds. *Physics and Chemistry of the Earth,* Vol. 9, pp. 785–795.

Meyer H.O.A., Tsai H.M. (1976) The nature and significance of mineral inclusions in natural diamond: a review. *Minerals Science and Engineering,* Vol. 8, pp. 242–261.

Prinz M., Manson D.V., Llava D., Keil K. (1975) Inclusion in diamonds: garnet lherzolite and eclogite assemblages. *Physics and Chemistry of the Earth,* Vol. 9, pp. 797–815.

Rickwood P.C., Mathias M., Siebert J.C. (1968) A study of garnets from eclogite and peridotite xenoliths found in kimberlite. *Contributions to Mineralogy and Petrology,* Vol. 19, pp. 271–301.

Sobolev N.V. (1964) An eclogite with ruby. *Doklady Akademii Nauk SSSR,* Vol. 157, pp. 1382–1384.

Sobolev N.V. (1974) Deep seated inclusions in kimberlites and the problem of the composition of the upper mantle. English edition, 1977, *American Geophysics Union,* Washington, DC.

Sobolev N.V., Kuznetsova I.K. (1965) New data on the mineralogy of eclogites from the Yakutian kimberlite pipes. *Doklady Akademii Nauk SSSR,* Vol. 163, pp. 471–474.

Sobolev N.V., Lavrent'yev Yu.G. (1969) Chrome pyropes from Yakutian diamonds. *Doklady Akademii Nauk SSSR,* Vol. 189, pp. 162–165.

Sobolev V.S., Sobolev N.V., Lavrent'yev, Yu.G. (1972) Inclusions in diamond from a diamond-bearing eclogite. *Doklady Akademii Nauk SSSR,* Vol. 207, pp. 164–167.

THE ANDRADITES OF SAN BENITO COUNTY, CALIFORNIA

By Tedd Payne

Discoveries in 1949 of andradite garnet in San Benito County, California, led to the formation in 1978 of a partnership to mine, cut, and market gem-quality andradite. These andradites are found in situ in serpentine outcrops and also in dry alluvial deposits. SEM microprobe analysis and X-ray powder diffraction show the chemistry and unit cell, respectively, to be nearly pure andradite. Cut stones and mineral specimens are produced in green, yellow, brown, and in combinations of these colors. Cut stones are generally under three carats and some are chatoyant. This is believed to be the only reported source of chatoyant garnet.

In 1949, Gemologist William Culver found a few water-worn andradite pebbles in a streambed in San Benito County, California. These first pieces were green and yellowish brown; some of the latter were chatoyant. In 1952, Bob and Ruth Getz found small amounts of rich, "emerald-green" and yellow-brown andradite in another nearby stream. The next few years brought no new discovery of deposits, but Culver sent earlier material to such gemological notables as Basil Anderson, Count Taaffe, and Richard Liddicoat for examination.

In 1978, Phil Maddox discovered a small in-situ deposit of andradite which later acquired the name *greenfire* because of its green color and high dispersion. In July of the next year, Maddox discovered a new deposit of this material. These small, pale, yellowish-green crystals were found in veins and proved to be suitable for faceting as well as for mineral specimens. That same year, Maddox, Culver, Dick Quackenbush, and Steve Bouch formed a partnership called Greenfire Mining.

Since July of 1979, numerous other in-situ and dry alluvial deposits have been found. The claims, 10 in all at this writing, are surrounded by private property and the partners do not want the location made public. These andradites commonly occur in situ as vein deposits in crevices and fractures in serpentine and as dry alluvial deposits at and near the surface, often downslope from serpentine outcrops. Other metamorphic minerals found in the area include grossularite garnet (some of which is a gem-quality yellow brown), idocrase, diopside, chlorite, calcite, magnetite, and chromite.

CHEMISTRY

The "ideal" composition for pure andradite is $Ca_3Fe_2Si_3O_{12}$, but varying amounts of manganese, magnesium, and iron may substitute for the calcium; chromium, vanadium, and aluminum may substitute for the iron; and some titanium may substitute for the silicon or iron or both. It is exactly this game of "musical elements" (known in geologic circles as isomorphous replacement) which leads to the fascinating diversity of the garnets in general as well as to the difficulty encountered in classifying many of the various garnets.

Two representative pieces, one green (a demantoid) and one brown (a golden cat's-eye), were examined by means of a scanning electron microscope (SEM) with microprobe analysis. The chemical compositions obtained for each are given in table 1. X-ray powder diffraction analysis gave the following cubic unit-cell dimensions for the above samples: demantoid, a=12.057 Å; golden cat's-eye, a=12.053 Å.

DESCRIPTION OF THE MATERIAL AND ITS IDENTIFYING PROPERTIES

The rough material recovered thus far has yielded faceted (transparent to translucent) stones averaging 20 points to one carat and cabochons (translucent to opaque) averaging one-half to three carats. The basic colors and transparencies of this material are summarized in table 2. In conjunc-

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tion with this table, figures 1 and 2 illustrate the emerald-green andradite and green-brown "topazolite," respectively, found in San Benito County. Figure 3 presents some of the cat's-eye cabochons formed from the chatoyant material.

Andradite found in situ often occurs as well-formed rhombic dodecahedral crystals. Alluvial material may be found as worn crystals, broken pieces, or rounded pebbles.

A variety of these andradites were tested for the usual gemological properties. The refractive index ranges from approximately 1.851 for the greenfire material to 1.888 for the darker green (demantoid) stones, with the brownish andradite giving intermediate indices. The specific gravity ranges between 3.77 and 3.85, with no observed relation to color. Common inclusions are "fingerprints," included crystals, and coarse, needle-

TABLE 1. Composition of two andradite samples showing weight percentages of the metallic elements expressed as oxides.[a]

Oxide	Demantoid (weight %)	Golden cat's-eye (weight %)
CaO	33.09	33.30
MnO	0.01	0.09
MgO	0.03	0.27
FeO	—[b]	—[b]
Fe_2O_3	29.75	28.37
Cr_2O_3	0.97	0.30
V_2O_3	0.04	0.02
Al_2O_3	0.06	0.44
SiO_2	36.03	36.88
TiO_2	0.02	0.33
	100%	100%

[a] *The figures have been adjusted slightly to total 100.*
[b] *None detected.*

Figure 1. Green (demantoid) andradite rough from San Benito County, California.

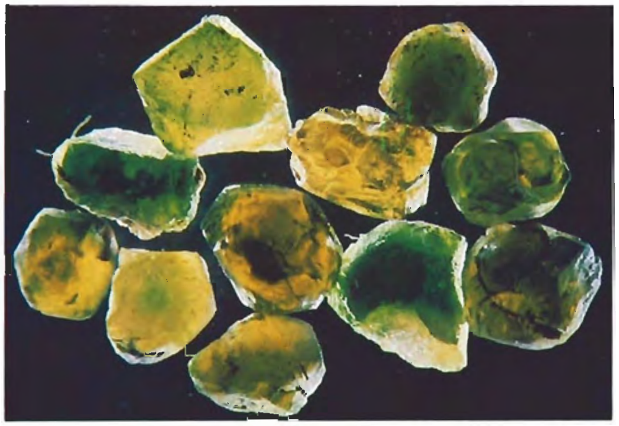

TABLE 2. Color description, size, and relative abundance of the faceted and cabochon andradites from San Benito County, California.

Cut and transparency	Color	Usual size	Relative abundance (% cutable material found thus far)[a]
Faceted stones, transparent to translucent	Emerald green, medium to dark (demantoid)	To ¼ ct.	5
	Orange-brown, yellow-brown, green-brown (all "topazolite")	To ¾ ct.	28
	Yellow	To ¾ ct.	2
	Yellow-green, pale, "greenfire"	To 1 ct.	35
Cabochons, translucent to opaque	Emerald green, medium to dark (very rarely chatoyant)	To 1 ct.	5
	Banded green	To 3 cts.	5
	Yellowish brown, "golden cat's-eye"	To 3 cts.	20
	Black (melanite)	Crystals to 1 ct.	N/A

[a] *Rough estimates.*

Figure 2. Orange-brown ("topazolite") andradite rough from San Benito County, California.

Figure 3. Cat's eye andradite cabochons from San Benito County, California.

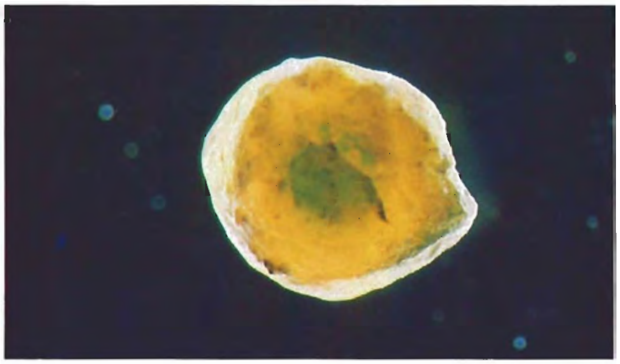

Figure 4. Color-zoned piece of andradite rough from San Benito County, California.

TABLE 3. Properties of the samples of greenfire, golden cat's-eye, and demantoid types of andradite found in San Benito County, California.

Type of andradite	Color	R.I.[a]	S.G.[b]	Inclusions	Chelsea filter	Ultraviolet fluorescence
Greenfire	Pale, semitransparent yellow-green	1.855	3.77	"Feathers" forming "rhombic corners," strings or clusters of round, white inclusions, coarse whitish needles	Pale orange	Inert[c]
Golden cat's-eye[d]	Translucent yellowish brown, resembles tiger's-eye quartz	1.877	3.81	Silky or fibrous	Brownish orange	Inert[c]
Demantoid[d]	Translucent, medium to dark green	1.882	3.81	"Fingerprints," included crystals, coarse, needle-like to fine silk inclusions	Orange-red	Inert[c]

[a] *Refractive index (all the sample stones are singly refractive).*
[b] *Specific gravity.*
[c] *Both long and short wave.*
[d] *Same samples as in table 1.*

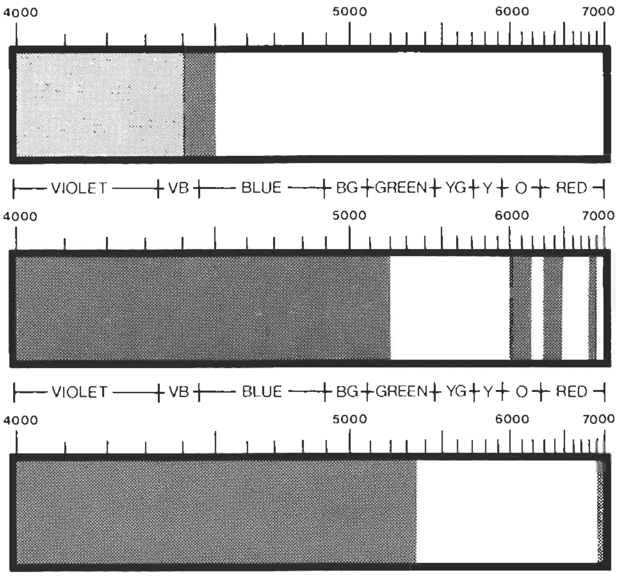

Figure 5. Color spectra for the "greenfire" (top), demantoid (center), and golden cat's-eye (bottom) andradites found in San Benito County, California.

like to fine silk inclusions. Some material shows color zoning, typically a green spot in the center of the crystal (see figure 4).

Table 3 presents the properties for three representative andradite samples, including the golden cat's-eye and demantoid types described above. The relevant spectra for these three samples appear in figure 5.

CONCLUSION

The San Benito County, California, deposit is unique both because it represents a new source of gem-quality andradite and because it is the only reported source of chatoyant garnet. The golden cat's-eyes, small demantoids, and especially the very rare cat's-eye demantoids make these deposits of keen interest to scientist and gemstone enthusiast alike.

