Gems and Gemology
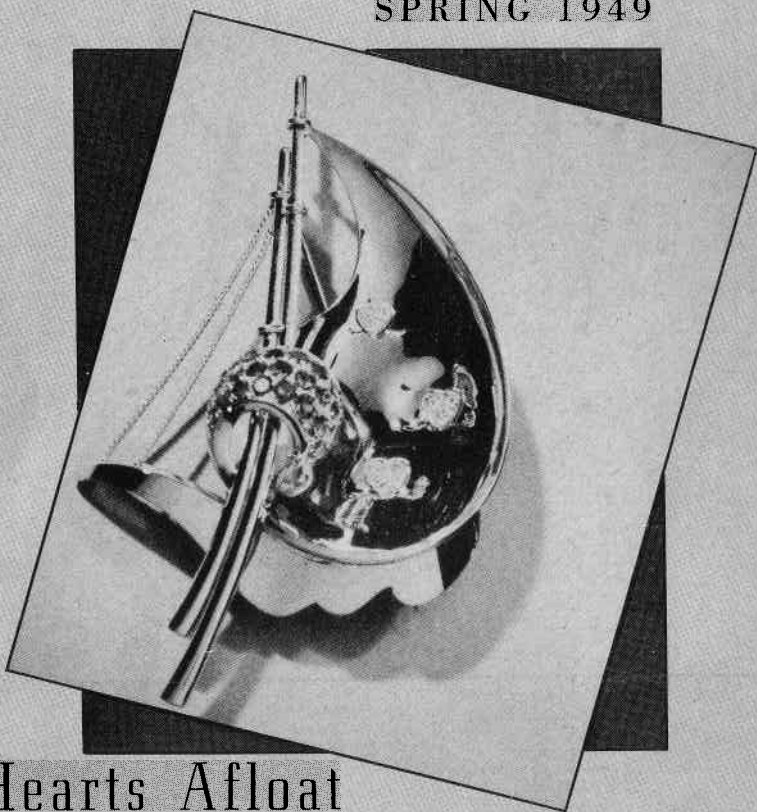
SPRING 1949

Hearts Afloat

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KIMBERLITE Discovery
in the Diamond Fields of BAKWANGA

by

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The celebrated Kasai diamond field is, quantatively, the leading diamond producer of the world. Since the opening of the mines in 1913, until the end of 1946, the total production of diamond has exceeded 90,000,000 metric carats (18 tons).

In 1945 the production reached 10,386,-000 carats, i.e., about 73% of the world production (URSS excluded). This percentage is measured in weight, not in value: more than 90% of the Congo diamond is of industrial grade, mostly crushing boart quality.

The diamond-bearing alluvial gravels occur along the valleys of the important tributaries of the big Kasai River. Flats and low terraces are mined by hand- and hydraulic methods. The gravel is washed and concentrated in mobile plants of the South Africa type (trommels, rotating pans and jigs). Final concentration and hand picking are performed in two modern and very efficient "central plants." One is located at Tshikapa, headquarters of the Forminiere Company, the other at Bakwanga, center of the Miniere de Bécéka Company. The Forminiere is general contractor for all diamond properties.

The diamondiferous alluvials of the left-bank tributaries of the Kasai (see map fig. 1) cross the frontier between the Belgian Congo and Portuguese Angola. The Angola Diamond Company, in cooperation with the Forminiere, works the Angolan deposits (yearly production about 800,000 carats, mostly of good gem quality). The shaded

areas of map fig. 1 show the extension of the Kasai gem quality diamond fields and the location of the Bakwanga industrial diamond deposit, limited to a small area along the Bushimaie River, at about 200 miles east of Tshikapa.

Bakwanga produces more than 90% in weight of the Congo diamonds, but only 2% is of gem quality.

GEOLOGY

The geological background of the Kasai diamond fields is quite similar to those of the Guiana and Venezuela placers.