Gem Trade LAB NOTES

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A NOTE FROM THE EDITOR

Like grapes and trouble, certain gemstones often come in bunches. For example, at one time for a period of several days, a large proportion of the stones coming in for identification will be emeralds. At another time, perhaps rubies or synthetic sapphires will predominate. Our latest "bunch of grapes" is a variety of ivory carvings, some of which will be seen in this section.

Also featured are several photomicrographs of inclusions in Chatham synthetic ruby. Because of the angles required to photograph these inclusions, the color is not a true representation of the face-up color of the stones.

DIAMOND

Concave Facets

The Los Angeles laboratory recently received for identification a ring set with a synthetic sapphire center stone and two triangular-cut diamond side stones. The two diamonds had an extremely unusual feature: they both had three concave facets on their crowns. The staff at the laboratory had never before seen a diamond cut in this manner. We have, however, heard that in the early 1900s there was a U.S. patent issued for the invention of a cut that was similar to a brilliant but with a concave table and numerous concave facets on the crown. The concave facets were formed by polishing with diamond dust, oil, and a suitably shaped tool.

Figure 1. Concave facets on diamond. Magnified 17×.

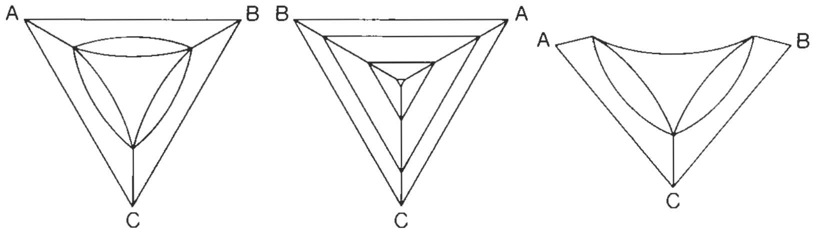

Figure 2. Diagrams of crown (left) and pavilion (center) facet arrangements on concave faceted diamond. Diagram on right shows crown viewed from an oblique angle.

Figure 1 shows one of the side diamonds with the table and an upper step facet in total reflection, so that the concave facets appear dark. The first two diagrams in figure 2 show the crown and pavilion facet arrangements, respectively. In the last diagram of figure 2, the crown is viewed from an oblique angle, thus making the curvature of the facet between A and B very apparent. The diagram in figure 3 shows a three-dimensional view of this very unusual cut.

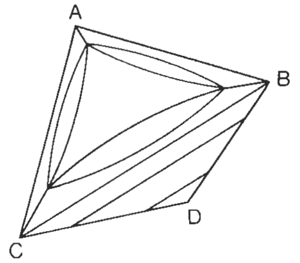

Figure 3. Three-dimensional view of concave faceted diamond.

EMERALD

A beautiful combination pin and pendant (see figure 4) was submitted to the Santa Monica lab for identification of the center stone. This stone proved to be a slice from an emerald crystal and measured 9.1 mm thick × 50.8 mm long × 40.35 mm wide. The emerald was carved on both sides in a low, bas relief floral design. This was certainly an innovative way to use a relatively

Figure 4. Brooch with carved slice from emerald crystal as center stone. Emerald measures 9.1 mm × 50.8 mm × 40.35 mm.

thin section of a crystal for personal adornment.

IVORY

A client submitted two items to the Santa Monica lab for identification. The first was an intricately carved section of elephant tusk, measuring approximately 9.2 cm × 3.5 cm × 20.7 cm high. Figure 5 shows the front view of the tusk.

Figure 5. Front view of carved elephant tusk that measures 9.2 cm × 3.5 cm × 20.7 cm.

The other item was an example of the ivory carver's art that is frequently seen in the trade. The outer orb was pierced and carved with a dragon design. Inside this sphere were five movable, concentric, pierced spheres. Figure 6 shows the inner spheres visible through one of the larger aperatures in the outer orb. The entire piece stands 8.5 cm high, including the carved monkey and cylinder base; the outer sphere is 4.1 cm in diameter. The monkey and cylinder were threaded and could be unscrewed from the orb.

A magnificent ivory carving of two horses richly caparisoned with rubies, emeralds, sapphires, and other gems was brought into Santa Monica to determine if there was any evidence of dye in the rubies or sapphires. We were happy to report that there was no evidence of dye in the stones we tested. The carving, seen in figure 7, measures 11.7 cm × 4.9 cm × 17.8 cm high.

Figure 6. Ivory carving with five movable spheres contained in the large outer sphere. Piece stands 8.5 cm high; the outer sphere is 4.1 cm in diameter.

NEPHRITE

The Santa Monica staff recently had the opportunity to examine a most unusual clock (figure 8), which consisted of a transparent brown face and back (probably smoky quartz) that measured about 11 cm in diameter, enclosing white metal hands set with what appeared to be diamonds. The numerals were enameled on metal, which was set with near-colorless stones all around the perimeter of the face. The clock was mounted on a carved nephrite duck that measured approximately 17.3 cm × 5.0 cm × 19.5 cm high, including the yellow metal and black stone base. The nephrite carving, the only part of the piece that was identified, was set with what appeared to be rubies. It is truly an interesting piece, reminiscent of Fabergé.

OPAL

Black Opal

A 2.93-ct. pear-shaped black opal was submitted to the Los Angeles laboratory for identification. In the examination of opal, the various types of treatment are always considered. This stone had been subjected to a type of treatment that was slightly different from what is usually encountered with opal.

When viewed with the unaided eye, an area that appeared to be natural matrix was seen on the bottom of the cabochon. Closer examination with the microscope revealed this area to be soft, with a waxy luster, and to have several hemispherical cavities, probably formed by air bubbles (see figure 9). Suspecting that this material was an applied, wax-type substance, and wanting to avoid damaging the area, we scraped off a very small amount with a razor blade for testing with the hot point. A low temperature setting of 20 on the GEM Thermal Reaction Tester was all that was necessary to cause this substance to flow easily and thus prove our suspicions. The waxy substance was used to fill a large cavity on the bottom of the cabochon, thus

Figure 7. Gem-encrusted ivory statue which measures 11.7 cm × 4.9 cm × 17.8 cm high.

improving the overall appearance of the stone. The rest of the opal proved to be untreated.

PEARLS

"Mabe" Pearls

Figure 10 shows what appears to be a large, 17-mm pearl with a yellow metal band that serves as a mounting for the chain. Examination under the microscope revealed a worked area on one side of the metal band, suggesting that the piece actually consists of two "mabe" pearls placed back to back. X-ray photography proved this to be the case. Using "mabe" pearls to simulate a single large pearl would seem to be a very clever deception.

RUBY

Synthetic Ruby

In the Spring 1981 issue of *Gems & Gemology,* we mentioned a flux-grown synthetic ruby that was examined in our New York laboratory and reportedly of recent Chatham manufacture. Since that time, we have had the opportunity to examine five of the newer Chatham synthetic rubies. Each stone weighed approximately one carat; the five ranged in color from a purplish red to an intense red that had only the slightest tint of purple.

Figure 8. Decorator clock mounted on a carved nephrite duck; 17.6 cm × 5.0 cm × 19.5 cm high.

Examination under the microscope showed that three of the stones contained residual unmelted flux that is typical of flux-grown synthetics. Several forms of flux inclusions were noted. Among them were small, somewhat rounded droplets arranged in flat "fingerprint" patterns (see figure 11) and both moderately coarse and fine irregular channels of flux in the form of wispy veils (figure 12). The flux in these stones was less coarse than that usually associated with this type of synthesis. We also observed the appearance of both of these forms of flux simultaneously in one area. Some of the inclusions exhibited the high-relief, opaque, whitish appearance typical of flux inclusions, while other areas were of low relief and much more transparent. An interesting feature noted in one of the stones was the presence of blue areas confined to small sections of the flux inclusions.

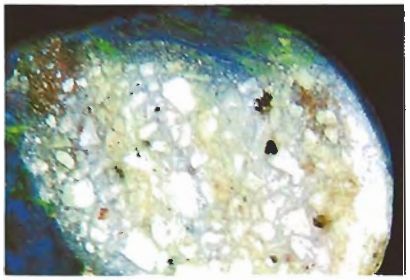

Figure 9. Hemispherical depressions in the waxy filling of a cavity on the back of a natural black opal. Magnified 20×.

Figure 10. "Mabe" pearls placed back to back to simulate a single large pearl. Magnified 1.5×.

Figure 11. "Fingerprints" of flux in a Chatham synthetic ruby. Magnified 27×.

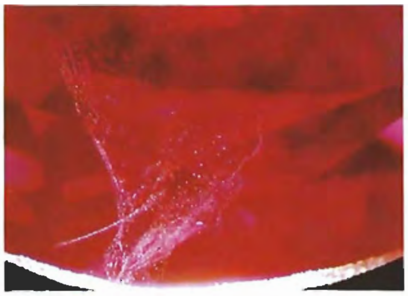

Figure 12. Moderately coarse and fine irregular channels of flux forming wispy veils in a Chatham synthetic ruby. Magnified 33×.

One of the stones examined contained a fairly large group of various inclusions, some of which were thin, hexagonal platinum flakes, ranging in form from very symmetrical to irregular. These platinum inclusions should not be confused with hematite platelets that may occur in some African rubies and have reportedly been seen in some rubies from Sri Lanka. When hematite occurs in natural rubies, it is usually seen as ultra-thin, submetallic platelets that may be nearly transparent (see figure 13). In addition, hematite will sometimes exhibit a reddish appearance and will be flat in contrast to the metallic and often curved nature of the platinum flakes.

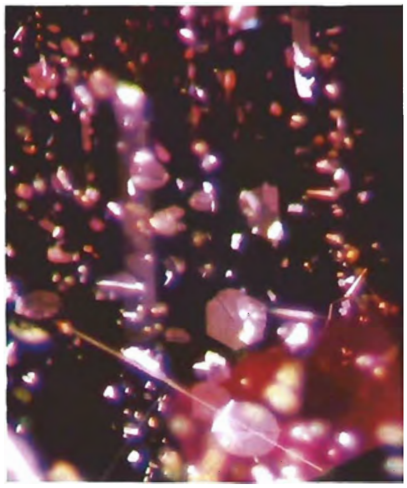

Figure 13. Ultra-thin hematite platelets in an African ruby. Magnified 63×.

Figure 14. Hexagonal flakes and needles of platinum in a Chatham synthetic ruby. (It is important to note that because of the special illumination that was required to photograph these inclusions, the color of the platinum is not illustrated accurately; its true appearance is a shiny metallic color.) Magnified 69×.

These hexagonal platinum flakes were interspersed with other randomly oriented inclusions in the form of small, thin, flat needles and numerous nondescript, minute, pinpoint-like inclusions (see figure 14). Another feature that was noted, and may be particularly confusing to some gemologists, was the presence of small, angular, transparent, near-colorless crystals (see figure 15).

Twinning and growth lines were

Figure 15. Angular crystals with slightly rounded corners in a Chatham synthetic ruby. Magnified 54×.

Figure 16. Angular growth lines extending completely through a Chatham synthetic ruby. Magnified 38×.

Figure 17. Straight, angular, and intersecting growth lines in a Chatham synthetic ruby. Magnified 39×.

also noted in several of these synthetic rubies, varying in appearance and nature from straight, parallel layers that did not extend into the stone to planes that extended completely through the stone and bore a remarkable resemblance to the laminated twinning that is often seen in natural rubies. Angular growth lines confined to one area were also noted (see figure 16). A few of these synthetic rubies contained growth lines that not only intersected, but also bent back and forth at various angles (see figure 17). Also observed in one of the stones was color zoning that resembled the "treacle" effect seen in some Burmese rubies. All five synthetic rubies were very slightly to slightly included and none was heavily included.

The refractive indices of the five synthetic rubies were quite constant, at 1.762–1.770 with a birefringence of 0.008. The specific gravities of four of the stones ranged from 3.99 to 4.00. The presence of platinum inclusions in one of the five stones affected the specific gravity of that stone slightly, raising it to 4.03.

Examination through the GEM Spectroscope revealed the expected ruby spectrum, with a very strong fluorescent line slightly above 6900 Å; there were actually two lines near 6928 Å and 6942 Å that were so closely spaced as to appear to be one line.

Exposure to long-wave ultraviolet light revealed a consistent, very strong red fluorescence, while under short-wave ultraviolet light the stones exhibited a fluorescence that ranged from faint to moderate red. The X-ray fluorescence of the five synthetics ranged from a weak to a moderate red.

SAPPHIRE

Parti-Colored Sapphire

Color zoning is commonly encountered in corundum, but more often than not strong zoning has a negative effect on the beauty of the cut stone. Recently, however, an attractive parti-colored sapphire, weighing 30.74 cts., was brought to the Los Angeles laboratory for identification (see figure 18).

This sapphire had an orange area in the center of the stone that gradually blended to purple, with a pink-

Figure 18. Parti-colored sapphire, 30.74 cts.

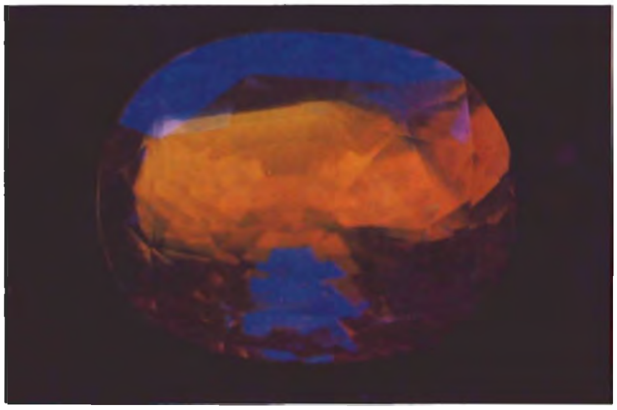

Figure 19. Parti-colored sapphire pictured in figure 18 as it appears when exposed to long-wave ultraviolet light.

Figure 20. Cat's-eye sillimanite, 1.99 cts.

ish-purple color resulting between the orange and purple sections. The zoning was very distinct and positioned in such a way as to create an attractive stone.

When the stone was exposed to long-wave ultraviolet light, there was a weak orange fluorescence overall with a much stronger orange fluorescence in the center (see figure 19). The central zoned area that fluoresced the strongest seemed to correspond with the orange in the center of the stone.

SILLIMANITE

A 1.99-ct. slightly brownish-yellow chatoyant cabochon (seen in figure 20) came into Santa Monica for identification. The color was very similar to that of cat's-eye apatite. However, the absorption spectrum showed a 4400 Å line rather than the lines near 5800 Å that are characteristic of apatite. The spot method revealed a refractive index of approximately 1.66. The movement of the spot when a polaroid plate was rotated over the refractometer suggested a birefringence of 0.015 to 0.020. The specific gravity appeared to be slightly higher than that of apatite. The results of the testing showed the stone to be cat's-eye sillimanite, also known as fibrolite. Because of the unusual yellow color, which none of us remembered having seen before in sillimanite, a tiny bit of powder was scraped from the unpolished back and the identity of the stone confirmed with X-ray diffraction.

ACKNOWLEDGMENTS

The photographs in figures 1, 9, 11, 12, 14, 15, 16, and 17 were taken by Bob Kane of the Los Angeles lab. Chuck Fryer took the photos that appear in figures 4, 5, 6, 7, 8, and 20. Tino Hammid, of the Gem Media department at GIA, supplied the photos for figures 18 and 19. And Karin Hurwit, of the Santa Monica lab, photographed the item in figure 10. The photograph for figure 13 was supplied by Shane McClure of the Los Angeles lab. Susan Kingsbury, of Gem Media, prepared the diagrams for figures 2 and 3.

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Beryl. *Australian Journal of Gemmology,* Vol. 1, No. 9, 1981, pp. 4–10.

Although titled "Beryl," most of this article deals almost exclusively with emerald. An extensive history of the uses of emerald and emerald deposits—from the ancient sources in Egypt to the well-known deposits of Colombia to the relatively obscure deposits of Norway—is given. Many interesting facts are also mentioned, such as the story of a specimen that was presented to Cortes by Montezuma upon the conquistador's landing in 1520 near what is now Veracruz, Mexico. The specimen was a large piece of limestone embedded with 10 deep green emerald crystals from one to two inches long. It was taken to Europe where it changed hands several times before it was housed in a museum in Vienna in 1900. The specimen was subsequently stored in the Salzburg salt mines to escape the Nazis and then hidden beneath a pile of rubble in a bombed-out room during the Russian occupation. Amazingly, the piece survived and is on display in the Vienna Museum today.

In a summary of the physical properties of emerald, inclusions typical of different localities are mentioned, such as pyrite in Chivor stones and bamboo-like blades of actinolite in stones from the Ural mountains. The article concludes with a brief description of fake emeralds, doublets, glass imitations, natural stones that resemble emerald, and synthetics. *SFM*

Des individus remarquables en voie de disparition (Natural masterpieces in peril). *Revue de Gemmologie a.f.g.,* No. 66, 1981, pp. 11–14.

"Among the treasures of the mineral kingdom, giant crystals are being systematically destroyed and are destined to disappear irretrievably from the face of the Earth." This article is illustrated with startling photos of crystals ranging from 250 to 4000 kg. The size of these enormous crystals, which may measure 3 m or

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

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

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

more in length, makes them a nuisance to construction and excavating concerns, which regularly break them up. No museum has ever had an exhibit of these giants.

The National Museum of Natural History in Paris and a few specialists have formed "Operation Giant Crystals" to attract the attention of the public and the scientific community to this problem and to acquire and install a collection of giant crystals in the Museum of Natural History. Among the species and/or varieties represented in giant form are beryl, topaz, mica, amazonite, orthoclase, and quartz. The sources of these giants are the ever-shrinking number of unexploited pegmatites, notably in Minas Gerais, Brazil. Most of the crystals that have been saved are in private hands and are unavailable to the public at large.

Those interested in helping with this project are asked to contact Operation Crystal Giants, 57 rue Cuvier, 75005 Paris, France. *Michel Roussel-Dupre*

'Geuda sapphires'—their colouring elements and their reaction to heat. H. Gunaratne, *Journal of Gemmology*, Vol. 17, No. 5, 1981, pp. 292–300.

Recently, the term *geuda* has been used exclusively to describe milky sapphires from Australia that are being heat treated to improve their color. Actually, *geuda* refers to any milky-white opaline character seen within and even outside a gemstone which is caused by a network of inclusions. In corundum, geuda results from excessive titanium which may exist as rutile inclusions in the stone.

The author describes the type of geuda stone that is most suitable for heat treatment. Such stones have been called diesel geuda: they have a faint blue tint, a milky-white sheen, and look like honey in direct light, thus resembling a film of diesel oil. It is essential that the stone be free of flaws and fissures, and that it have only a small number of inclusions other than geuda.

Gunaratne argues that syngenetic rutile (that which formed at or about the same time as the host) is characteristic of those corundums that react most favorably to heat treatment. He theorizes that the growing crystal of corundum incorporated liquid rich in titanium and, as temperatures dropped, this liquid crystallized into microscopic rutile inclusions. During subsequent heating, the titanium ions realign and function as coloring agents, imparting color to the corundum. Unfortunately, the author's explanation of the role of iron and titanium in producing color is incomplete.

A brief description of the three techniques commonly used in Sri Lanka to treat geuda stones follows. Basically, these involve prolonged heating of stones that have been coated with a thick paste in a gas, dieselene, or electric furnace. After a short discussion on heating parti-colored blue sapphires and pale yellow geuda stones, the author lists eight characteristics of geuda stones that have been successfully heat treated.

He concludes by stressing the need for further analysis to explain the nature of the change that occurs during treatment and to devise nondestructive tests for separating heat-treated corundum from its untreated counterpart. *Stephen C. Hofer*

Jade, part two, a brief review: occurrence and structure. R. A. Ball, *Australian Journal of Gemmology*, Vol. 1, No. 7, 1980, pp. 10–14.

Following a review of the properties of nephrite and jadeite, Ball discusses the geology of the nephrite deposits in Australia. In New South Wales, the nephrite occurs in ultramafic rocks, while in South Australia it is associated with metamorphic rocks that were later recrystallized. The author states that there are no known economically important occurrences of jadeite in Australia. This discussion is followed by a description of jadeite from Burma, Japan, and Guatemala and of nephrite from British Columbia, New Zealand, and the Philippines.

The remainder of the article reports on a study of fracture surfaces in both minerals. Jadeite features triangular cleavage fractures, while nephrite has fibers and bundles extending from the surface. Thirteen scanning electron micrographs, including five of jade substitutes, illustrate these features. A helpful bibliography is included. *DMD*

'Korite'—fossil ammonite shell from Alberta, Canada. W. Wight, *Journal of Gemmology*, Vol. 17, No. 6, 1981, pp. 406–415.

Korite is the latest name given to the commercially marketed fossil ammonite from Alberta, Canada. Other fossil ammonites from Alberta have been marketed under the names *ammolite* and *calcentine*. These fossil ammonites are of the class Cephalopoda, subclass Ammonoidea, and species *Placenticeras meeki*. They are about 71 million years old. Average diameter is about 20–25 cm, and shell thickness is usually less than 6 mm.

The gem material is actually the nacreous layer of the ammonite shell, which usually shows a red and green iridescence. The nacre is primarily composed of the mineral aragonite. The average R.I. was noted to be α 1.520 and γ 1.670, with a birefringence of 0.150. The specific gravity was 2.80 ± 0.01, and the hardness was 4 on the Mohs scale. Because of its low durability, this gem material is usually fashioned into cabochon triplets, with a quartz cap and natural shale as a backing. *GSH*

Malachit-azurit (Malachite-azurite). S. Koritnig, *der Aufschluss*, Vol. 32, No. 1, 1981, pp. 1–5.

Mr. Koritnig discusses the formation of malachite, $Cu_2[(OH)_2CO_3]$, and azurite, $Cu_3[(OH)_2(CO_3)_2]$, and compares these two substances from the standpoints of frequency of occurrence, formation of pseudomorphs, and crystal size.

These conspicuously colored minerals—deep green malachite and deep blue azurite—are formed by the weathering of copper sulfides with water that contains oxygen and carbon dioxide. They differ chemically only in their ratios of Cu:OH:CO_3, but they have several physical differences in addition to color. For example, malachite is much more common than azurite (though occasionally the minerals occur next to each other in the same locality). Also, malachite often replaces azurite and forms pseudomorphs, but rarely are pseudomorphs of azurite after malachite found. Lastly, azurite is found as single crystals, sometimes of good size, while malachite generally occurs in clusters of small crystals.

The chemical formulas of these two minerals are easily compared by reducing both to ratios with only one copper molecule: malachite, $Cu_1(OH)_1(CO_3)_{0.5}$, and azurite, $Cu_1(OH)_{0.67}(CO_3)_{0.67}$. This shows that azurite is richer in CO_3 and malachite in OH. Because water is always present in sufficient quantity during formation, the author surmises that it is the CO_3 content that determines whether the mineral formed is azurite or malachite.

Results are given from two experiments which show that at certain concentrations (0.5% volume) of CO_2 and H_2CO_3, both minerals form at the same time. If the H_2CO_3 content is increased, more azurite is formed; if it is decreased, more malachite is formed. The latter case is much more common in nature; hence, more malachite than azurite is found.