A series of soft and nearly horizontal sandstones rests on the granites and metamorphic rocks of the Basement Complex. The sandstones are presumably of Mesozoic age (Karroo). Their lower division is diamondiferous, although conglomerates are poorly developed.

The big rivers cut across the sandstone blanket: part of their present course is established on the granitic basement rocks. In recent times the fast flowing waters of these rivers acted as efficient concentrators of the diamonds weathered or eroded out of their sandstone matrix. Obviously, the sandstones are secondary sources. Until 1946, no primary source was known and the origin of the diamonds remained an unsolved problem. It seemed improbable that kimberlite pipes could be discovered, because the post-kimberlite sandstones blanket more than 99% of the surface of the basement rocks.

In the extensive gem diamond fields astride the Congo-Angola borderline, the discovery of kimberlite is still a remote possibility. The dense minerals which accompany the diamond in the concentrates do not give any clue, because they are not of kimberlite origin.

But the geological situation at the Bakwanga deposit is more or less different. Here a thick series of flat-bedded limestones and dolomites rests on the basement granite. The plateau-sandstones overlie the older limestone series (Bushimaie Series) but are rather deeply eroded and dissected by the Bushimaie River. The slopes of the valley are cut in the limestone. Downstream of Bakwanga, the flats of the river are very rich in diamonds, on a length of a few miles.

The Bakwanga mining town is located on top of a small plateau, about 100 meters above the Bushimaie. This hill lies between the river and a small left-bank tributary, which is also diamondiferous. So are the alluvial gravels and sands which blanket the hill slopes. Those slope gravels are mostly a rubble of angular pieces of silicified limestones with occasional sink holes filled with rich gravels.

On top of the hill, the gravels are concealed underneath a thick overburden of
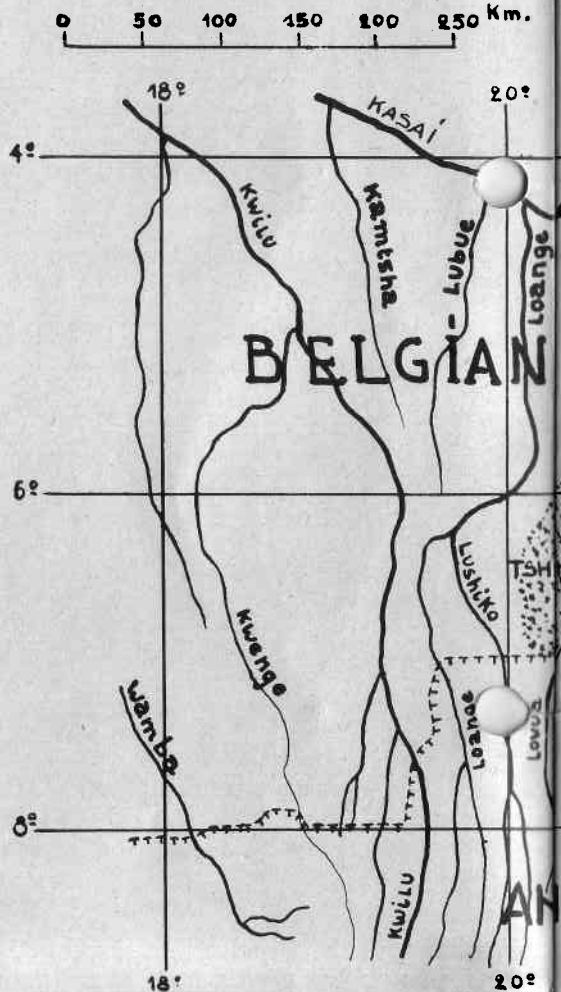
fine red sand, probably windblown (see schematic cross section, fig. 2).

During 1946, deep prospecting pits were laid out on top of the hill. Most of them reached the bed rock limestone, but some did find under the gravel a very decomposed conglomeratic rock, containing some recognizable pieces of gneiss and granite. Quite unexpectedly those pits struck a shallow water level.