The author also explains the cause of pseudomorphs of malachite after azurite. When the solution is such that both minerals may form, a change occurs where the concentration of H_2CO_3 falls short of the necessary amount; the azurite then becomes unstable and is changed into malachite. A factor facilitating the malachite pseudomorph after azurite is the difference in specific gravity between the two minerals. The specific gravity of pure azurite is 3.83, and that of malachite is 4.00; therefore, malachite requires less room to form.

Koritnig concludes with a brief comment on crystallization. When crystals begin to form out of a solution, nuclei are present. Some solutions have numerous nuclei, while other solutions have only a few. When the solution has numerous nuclei, like the malachite solution, many small crystals form. When the solution has few nuclei, like azurite, a few large crystals form. It is not known why some solutions have many, and other solutions have few, nuclei. *Barbara Taylor*

Observations on some scapolites of central Tanzania. G. Graziani and E. Gübelin, *Journal of Gemmology*, Vol. 17, No. 6, 1981, pp. 395–405.

Inclusions are a major interest in today's gemological research. Although intrigued by the chatoyancy, asterism, and high birefringence of East African scapolites, Graziani and Gübelin focus their investigation on unusual prismatic channels and their crystal fillings in yellow and colorless scapolites from Umba, Tanzania. Following a review of recent literature on scapolite, the authors describe in detail the procedures and equipment used to test these samples. Tables summarize the X-ray data, optical properties, and microscope analyses. Based on the chemical composition determined, the authors conclude that these scapolites are mizzonites, two intermediate sodic-calcic end members of the marialite-meionite solid-solution series.

The authors examined closely two types of inclusions: corroded growth tubes that have been filled with red and yellow scales; and thin, black pseudohexagonal plates. The electron microprobe results agree with previous reports that the fillings are iron oxides or hydroxides. On the basis of the percentages of iron, sulphur, and copper determined in the plates, the authors conclude that these are cupriferous pyrrhotite.

From these results, the authors attempt to reconstruct the physical and chemical history of the specimens. Originally, the growth tubes were filled with iron-rich fluids that formed lepidocrocite, an iron-rich hydroxide. With changing conditions, the lepidocrocite hydrated into the iron oxides hematite or maghemite. When temperatures were between 350°C and 500°C, maghemite would form; when temperatures rose to greater than 500°C, hematite would form. That these variations occurred rapidly is verified by the fractures and healed fractures in the stone. *DMD*

On monazite inclusions. S. Hornytzkyj, *Journal of Gemmology*, Vol. 17, No. 6, 1981, pp. 373–380.

Armed with the knowledge that nonopaque, nonmetamict monazite $(Ce,La,Pr,Nd,Y,Th)PO_4$ appears green under the unfiltered light of a medium-pressure mercury vapor lamp, Hornytzkyj designed an experiment to test whether monazite inclusions in gemstones could be identified the way crystals and loose grains are. Since this change of color is due to the presence of rare-earth metals, especially neodymium, the spectroscope can also identify this gem. Hornytzkyj examined approximately 3,000 specimens of rough and cut gemstone material and chose 36 for further study with the quartz-mercury lamp, the Rayner prism spectroscope, and the Wild microscope at 100× magnification.

The author describes the results of these tests on the inclusions found in topaz from Nigeria and Madagascar, in garnet from India, Sri Lanka, Australia, and Finland, and in kyanite from Zimbabwe (Rhodesia). The article also presents six photographs of inclusions, a reproduction of monazite absorption spectra, and the four main spectral radiation lines of the mercury vapor lamp.

Hornytzkyj concludes that it is probable, from the results of this study, that the inclusions discussed were monazite. Both methods (change of color and spectroscope) can be used to identify this mineral, provided that the host material will transmit the proper radiation wavelengths, that the inclusions are of a sufficient size, and that the lighter rare-earth metals, neodymium particularly, are present in correct proportions.

JPG

The peerless pearl. N. T. Birmingham, *Town & Country,* Vol. 135, No. 5014, 1981, pp. 147–151, 196–198.

This article offers a good introduction to pearls. Probably written as a result of the recent resurgence of interest in pearls, the article briefly covers pearls in fashion and how sales have soared. Lore is discussed, with tales of the passion Europeans have for pearls. The author also reviews different varieties of pearls and their sources. Twenty color photographs illustrate different styles of jewelry that use these various forms.

For years, obtaining natural pearls was a treacherous business. Then, at the end of the 19th century, Kokichi Mikimoto developed a method of culturing pearls and revolutionized the industry. The article explains how culturing is done today in Japan's Ago Bay.

Birmingham concludes the article with a discussion on how to care for pearls. She emphasizes why proper stringing of the pearls is so important, as is guarding against the effects of chemicals and acids.

Diane Saito

Strukturverfeinerung von Liddicoatit (Structural refinement of liddicoatite). V. B. Nuber and K. Schmetzer, *Neues Jahrbuch für Mineralogie Monatshefte,* No. 5, 1981, pp. 215–219.

The general formula for tourmaline is $XY_3Z_6[(O,OH,F)_4(BO_3)_3Si_6O_{18}]$. Liddicoatite is a member of this complex group, with an ideal formula of $Ca(Li,Al)_3Al_6[(O,OH,F)_4(BO_3)_3Si_6O_{18}]$. When Na^+ (sodium) takes the place of Ca^{+2} (calcium), the result is elbaite; thus, liddicoatite is the Ca analogue of elbaite. It has been surmised also that there exists an unbroken compositional range between liddicoatite and elbaite with only slight structural differences. This study sought to verify these two assumptions.

A green fragment purported to be liddicoatite from Madagascar was extensively examined by the authors. Chemical analysis showed that it contained 65% liddicoatite composition. Selected interatomic distances were measured and showed values very close to those of liddicoatite. This information is presented in one of two tables; the other contains the atomic coordinates and thermal parameters. A Syntex R-3 diffractometer yielded an R value of 3.3%. It was found that the ditrigonal Si_6O_{18} rings were less distorted in liddicoatite than in elbaite because the Ca^{+2} which occupies the X position in liddicoatite is smaller than the Na^+ of elbaite. Also, the Si_6O_{18} rings of liddicoatite form a nearly ideal hexagonal ring.

Analysis of the data shows the obvious similarities of the two structures and, as anticipated, supports the theory that there exists between elbaite and liddicoatite a continuous solid-solution series.

Barbara Taylor

Ten gems: mystery, history and sales facts. *Jewelers' Circular Keystone,* Vol. 152, No. 4, 1981, pp. 80–88.

This well-organized, highly readable, and informative article is part of the April issue's "AGS special report: Profit Now from Colored Stones." Clearly illustrated with excellent color photographs, the article describes tanzanite, tourmaline, spinel, peridot, topaz, kunzite, sapphire, aquamarine, garnet, and amethyst. For each gem, a brief history and some mythology is followed by a list of the stone's properties, including its durability, and a description of suitable cleaning methods, with cautions against techniques that might cause damage. For example, under tanzanite we read, "A soft brush with lukewarm water and mild detergent is recommended. Ultrasonics are absolutely forbidden: The stone will fracture." And for topaz, the article advises, "Topaz reacts fairly well to an ultrasonic cleaner. Steaming and boiling should be avoided." For garnet, sapphire, topaz, spinel, and tourmaline, all of which vary greatly in monetary value depending on factors such as clarity and color, information on the wholesale price range is also given. This is one of the most useful and enjoyable articles to appear in a trade journal in some years. *FS*

DIAMONDS

Diamond: the claims of Henri Moissan. B. Anderson, *Retail Jeweller,* Vol. 20, No. 493, 1981, pp. 3, 22.

In a continuation of his series on the history of research into synthetic diamonds, Anderson focuses on Henri Moissan, the Nobel Prize–winning scientist who is famous for his isolation of the gaseous element fluorine. In 1872, Moissan joined the Museum of Natural History in Paris to study under Edmond Fremy; Verneuil, who created synthetic rubies, the first man-made gemstones, became an assistant there as well. Undoubtedly influenced by the discovery of diamonds in meteorites, Moissan designed an electric furnace in which he attempted to synthesize this gem. The procedure involved placing iron and sugar carbon in a graphite crucible that was heated to approximately 3000°C, cooled suddenly, and then chemically treated. Of 12 successful runs, 4 produced residues of a total of 20 small diamond crystals after the acid treatment. Anderson describes these results as well as efforts by other scientists to duplicate Moissan's work.

Anderson goes on to question the popular story attributed to Moissan's widow that one of Moissan's assistants salted the results with natural diamond fragments to "please the old man." On the contrary, Moissan would have detected the substitution; he died of complications resulting from fluorine and carbon monoxide poisoning at 55, more than 10 years after his initial experiments on diamonds. This is a fascinating look at the life of a respected scientist. *DMD*

The famous Golconda d'Or diamond. *Australian Journal of Gemmology*, Vol. 1, No. 7, 1980, pp. 5–6.

The Golconda d'Or, a famous diamond from India's Golconda mines, is a golden, flawless, perfectly proportioned emerald-cut diamond that currently weighs 95.40 cts. Its known history dates back to 1739, when it was seized in a looting of Delhi by Nadir Shah, the Persian invader. Its subsequent travels are unclear until the 1800s, when the Golconda d'Or became part of the Crown Jewels of Turkey.

In 1876 a repressive ruler, Abdul Hamid II, came to power in Turkey. A secret society, the "Young Turks," plotted to depose him, eventually gaining control over the army. In 1908, they seized the throne and the Crown Jewels, which included the Golconda d'Or.

In 1909 the first president of the Turkish Republic, Mustapha Kemal, sold the Golconda d'Or to a wealthy Turkish family, with whom it remained until 1962 when Dunkings the Jewellers, of Melbourne, Australia, purchased the stone. *Peter G. Hess*

Editor's Note: As reported in an Australian newspaper on October 20, 1980, the Golconda d'Or was stolen while on exhibit at the Sydney Lower Town Hall in Australia. Valued at $2 million, the famous stone was removed as 80 people milled around the hall.

New data on the composition of inclusions in diamond. A. I. Botkunov, V. V. Koval'skiy, K. N. Nikishov, V. F. Makhotko, G. P. Bulanova, *Doklady Akademii Nauk SSSR*, Vol. 240, 1980, pp. 187–190.

The authors systematically inspected included diamonds from the Mir and the Internatsional'naya diamond pipes in the U.S.S.R. under a binocular microscope, selecting garnet, rutile, and chromite inclusions for detailed chemical analysis. The inclusions, some as small as 0.5 mm, were extracted from their diamond hosts and then, along with selected natural mineral standards, were examined by means of the electron microprobe.

The data obtained were compared to other published information. The results showed that the chromite inclusions contained from 5.6% to 6.8% aluminum oxide, which placed them in the high alumina area of the composition field. The rutile analyzed showed a slight enrichment in iron. The garnets were divided into two groups: (1) those showing a high Cr_2O_3 (chromium oxide) and a low CaO (calcium oxide) content, and (2) those showing an average Cr_2O_3 and a high CaO content. The authors conclude that the garnet inclusions had a wider compositional range than was expected based on earlier reports. *JIK*

Recent research—the diamond geologists' tale. J. W. Harris, *Industrial Diamond Review*, December 1980, pp. 470–477.

Harris presents a major review of recent research on diamonds, nodules, and kimberlite, the matrix rock of diamonds. He draws conclusions about the origins of upper-mantle materials and their interrelationships.

Prior to 1975, a number of authors had written about diamonds from various localities. Then Harris, J. B. Hawthorne, M. M. Oosterveld, and E. Wehmeyer presented a diamond classification system which quantified characteristics such as crystal form, inclusions, color, transparency, and surface features, thus establishing a framework for future research.

Recent articles have been able to dispute previously held theories about sources of alluvial diamonds in Africa. However, not all of the research focuses on South Africa: McCallum has studied the pipes on the Colorado-Wyoming border, and Mendelssohn et al. have examined cathodoluminescence in diamonds from Central African Republic and Brazil.

Another major area reviewed involves inclusion research. Inclusions in diamond are divided into either peridotitic or eclogitic groups on the basis of the xenoliths (inclusions of preexisting rock in another, usually igneous, rock) found in the kimberlites. Peridotites are rocks composed of olivine and enstatite and usually some diopside and garnet; eclogites are rocks consisting of garnet and omphacite. Although both types of inclusions are never found in the same diamond, both can be found in separate diamonds from a single kimberlite. Therefore, there are at least two major environments in which diamonds can grow.

Knowledge about the chemistry of the included minerals can also be used to estimate the physical conditions in the upper mantle where the diamonds crystallized. Relationships between temperature and pressure can be derived from considering changes in the chemistry of these minerals. Harris includes one table of temperatures and pressures for peridotitic inclusion suites from different localities and another for eclogitic inclusions. He reports that the lead-isotope characteristics of sulphide inclusions are very useful in determining when the diamond formed.

Harris also reviews how information is obtained about the chemical environments in which diamond forms. Once again, inclusions are a major focus of research. Here, Harris summarizes recent conclusions: eclogites and eclogitic diamonds are products of melting events in the upper mantle that are separate from and probably previous to the melting events that give rise to peridotitic diamonds and kimberlites.

Although studies on kimberlites have been neglected for the most part, Harris references those mineralogical investigations that have been carried out.

A considerable amount of technical information is presented in this article; yet the reader need not be versed in mineralogy or geochemistry to understand it. Harris defines much of the technical vocabulary and summarizes the research techniques. An additional contribution is the extensive bibliography of 55 citations. *Ray Page*

Research into green diamonds. F. A. Raal and D. N. Robinson, *Diamond News & SA Jeweller,* Vol. 44, No. 6, 1981, pp. 47–48, 51, 52.

Dr. Raal and Dr. Robinson discuss the results of a study of 40 diamonds that were recovered from the Witwatersrand gold mines in South Africa and are now museum pieces. They are all rough stones, varying in color from a very light to a dark, almost black, green. That the color is confined to the surface was verified when small windows were polished on four of the stones. When these diamonds are heated in the dark at 400°C for a few minutes, they lose their green color and become yellow. If they are then exposed to sunlight, they rapidly revert back to green. Using a qualitative study of the infrared absorption spectra and optical spectra recorded at different temperatures, Raal and Robinson conclude that these stones are the type Ia variety (which contain substitutional nitrogen in platelet configuration), and that their color and chameleon behavior are the result of natural irradiation and heating to a temperature that does not exceed 500°C. This theory is substantiated by the chameleon behavior of diamonds irradiated in the laboratory.

Buried in the conglomerates of the Witwatersrand Supergroup in association with gold and uranium, these diamonds were recovered by older gold recovery processes. Unfortunately, the techniques used today crush all the conglomerate, destroying any diamonds that might be present. *ET*

GEM INSTRUMENTS AND TECHNIQUES

Étude des turquoises au microscope électronique á balayage (Study of turquoise by scanning electron microscope). M. Hoyos, J. Casas, J. Medina, *Revue de Gemmologie a.f.g.,* Vol. 65, 1980, pp. 12–15.

This study reports how the use of the scanning electron microscope (SEM) allows examination in detail of the surface characteristics of turquoise. The purpose of the work was to establish the main differences between turquoise, treated turquoise, and turquoise simulants. The samples, which were first identified as turquoise by X-ray diffraction, were found upon examination with the SEM to differ in texture according to the crystalline structure and the size of the grain. Natural turquoise has large, elongated crystals that are partially oriented; some crystals exhibit a triclinic habit. Gibbsite, which had been previously identified as turquoise, was the simulant examined. Its structure consists of smaller crystals, all with a definite orientation, that have been cemented by a mixture of phosphate and copper sulfate. Another sample has spherical particles composed of chlorine and copper sulfate, which indicates chemical treatment. Ten micrographs at magnifications from 2500 to 10,000 help illustrate the article. A bibliography provides references for the interested reader. *Anne Latrille*

Photonics: an innovation in gemmology. M. Grossmann, P. D. Meyer, P. Meyrueis, E. Bres, *Diamant,* No. 244, 1980/81, pp. 45, 46, 48, 50.

In the first article of a series, the authors introduce the subject of photonics. Reviewing recent progress in physics and touching on lasers, holography, and fiber optics, they define *photonics* as the range of new technologies that use light to measure, transmit, transform, or record.

According to Grossmann et al., gemology is going to be revolutionized by photonics. Here the emphasis is on the commercial aspects of gemology, namely the certification of diamonds. To date, the evaluation of diamonds is done mainly by human, subjective criteria. Cut and clarity are still analyzed with a 10× loupe and color with comparison stones. The authors argue that the new methods, which analyze the interaction of light and given materials, can remove this subjectivity. *Dianne Eash*

GEM LOCALITIES

Diamond diggers in Namibia sift ocean sands for gemstones. T. S. Green, *Smithsonian,* Vol. 12, No. 2, 1981, pp. 49–56.

In this article, which is adapted from his book *The World of Diamonds,* Timothy Green discusses the importance of South Africa in the diamond world from the turn of the century to the present, with a specific focus on diamond mining in the southwest African country of Namibia. DeBeers Consolidated Diamond Mines (CDM) has converted the west coast of Namibia into a rich alluvial mining region that now has an annual gem production of 1.6 million carats.

For centuries, diamonds have been washing down the Orange river from the interior of the continent. When they reached the sea, some were deposited at the river's mouth, but by far the richest deposits were laid down in marine terraces 60 miles north of the Orange estuary on Namibia's coastline. These terraces are now being mined in a unique way. Large bulldozers and earth-movers strip the sand away layer by layer. After the diamonds have been sifted out, the sand is then dumped at the ocean's edge to form huge dykes and permit the exploration of more marine terraces.

Even as the mining goes on, the Namibians are struggling for their real freedom from South Africa, which refuses to acknowledge the U.N. resolution of 1966 granting Namibia independence. Many of the Ovambo tribesmen who form the major part of the labor force attempt to smuggle diamonds out of the high-security mine area to help finance the South West Africa Peoples Organization, the foremost group fighting the undeclared war for liberation.

The undercurrent of political struggle that moves within the steady work flow makes an interesting counterpoint to the actual mining. One gets the feeling that even as the sands are being shifted, so is the power over the diamond mining. And even as these changes take place, CDM continues to harvest Namibia's shores for its rich crop of gems. *EBM*

Gemstones found in the Jabal al Hasáwnah and Jabal as Sawdá Mountains, Libya. T. Mrázek, *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* Vol. 29, No. 3 and 4, 1980, pp. 135–148.

The author prefaces his article with a discussion of the geology and mineralogy of the Jabal al Hasáwnah and Al Washkah region, Libya. Two geologic maps and a stratigraphic column of the region's Paleozoic-Tertiary sediments and volcanic rocks are included.

Mrázek classifies the region's gems into (1) gemstones of basalts and those related to contact with basalt bodies (olivine, chalcedony, porcellanite); and (2) gemstones of sedimentary origins, both from marine sediments (cherts, chalcedony, agate, aragonite) and from freshwater sediments (lacustrine silicites).

Since the quartz geodes and aragonite specimens present are of interest only to collectors, and the olivine is not considered suitable for cutting, Mrázek concludes that the cherts represent the most exploitable gem resource yet tested in the area. *JPG*

Mineral resources of the Wide Bay–Burnett region. Geological Survey of Queensland, *Queensland Government Mining Journal,* Vol. 82, No. 954, 1981, pp. 153–178.

The Geological Survey of Queensland did a general resource investigation of this region in southeast Queensland, Australia. In the process the geologic history of the region was established, and the individual structural units are described in the text. In addition to the gold, copper, and heavy mineral sands that have been economically important to the area, there have been occurrences of many other minerals, including a variety of gemstones.

Rich deposits of alluvial gold were discovered in Gympie in 1867 and had a major influence on the early history of Queensland. Reef mining began later and continued into the 1900s. A list of the gold fields and a mineral locality map document these deposits as well as those of other minerals.

Although none of the gemstones found in this area has proved economically significant, an extensive list of their locations and types is included. Topaz, tourmaline, opal, beryl, rhodochrosite, amethyst, spinel, and zircon are just a few examples. The agate and garnet deposits require mining leases from the government. No production statistics are given. An extensive bibliography concludes the article. *DMD*

Source rocks of gem minerals: a case study from Sri Lanka. K. Dahanayake and A. P. Ranasinghe, *Mineralium Deposita,* Vol. 16, 1981, pp. 103–111.

In this paper examining Sri Lanka's traditional gem mining district, Dahanayake and Ranasinghe begin by summarizing the geology as illustrated by two geologic maps. The island is dominated by Precambrian metamorphic rocks which have been divided into the Highland Group, the Southwestern Group, and the Vijayan complex. Reports of occurrences of corundum in the Highland Group are then reviewed.

The authors sampled two river valleys in the Weddagala areas of Ratnapura. In these Highland deposits, the major rock types are granulites, garnetiferous gneisses, and amphibolites. The underlying rocks of the Kaswatta drainage basin are for the most part garnetiferous gneisses; those in the Delgoda basin are primarily granulites.

The data derived from the separation and subsequent identification of the minerals in these two areas are presented in tables of heavy minerals and summarized in two graphs of the distribution of beryl, corundum, spinel, topaz, tourmaline, and zircon. While the gneisses contain more spinel, tourmaline, and muscovite, the granulites are richer in beryl, topaz, and corundum, which the authors relate to increasing pressure-temperature (PT) conditions. The authors conclude that since the PT factors of the granulite facies were more favorable for gem deposits, this area warrants further exploration. *DMD*

Sphene, Sri Lanka's newest gemstone. P. C. Zwaan and C. E. S. Arps, *Scripta Geologica,* No. 58, 1981, pp. 1–11.

Zwaan and Arps are excited about the potential for cuttable gem-quality sphene from southern Sri Lanka. This represents an addition to the previously reported sphene localities in Brazil, California, and Switzerland. Five samples of sphene from Sri Lanka and three from Brazil were investigated for refractive index and specific gravity, and were tested by electron microprobe and X-ray diffraction.

Strong pleochroism was observed as well as strong birefringence, which was indicated by the noticeable doubling of back facets when the stones were viewed through a microscope. The strength of the didymium absorption spectra was directly related to color intensity, which results from the presence of rare-earth elements neodymium and praseodymium.

The authors report the presence of inclusions of liquid feathers and healed fractures. Although apatite crystals are hypothesized in one of the Brazilian stones, on the whole none of the physical or optical properties of the various samples allowed differentiation of the sphenes based on origin. Zwaan and Arps anticipate that future analyses on trace elements in rough specimens may produce the data necessary for such a differentiation as more material comes out of this site. *GSH*

Western Australian chrysoprase: its history, occurrences, and value. C. Boesworth and H. Boesworth, *Australian Lapidary Magazine,* Vol. 17, No. 8, 1981, pp. 17–19.

Gem chrysoprase is the most prized variety of chalcedony. The finest gem grades ever known have been produced in Western Australia.

Although chrysoprase has been carved into cameos and intaglios since the height of the Roman empire, its early source is unknown. Silesia was a known European source for chrysoprase as early as the 1730s, and the Ural Mountains have produced a small amount. The 1880s saw the discovery of chrysoprase in California and western Oregon, and still later it was mined in Brazil. A green variety of chalcedony has been found in Zimbabwe (Rhodesia), but this material turns red under the chelsea filter and should not be referred to as chrysoprase. None of these sources is considered as important as the mines in Western Australia.