IDENTIFICATION OF THE KIMBERLITE

At the end of 1946, Bakwanga was visited by a geophysical crew, headed by the author.

Of course, the peculiar findings on top of the hill attracted full attention and the

Figure 1

existence of kimberlitic yellow ground became at once an attractive hypothesis.

We may recall here that the dark kimberlite rock alters readily in the tropical climate. Changing first into a soft "blueground," the thorough near-surface oxidation changes it into "yellow ground." This loose material retains only, in a recognizable shape, the very stable components of the kimberlite. Very characteristic are the "heavy minerals:" a part diamond itself, the yellow ground contains an abundance of jet black magnesian ilmenite and red garnet; also, in small amounts, some other characteristic minerals, among which the green chrome-diopside is very striking.

In the Bakwanga gravels the characteristic ilmenite is abundant. Red garnet is present and its percentage increases uphill. Green diopside is rare, but was found in
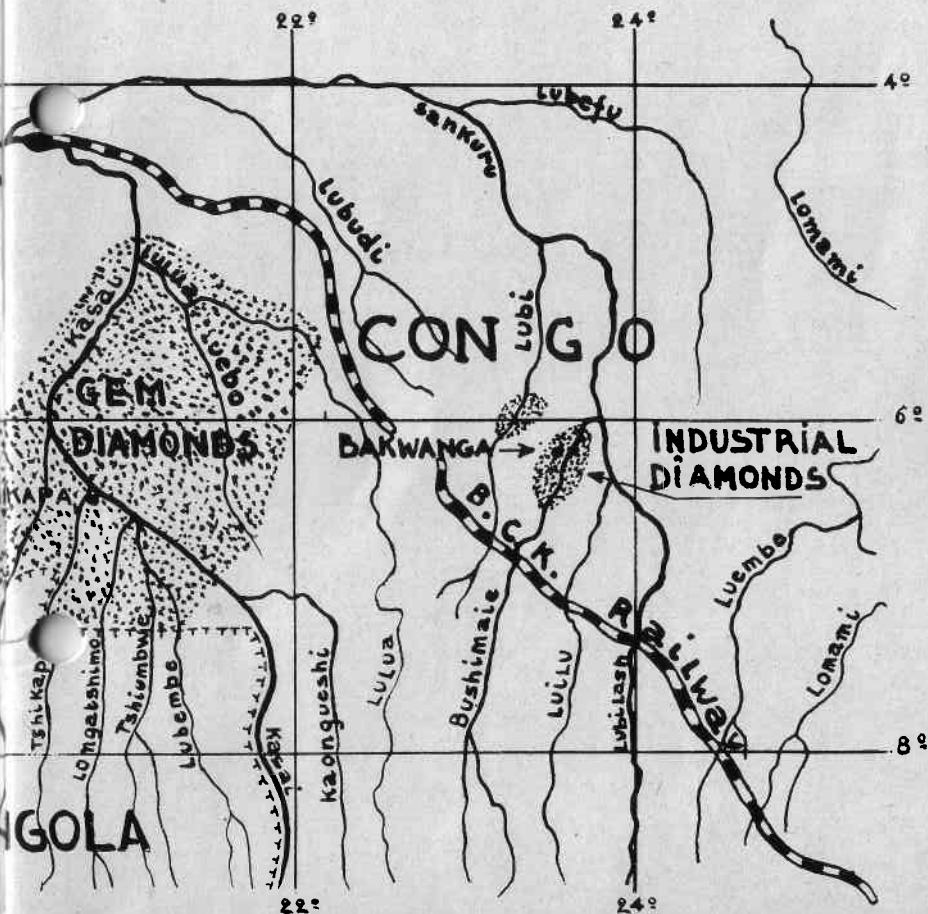
the problematic decomposed rock together with ilmenite, garnet, and orange zircon. This fact was of course a favorable omen, but not the absolute proof that the questionable rock was yellow ground. Further clues had to be found.