The mine near Wingelina in the Warburton Range in Western Australia became the world's largest producer of chrysoprase between its discovery in 1965–66 and its close in 1973. It is estimated that approximately 400,000 kilos of chrysoprase and up to 100 tons of "citron chrysoprase," along with a substantial amount of moss agate, were removed from this mine. This material was suitable for carving into snuff bottle tops, ashtrays, and the like, but was not considered gem grade because most of it was highly included and of uneven color. Some of the material even faded in direct sunlight because of its halide content. The quality of the material, coupled with the expense of mining and sorting, made this mine an unsuccessful venture.

In 1969, a nodular variety of chrysoprase was discovered at Yandramindra, Western Australia. This material, which is of excellent color and quality, is said to surpass chrysoprase found elsewhere at any time. Exceptional grades have commanded prices of $600 per kilo. Financial problems forced the closing of this mine in spite of the high price commanded by, and worldwide demand for, its production.

Late in 1979, another gem-grade nodular chrysoprase deposit was discovered. This material is very similar to that of the Yandramindra nodules. This most recent find is located in the Kalgoorlie area of Western Australia and has already produced two extraordinary specimens weighing 700 kilos and 1470 kilos, respectively. These are the largest nodules of gem chrysoprase on record; they are scheduled for exhibition in the near future. *CKG*

The Yogo sapphire, Montana's elusive treasure. H. M. Willard, *Lapidary Journal,* Vol. 35, No. 4, 1981, pp. 868–872.

Helen Willard provides a most colorful account of the history surrounding the Yogo sapphire mines in Montana. The discovery of sapphire in this region, the mining methods used, changes in ownership of the mines, and descriptive accounts of the successes and failures of the mining operations are discussed. In addition, geographical maps of the mining area plus pictures of jewelry set with Yogo sapphires are included. Ms. Willard also briefly discusses the qualities of Yogo sapphires that make them so desirable, and summarizes the current outlook for this mining area. *NPK*

JEWELRY ARTS

Anne Hull Grundy: champagne, bananas, pigeons and jewels. V. Becker, *Antiques World,* Vol. 3, No. 6, 1981, pp. 34–41.

There is an enormous collection of antique jewelry at London's British Museum of Natural History. In this article, Vivienne Becker, author of *Antique and 20th Century Jewellery: A Guide for Collections,* tells us about the collection's eccentric donor, Anne Hull Grundy, and her antique jewelry.

Through this article, we are introduced to this lover of antique jewelry who has donated or supplemented collections to 60 museums throughout Britain, each assemblage suited to that particular location. Mrs. Hull Grundy, who does all business from her bed, hates diamonds and "lumps" of precious gemstones. She is instead concerned with the craftsmanship characteristic of each age.

Twelve hundred pieces from Mrs. Hull Grundy's private collection are currently on display in London's British Museum. Much of the collection covers the period from 1700 to 1930, with an emphasis on 18th- and 19th-century pieces. Her relish for jewelry made from inexpensive materials such as tortoise shell, jet, steel, seed pearls, mother-of-pearl, and ivory is apparent. As Becker states about the collection, "Its great strength lies in the fact that it traces popular jewels, those that reflect the atmosphere, customs, and beliefs of the age as well as documents the changing role of both the craftsmen who produced the jewels and the women who wore them."

The author then focuses on different aspects of the collection, commenting on particular groups such as cameos or on a particular piece such as an art nouveau brooch called "The Kiss." These are accompanied by photographs, including one of the extraordinary Anne Hull Grundy. *Diane Saito*

Basic metallurgy for goldsmiths—VI. M. Grimwade, *Aurum,* Vol. 81, No. 5, 1981, pp. 39–45.

In the sixth of a series of articles on basic metallurgy for goldsmiths, Grimwade focuses on the mechanical properties of metals and alloys and the methods used to measure these properties. A number of the topics, such as tensile strength, ductility, and sheet formability, will be of interest only to the metallurgist. However, a major part of the article is devoted to hardness, which is an important concern to gemologists as well.

Methods to measure hardness similar to those used for diamonds are included here. All three—the Vickers, Brinell, and Rockwell tests—determine the material's resistance to penetration by a standard indenter, thus giving a more precise value than the Mohs scratch test. The author elaborates on the Vickers test because it utilizes a smaller indenter and can be used on a wider range of materials, from very soft metals such as gold to hard stones such as diamonds.

Photographs of equipment, diagrams of how the tests work, and graphs of the results are useful additions to the article. *RSS*

Gold made to measure. The International Gold Corp. Ltd. and T. Green, *Hong Kong Jewellery,* Vol. 1, 1981.

In the Middle East, wealth is not deposited in savings accounts but worn in the form of gold jewelry, which is usually 21 karat but never less than 18 karat. Unlike most stores in the U.S., a single jewelry shop in the Middle East may display 20 kilos or more of gold. The main reason for buying gold jewelry is as a form of savings.

In the past, Beirut (Lebanon), Damascus (Syria), and Aleppo (Syria) have been the great gold manufacturing centers of this region. However, as a result of recent wars, many smaller and more regional shops have appeared. Along with the continued growth of domestic manufacture, wholesale importation of jewelry from Italy has also mushroomed. Over 300 tons of gold are made into jewelry and coins annually, with another 100 tons of jewelry being imported.

Distinct cultural attitudes are connected to the acquisition of gold, which the author terms *hoarding* in this region. In prosperous times, profits are not put in bank accounts but rather used to purchase gold. Family members working outside these countries send their wages home to buy gold. Dowries for daughters must include large amounts of gold ornaments.

In less prosperous times, the reverse happens and much gold is sold back to the dealers. In 1973/74, 150 tons of gold jewelry was melted down and sold in the London and Zurich gold markets. Therefore, there is no place where the ups and downs of the gold market are felt more immediately and drastically than in the Middle East. The author concludes that unlike Europe, America, and Japan where "adornment jewelry" is purchased, the Middle East buys "investment jewelry." *RSS*

Gold wire in antiquity. A. Oddy, *Aurum,* No. 5, 1981, pp. 8–12.

Today gold wire is made by drawing rods through a draw plate, a steel plate with holes of decreasing size. In the infancy of gold working, however, gold wire had to be hammered into thin rods or sheets. This was followed in time by 'block twisting,' 'strip twisting,' and swaging; the latter method is still used today. Oddy points out that development in gold wire making has not always followed a simple chronological sequence; some examples of ancient jewelry have gold wires that were made by a combination of techniques.

In comparing gold wire produced in pre-Columbian South America with that produced in ancient Europe, Oddy found that hammering was common to both. However, although twisting and rolling were practiced in Europe in early times, these techniques were not common in South America. Conversely, the casting of free-standing wire as filigree was done in South America but not in Europe. Oddy closes with the comment that the study of ancient wire making is still in its infancy. The material that has been closely studied, however, attests to the skill and ingenuity of the ancient goldsmith. Also, these studies have helped expose forgeries of early pieces because the techniques used were modern.

The author, who works in the Research Laboratory at the British Museum of Natural History, has included seven photographs of jewelry from various antiquity departments in the British Museum. In addition, two diagrams of the stages involved in making different wires and an interesting scanning electron micrograph of a wire in a necklace produced in early Rome are presented. *Christina Lopez*

An introduction to hard fired enameling. J. Pettit, *American Jewelry Manufacturer,* Vol. 24, No. 4, 1981, pp. 86–95.

Joseph Pettit, enamelist and enamel room foreman, offers an interesting condensation of an extremely complex art form. After a brief introduction to the history and state of the art of enameling, he examines the basic types of enamel and some of the enameling methods. He also presents a definition of enamel and discusses its production and physical qualities.

The author's description of metals usable for enameling and the methods of preparation are somewhat more comprehensive. Application techniques, such as sifting and wet charging or wet inlay, are described in clear detail. Firing, with its attendant relationship to metals, firing temperatures, and finishing processes conclude the article.

As the cover statement to the article promises, Pettit does offer "the beginner the basics in terminology, types of enameling and techniques," but they are indeed basic. This introduction may well serve, however, as an incentive to the beginner to seek out more comprehensive information, or it may even induce someone with a passing interest to become a beginner.

Archie V. Curtis

Jewelry making Italian style. N. B. Winkler, *Jewelers' Circular-Keystone,* Vol. 152, No. 5, 1981, pp. 94–98.

The author reports his observations of the Italian jewelry industry, made while touring factories ranging in size from a two-man facility to one with 1200 workers.

Winkler's first impression is the wide range of colored stones and substitutes used in Italy as contrasted with American jewelry. Turquoise, chrysoprase, onyx, and hematite are featured in novel settings and cuts, sometimes set off by thin gold "walls," sometimes by rows of diamonds. Next, he mentions the frequent use of stainless steel, which may be darkened and arranged with gold for contrast.

The primary quality he notes in contemporary Italian jewelry is its light weight. Many designs make use of openwork patterns. A great deal of the jewelry is hollow: items are made with base-metal cores and covered with karat gold; acid baths dissolve the cores, leaving the very light gold pieces.

Winkler also visited a school for jewelers, where students are enrolled at the age of 15. In addition to the jewelry-making apprenticeship, the students follow a full academic curriculum. The laboratory work is reported to be of high quality.

The article includes a description of one factory that produces silver flatware and of another where silversmiths produce chandeliers, floor lamps, and numerous other very large pieces, carrying out practically all processes manually. This work is in sharp contrast to that of the largest factory, where all kinds of jewelry are produced in a highly mechanized setting. Here, chain and hollow chain are produced; both centrifugal and vacuum casting methods are used. Still, in part of the factory, hand-made jewelry is also fashioned.

The photographs include suites of Italian jewelry, craftspeople putting enamel on jewelry in one factory and assembling link bracelets in another, as well as machines that make chains and others that turn cast gold into sheets. *SLD*

The jewels of the twenties. *18 Karati,* No. 51, 1981, pp. 76–81.

This short account of jewelry from the 1920s features bracelets, necklaces, rings, and earrings signed by Van Cleef & Arpels and Cartier. While many would consider the pieces too elaborate for today's fashions, the continuing desire to own these creations is illustrated by the prices they brought at recent auctions. This reflects not only a nostalgia for that time period but also an acknowledgment of the quality of craftsmanship involved. Their further value as international currency is said to have been reinforced by the wealthy Russians who fled the Soviet Union following the revolution. The article includes photographs of five suites of jewelry with a description of the stones and the prices paid at auction. *DMD*

More mythological animals in netsuke. P. Schneider, *Arts of Asia,* Vol. 10, No. 6, 1980, pp. 126–132.

This article is the second in a series on mythological animals in netsuke, the carved object attached to the end of the Kimono cord which functions as a toggle. The first article appeared in the March-April 1976 issue of *Arts of Asia.* This installment covers the dragon, the shojo (the smiling ones), the namazu (the earthquake fish), the ho (a fabulous bird that comes down from the heavens only once in a thousand years), the kitsure (the fox), the tanuki (the badger), the neko (the cat), and the hare (the rabbit in the moon). It answers such questions as: What is a kirin? An animal that is half cow, half dragon. Who are the shojo, and why are they always smiling? They are neither animal nor man; but are happy, harmless beings who are very fond of sake and almost always drunk (which explains why they are always smiling). The article also explains how earthquakes are caused by the fabulous earthquake fish, the namazu, a huge subterranean catfish whose body is hidden under the greater part of Japan with its head under the province of Hitachi. From time to time, the namazu grows restless and wiggles now its tail, now its head, causing the earthquakes so common in Japan. "More Mythological Animals in Netsuke" is a well-illustrated collection of Japanese folk tales that is engagingly written and will interest students of netsuke or Japanese culture, or those who just enjoy a good story. *ET*

Netsuke and the Sōken Kishō. M. Mikoshiba and R. Bushell, *Arts of Asia,* Vol. 10, No. 6, 1980, pp. 103–117.

For those interested in netsuke, this article is a rare find. It is based on quotations and illustrations taken from the *Sōken Kishō, "An Appreciation of Superior Sword Furnishings,"* the first book to mention netsuke. Written by Inaba Tsuryu in 1781, the book is devoted to the fittings of the Japanese sword; however, the seventh and final volume deals with ojime, the slide bead, and netsuke. This earliest source of information on netsuke lists netsuke-shi (netsuke artists and carvers) who were active before 1781 and illustrates netsukes popular at that time.

In the introduction, the authors touch on the development of netsuke carving and then provide a brief analysis of the 55 carvers listed in the *Sōken Kishō*. For convenience, the carvers are numbered in parentheses according to the sequence in which they appear in the book, although Inaba did not number them. The introduction also covers some of the difficulties of translating and interpreting this text.

The main body of the article is a translation and adaptation of the part of volume 7 of the *Sōken Kishō* that deals with netsuke. All information and observations not written by Inaba are set in italics within brackets. Ueda Reikichi, author of *Shumi no Netsuke (Netsuke as a Hobby)*, is a major source of additional information. His book, published 150 years after the *Sōken Kishō*, was the second manuscript to be printed on netsuke.

Care and planning are evident in the selection of illustrations for this article; the authors paired photographs of drawings from the *Sōken Kishō* with actual netsuke of identical or similar models. The result is something like a beginning textbook. Carefully researched, well written, and beautifully illustrated, this article is a must for the student of netsuke. *ET*

RETAILING

An armchair exploration of the auction house mystique. J. M. Daviee, G. Knight, K. C. Marshall, N. M. Perlmutter, M. H. Sussmann, K. Tulenko, *Art Voices*, Vol. 4, No. 2, 1981, pp. 13–21.

Sooner or later every jeweler is asked to appraise or assist in the disposal of collectibles. Some of these collectibles will be in the form of jewelry, but in many cases they will include such items as paintings, photographs, pieces of sculpture, lamps, and even signatures of famous people. How can a jeweler appraise these infrequently encountered items, and how can he find a buyer for them?

Representatives from nine different auction houses present guidelines to the "ins and outs" of disposing of collectibles. Each describes the fees involved in estimating values and the commissions charged for auctioning items. Also discussed are how items are sent to the individual houses for appraisal and auction, security precautions, and how the collectibles are categorized and eventually sold. This is an interesting and informative article that should be read by anyone who is ever confronted with a situation involving collectibles of any sort. *NPK*

The business of jewelry: marketing analysis of a retail jewelry shop. M. Farmer and A. Montrose, *Metalsmith*, Vol. 1, No. 3, 1981, pp. 53–58.

This article analyzes a small retail store that sells merchandise manufactured on the premises. It addresses the problems of marketing and pricing and recognizes that there is a scarcity of information on the market base, demographics, and financial history of the store. Farmer and Montrose detail one method of arriving at prices for this type of operation and suggest a formula that the store owner may use to determine the best merchandise mix. The importance of working with professionals through universities and the Small Business Administration is pointed out, especially the low cost of such help. *H. David Morrow*

SYNTHETICS AND SIMULANTS

Diamond and its imitations. E. Gübelin, *Diamant*, No. 248, 1981, pp. 35–40.

Ever since the discovery of diamond, people have tried to manufacture imitations of this stone. The development of polishing techniques in the 14th century permitted the manufacture of diamond imitations. Since then, the ever-growing challenge of detecting imitations has presented itself to everyone interested in diamonds.

Knowledge of the internal and external characteristics of diamond can help the gemologist distinguish the natural stone from its imitations. Many of these characteristics can be seen with the aid of a loupe, including the sharp facets, flat faces, and precision polishing. A diamond's rough girdle, with its naturals and bearding, knots, growth marks, and water-repellent quality, also helps distinguish it from its substitutes. Internal characteristics peculiar to diamond include a variety of mineral inclusions, cleavage cracks, fissures, and structural and growth irregularities. In many cases, a knowledge of these characteristics will enable the gemologist to separate diamond from its imitations without sophisticated instruments or laboratory facilities.

Laboratory techniques for distinguishing diamonds use various instruments with which characteristic properties can be determined. Among the more recently developed instruments are the Riplus Refractometer, which reads refractive indices up to 2.21, and the Ceres Diamond Probe, which detects thermal conductivity—that of diamond being 20 to 300 times greater than that of its substitutes. Transparency to X-ray, fluorescence and subsequent phosphorescence under UV light, absorption spectra, and electrical conductivity (of natural blue diamond) are other means of identifying diamond. In addition, several reflectivity meters, which indicate the reflective capacity of diamond, are available.

Gübelin concludes by predicting that even if other diamond imitations appear in the future, our growing experience with practical methods and instrumentation will provide the means to recognize diamond by its unique properties. This article appears in English, Dutch, and French, side by side. *CKG*

Editor's Note: A similar form of this article, written in German by Dr. Gübelin, appeared in the December 1980 issue of Journal Suisse de Bijouterie et d'Horologerie. *Twenty-six color photographs illustrate the characteristics discussed. In addition, three tables document the properties of diamond and some of its substitutes.*

An investigation of synthetic turquoise and the turquoise substitute of Gilson. K. Schmetzer and H. Bank, *Journal of Gemmology*, Vol. 17, No. 6, 1981, pp. 386–389.

The various efforts to duplicate turquoise have resulted in a variety of material. Pierre Gilson, Sr., the French producer of synthetic and imitation stones, has offered one material labeled synthetic turquoise and another called Gilson substitute. Schmetzer and Bank tested three samples of the synthetic turquoise, one Gilson substitute, and a natural Nevada turquoise with the aid of an X-ray powder diffractometer and a scanning electron microscope (SEM).

In the three "synthetic turquoise" samples, several additive lines in the X-ray powder diagrams are present. These do not belong to turquoise but rather to "one or more other crystalline phases," which leads the authors to conclude that the term *synthetic turquoise* does not designate the composition of the material and should not be used.

Tests on the Gilson substitute showed that the major element is calcium with traces of silicon, phosphorous, sulfur, and iron. The authors conclude that this material is a mixture of calcite and other crystalline phases. *JPG*

MISCELLANEOUS

History of placer mining for gold in California. C. V. Averill, *California Geology*, Vol. 34, No. 7, 1981, pp. 150–151.

Recent price fluctuations in the gold market have generated a renewed interest in mining processes. The earliest techniques used in California took advantage of the high specific gravity of this metal, beginning with the concentration of gold in crevices followed by panning for gold.

The next technique developed involved cradles and sluice boxes to wash the gravel in which gold was thought to occur. Since this method requires a high concentration of gold to be productive, it had declined by 1860. In the meantime, the hydraulic method, whereby jets of water are forced against banks of gravel, had been developed. When angry agricultural interests were able to bring an injunction against this method in 1883, placer mining slowed to a very low level and was replaced by lode mining of quartz veins. Again, a technological development, the connected bucket dredger, resulted in greater production levels from 1900 on into the 20th century.

The impact of inflation following World War I counteracted the rising trend of gold production, even after the price of gold was increased to $35 per fine ounce in the early 1930s. In 1942, activities by the War Production Board brought a halt to lode gold mining. Later, when mining resumed, much damage from flooding and cave-ins was found in the old tunnels. *DMD*

Source of Mother Lode gold. R. Smith, *California Geology*, Vol. 34, No. 5, 1981, pp. 99–103.

The author hypothesizes the relationship of the Mother Lode gold-quartz veins to the Foothill copper-zinc belt of sulfides in the central part of the Sierra Nevada Mountains in California. One of the difficulties with previous theories was explaining why the quartz veins were a mile or more long while the gold-bearing part was shorter and, in fact, about the same length as the massive sulfide deposit.

Smith describes the conditions under which the gold-quartz veins were deposited by hydrothermal solutions composed of meteoritic water. Apparently the quartz was leached from wallrock of metasedimentary and metavolcanic origin. At high pressures, but low temperatures, the silica was deposited upward in a series of quartz veins. Later, and as temperatures rose, zinc, lead, copper, silver, and gold—derived from volcanic sulfide deposits in preexisting rock—were deposited, the most soluble first. Finally, only gold, which can replace all the others, was left in the deep parts of the veins.

This theory views the sulfide deposits as much more extensive than previously thought. They had to have been more deeply buried, and more abundant and widespread, to account for the amount of gold that has come from the Mother Lode deposit. *RSS*

BOOK REVIEWS

John I. Koivula, Editor

THE WORLD OF DIAMONDS

By Timothy Green, 300 pp., William Morrow & Co., New York, 1981. US$12.95

This nontechnical book written for consumers actually belongs on the jeweler's bookshelf. Told from a journalist's point of view, it describes in detail the intimate workings of the diamond industry from the miner to the Madison Avenue persuader who entices lovers to buy the cut stones. In an entertaining fashion, Green has captured the excitement of dealing in diamonds and conveyed it to the reader.

The book is divided into four parts, beginning with "The Diamond in History." Although this is a much-told story, Green's brief account of the discovery of diamonds in Africa and the formation of the diamond monopoly is fresh and enlightening.

Part II—"The Miners," describes the prospecting for and mining of diamonds in detail. This section is one of the best narratives on the sources of diamonds and methods of recovering them. Although very detailed, it is not boring. The chapter on the Soviet Union is especially interesting.

Part III—"The Salesmen," begins with a thorough report of the organization and function of the Central Selling Organization and weaves its way through the diamond world of high finance, world economics, political intrigue, and smuggling. The fascinating story of the founding of the diamond industry in Israel alone makes the book worth reading.

Part IV—"The Buyers," is divided into three chapters. The first chapter is the story of DeBeers's long-running advertising campaign, its successes and disappointments. The second chapter describes the investment boom. Green's description and analysis of the diamond investment market is factual, and every potential investor should read this revealing chapter. The final chapter is a brief account of the use of diamonds in industry, from bread-and-butter applications to the exotic job of a delicate surgeon's scalpel for eye surgery. It is a fitting ending to a very thorough book.

Anyone in the diamond industry will enjoy this book. The author's many amusing anecdotes and enlightening analogies will be quoted by diamond salespeople for years. This authoritative and factual book lives up to its billing as the inside story of diamonds. It is well organized, with good footnotes and an excellent index.

DENNIS FOLTZ
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GEMSTONE AND MINERAL DATA BOOK

By John Sinkankas, 352 pp., Van Nostrand Reinhold Co., New York, 1981 paperback edition after the 1972 first edition. US$6.95

This book, subtitled "a compilation of data, recipes, formulas and instructions for the mineralogist, gemologist, lapidary, jeweler, craftsman and collector," is the gourmet cookbook of gems and minerals. There are no illustrations, and you wouldn't want to read it for pleasure, but you wouldn't want to be without it either.

There are twelve parts, each of which contains numerous listings of otherwise hard-to-find data. Among the subjects covered are weights, mathematical formulas, chemicals, cleaning methods, lapidary techniques, precious metals, coloring methods, physical properties, and optical data. The book is easy to use because of the detailed table of contents and index.

John Sinkankas, a life-long mineralogist and gemologist, is an unquestioned authority in the field of gems and minerals. John has succeeded in this book as he has in his many other publications to deliver a phenomenal amount of important data in a manner that is both understandable and useful to amateur and professional alike.

JOSEPH O. GILL
San Francisco, California

RUBY AND SAPPHIRE

Edited by L. M. Belyaev, 443 pp., illus., Amerind Publishing Co., New Delhi, India, 1980. Available from the U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161, as Document TT-52020. US$32.00

This volume is a translation, published in India for the U.S. National Bureau of Standards, of a U.S.S.R. volume first published in 1974 and subsequently revised in 1978. It deals primarily with the technological and scientific aspects of ruby production for laser use.

Upward of 30 authors have contributed 56 sections, which are organized into seven chapters. The level of treatment is very uneven, ranging from detailed research reports via equipment design data to almost unreferenced summaries (flux growth appears to have but a single reference, to the year 1963).

The translation is competent, but inaccurate statements appear occasionally, undoubtedly the result of literal translation. The quality of the paper stock used and the photographic reproductions is reasonable only when judged by the low price (by today's standards) of less than 7¢ per page for the book.

The most serious drawback is the absence of an index, a severe defect in a volume such as this with large amounts of poorly organized material. There are 719 references at the end of the book which are compiled by chapters. Referencing is solid to 1970 and patchy to 1975.

The gemologist will find little of interest in this book. The dedicated bibliophile will, of course, wish to own a copy, and will find that it offers an interesting picture of Russian technology as well as many Russian references not easily found elsewhere.

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GEM NEWS

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DIAMONDS

Angola. Angolan production of industrial and gem diamonds for 1980 represents the highest output since the country gained its independence in 1975. The total of approximately 1.5 million carats contrasts with 840,000 carats for 1979 and 650,000 carats for 1978; although in 1973, prior to independence, Angola's Diamang mines produced 2.12 million carats, 8% of the world production. Civil war interrupted production in 1975, when the total had been expected to reach 3.5 million carats.

Seventy-seven percent of the shares in the Diamang mines are held by the Angolan government, which assumed control of the Portuguese holdings. British, South African, U.S., Belgian, and Swiss interests in the mines were unaffected.

Australia. The Ashton Joint Venture expects its large plant in Argyle, Western Australia, to begin operation some time in 1985. Once in operation, the plant is expected to employ 500 people (the current work force is 225) and to produce 20 to 25 million carats of diamonds a year from five million tons of ore. This amount represents a considerable percentage of world production, which in 1980 totaled 50 million carats. It is estimated that perhaps only 10% of the Ashton product will be stones of gem quality.

Botswana. The large new Jwaneng mine is expected to begin operation in 1982 and to produce 6 million carats per year by 1985, which will bring Botswana's total annual production to 10 million carats. The government of Botswana plans to establish a pilot diamond-cutting and polishing plant at Gabarone in cooperation with the Antwerp cutting firm of Mabrodiam. There will be an initial staff of 50 employees, with an anticipated expansion to 500.

Lesotho. The second phase of a joint Canadian/Lesotho diamond mining project, begun in 1978, will be Canada's grant of C$882,000 toward developing a cooperative for Lesotho diamond miners in the Maluti Mountains. The Canadian International Development Agency is providing a mining advisor, training, and mining equipment; the agency is also covering operating and maintenance costs. Twenty-five percent of the equity in the mining company is held by Lesotho, a small country in southern Africa. After amortization of the capital investment, 62.5% of the profits will accrue to the Lesotho government through taxes and dividends.

U.S.A. Increased tourism and pressure from commercial mining companies have followed the discovery on June 23 of an 8.82-ct. diamond at Crater of Diamonds State Park, Murfreesboro, Arkansas. Nearly 4,000 gemstones have been found at the site since it became a park in 1972. The stone discovered this year is the second largest on record; the first is a 16.37-ct. stone found in 1975. Anaconda Company and Superior Oil Company have joined other companies that have been purchasing mining rights from landowners near the park and propose to evaluate the commercial potential of the crater and the surrounding area.

U.S.S.R. A new diamond mine is under development in the Yakut area of Russia. Two shafts—one for extraction and one for ventilation—are already being excavated, and will reach a depth of almost 1,000 m.

PAKISTAN ENTERS THE GEM SCENE

Editor's Note: We are greatly indebted to Dr. Edward Gübelin for this report on current gemstone activity in Pakistan, where he traveled this past spring.

In recent years, with the discovery of large deposits of emerald in the valley of Swat and of ruby in the rugged Hunza Valley, Pakistan has become both producer and potential marketer of these stones. Pakistan is now producing a variety of gemstones, which mainly include emerald, ruby, spinel, topaz, aquamarine, chrome diopside, kunzite, garnet, chrome-tourmaline, and quartz; there are also ornamental stones such as agate, chalcedony, jasper, sodalite, serpentine, turquoise, and nephrite.

Emerald. Some of the finest emeralds in Pakistan come from the valley of Swat, in the foothills of the Hindukush range. The Gemstone Corporation of Pakistan, founded in February 1979, has resumed operation of the emerald mines near Mingora, which produced about 410,000 carats in 15 years. All the mines—one large and two smaller ones—are being operated at the moment, and the emeralds excavated have become well known for their brilliant, medium-to-deep green color as well as for their unique transparency, comparable to the finest specimens from Muzo, Colombia. The stones are small, with cut gems averaging less than one carat, although a few larger stones have been found. Faceting of the stones presently lacks precision, but the corporation is aware of this deficiency and is introducing at least one automatic cutting machine as well as training a staff of lapidaries.

Ruby. Rubies that range in color from pigeon's-blood to pale red are found in abundance below the Karakoram Mountains in the Hunza Valley. These deposits are presently mined on a small scale, but expansion is anticipated. In this region, mica schists are frequently traversed by relatively broad banks of crystalline marble in which ruby, spinel, and chrome diopside are found. Hunza Valley rubies occur in very large sizes—some up to 40 mm in length. However, the majority of the stones are turbid, that is, marred by various inclusions and cracks, and many display large white patches of calcite. While the area has not yet produced transparent stones for faceting, the best-quality material lends itself very well to cabochons. The principal feature of the Hunza rubies is their color, which in numerous specimens is identical to that of the finest Burmese rubies. Those emerald and ruby crystals that are not suitable for cutting but are extracted on matrix are often attractive to collectors as mineral specimens. It may be expected that the quantity and quality of both emeralds and rubies will increase as prospecting and mining techniques in the area improve.

Spinel. Well-shaped crystals of spinel in a variety of colors—bluish pink to deep red, violet-blue, and purple-red to almost black—have been found associated with rubies in the Hunza Valley. Because of their clean crystal shapes, they are used primarily for mineral specimens on matrix.

Topaz. Topaz crystals of rare natural pink color (not treated, as those from Brazil are) were mined a couple of years ago at Katlang in the Mardan area, about 75 km northeast of Peshawar. That deposit may now be exhausted; demand for the stone has depleted the available supply.

Aquamarine. Large, clear, colorless goshenite crystals and light blue aquamarine crystals are found in great quantity beneath the famous K-2 peak—the second highest in the world—of the Karakoram range above Dassu in the area of Skardu. Close inspection of some crystals reveals that many specimens offered for sale have been fraudulently misrepresented: for example, some crystals were found to be sawed, with terminations artificially formed by grinding and polishing the stones. A note in an American journal recently mentioned a new source of aquamarines in the Haramosh Valley; however, there is no such valley and the Haramosh Mountain does not house aquamarine. Apart from quartz of inferior quality and a few odd goshenite crystals, the Haramosh Mountain does not appear to produce any desirable gemstones. The pegmatites in which the quartz and goshenite occur are covered by snow most of the year.

Chrome Diopside. Locally known as "Hunzanite," large emerald-green crystals of chrome diopside frequently are found associated with rubies in the Hunza Valley. Some of the more turbid specimens yield a cat's-eye effect when cut as cabochons.

Kunzite. Large, clear crystals of kunzite of cyclamen hue are commonly found in Chitral Province.

Garnet. Pyrope garnet is commonly found near Dir, in the Swat Valley in Chitral Province, and in the valley of Baltistan. It is quite abundant in the goldsmith and jewelry shops of northern Pakistan. Whether demantoid garnet is really found in the emerald-bearing belt in Swat, as is claimed in some gem booklets, is most uncertain.

Chrome Tourmaline. Chrome tourmaline has been observed to occur in calcareous rocks near Alpurai in the Swat Valley, but samples have proved too small for use as gemstones.

Quartz. Large, clear, and transparent quartz crystals (rock crystal and smoky quartz) occur in quantity near Dir, in Chitral Province, in the Gilgit area, and in the valley of Baltistan.

Ornamental Gems. Agate, chalcedony, and jasper also occur widely at several different localities in Pakistan. In the southeast corner of Swat Province, sodalite has been found. Other ornamental gems found in Pakistan include serpentine, green turquoise, olive green nephrite, and large deposits of chalcedony of fine luster and hardness in brown, chocolate brown, green, and bluish hues. Such stones, sometimes in the form of carved ornaments, may be encountered in shops all over the country. Lapis lazuli, tourmalines, and emeralds from Afghanistan are sold in large and small quantities by dealers in Pakistan. Synthetic stones and imitations are also in abundance.

EXHIBITS

American Museum of Natural History—Central Park West & 79th St., New York, NY 10024. Telephone (212) 873-1300.

"Through the Looking Glass: History of Microscopes" is an exhibition organized by the American Museum and the New York Microscopical Society which shows the development of the microscope "from an amazing curiosity to an important scientific tool." Numerous modern optical microscopes and the scanning electron microscope are subjects of the display, which uses enlarged photographs and videotapes, as well as the instruments, to tell the story. Opened September 30 and runs through December 30, 1981, in the museum's Akeley Gallery.

Arizona-Sonora Desert Museum—Route 9, Box 900, Tucson, Arizona 85704. Telephone (602) 883-1380.

The museum adds to its presentation of the origins and development of the American Southwest with a new main exhibit gallery, mineral hall, replica of an underground mine showing four mineral pockets, and terrace with amphitheater. The main gallery contains a number of exhibits depicting the history of the earth through dramatically presented films, sound effects, and natural settings which include live plants and animals. On display in the mineral hall are regional minerals, some in specimens viewed through microscopes, cut gemstones, and jewelry. The technology and equipment for dramatizing the various exhibits were developed only recently; in several instances, they are used here for the first time. Dedication ceremonies will be held December 10; the new exhibits will be open to the public December 11.

ANNOUNCEMENTS

Sri Lanka's First International Coloured Gem Stones Conference and Gem and Jewellery Exhibition will be held in Colombo February 1–2, 1982, at the Bandaranaike Memorial International Conference Hall. The conference theme is "Why Coloured Gem Stones?" Dr. Edward Gübelin will speak on the first day; there will also be talks by other gemologists, jewelers, and gem dealers as well as panel discussions. Further information may be obtained from Conventions (Colombo) Limited, P.O. Box 94, Colombo 1, Sri Lanka. Telex: 21124 MAKINON CE.

Preparations are under way for the first International Gemological Symposium, to be held in Los Angeles February 12–15, 1982. GIA will host the event at the Century Plaza Hotel, where there will be presentations by over 60 speakers from the international gemological community. Also planned are an open house at GIA and a ball at the L.A. County Museum of Natural History, which houses over 2,000 mineral specimens and the Hixon Collection of cut gemstones. Information is available by writing to Elizabeth E. Knowlton, Symposium Coordinator, GIA, 1660 Stewart St., Santa Monica, CA 90404. Telephone: (213) 829-2991

The annual commodity meeting of the Institution of Mining and Metallurgy will be held Thursday, December 3, 1981, at the Goldsmiths' Hall, London. Entitled "Gemstones," the meeting will cover exploration, production, and marketing of natural gemstones, as well as production of synthetics and problems of their identification. Speakers will include representatives from the Anglo-American Corporation of South Africa, the Diamond Trading Company of London, CRA Exploration of Western Australia, and Rio Tinto Mining of Zimbabwe. Information on papers to be presented and displays, as well as registration forms, is available from the Conference Office, Institution of Mining and Metallurgy, 44 Portland Place, London W1, England. Telephone: 01-580 3802; telex: 261410.