The material in a kimberlite pipe often resembles a true explosion-breccia: the dark kimberlite matrix encloses angular and rounded pieces of various rocks, each of which can be traced down to the formations cut by the chimney. Very characteristic in all diamond-bearing pipes are the *eclogite* fragments. Eclogite is a heavy rock consisting of green diopside and red pyrope garnet. The diamond seems associated intimately with this rock of deep origin and several experts consider it the true source of the gem.

Our party found in the decomposed rock a single fragment of eclogite and several pieces of other garnet-bearing metamorphic rocks. This was very significant and the presence of kimberlite was inferred, although the decomposed rock did not have the usual aspect of yellow ground: the rock was reddish and contained quartz grains. It was interpreted as an eluvial mixture with the sandy overburden and it was predicted that normal yellow ground would be found underneath. This conclusion turned out to be true, when later the prospecting pits were deepened.

No olivine, nor any blueground have been found as yet. It is to be foreseen that the decomposition and oxidation are very deep, because the surrounding limestones are fissured and practically dry down to the base of the hill.

The peculiar orange-colored zircons are well known in several South African kimberlite pipes.

ELECTRICAL MAPPING OF THE KIMBERLITE MASS

The approximate contours of the kimberlite mass were known on one side, thanks to the prospecting pits.

A couple of "electrical soundings" revealed at once that the electrical resistivity of the yellow ground was very much lower than the resistivity of the surrounding limestones. It seemed that electrical profiles could determine approximately the boundaries of the kimberlite.

In three days work, six profiles were laid out in a radial pattern and measured with a suitable electrode interval. Generally, the sudden increase of resistivity associated with the limestone contact showed up nicely. The boundary was crossed in ten different points. Some difficulties arose in connection with the irregularities of the surface of the bedrock, under the sandy overburden.

Finally the inferred contours of the kimberlitic mass were drawn by interpolation. The contour enclosed an oval area of about 160,000 square meters. Later pitting did substantially confirm the geophysical prediction.

The Mighty Waters of the Kasai River

Kanshi

Bushimaie.

LEGEND

Fine sand.

Alluvials

Eluvials

Mixed sand and yellow ground.

Yellow ground.

Limestones.
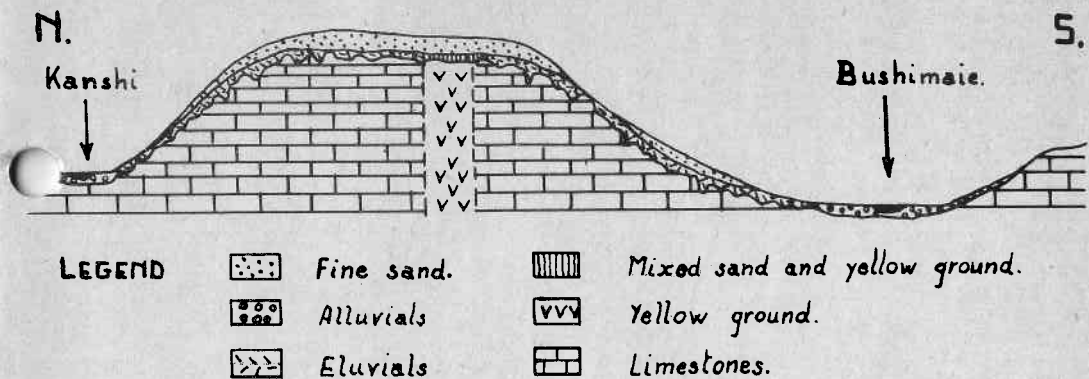
Figure 2

CONCLUDING REMARKS

According to its outcrop area, the first Bakwanga pipe ranks among the biggest known kimberlite masses. Recently an even bigger kimberlite mass has been discovered on the plateau extending westwards from Bakwanga. This mass seems to have a very elongated shape.

Both masses have still to be prospected in detail and the mean diamond content is still unknown. Similar occurrences may be discovered in the near future along the Bushimaie, in connection with other alluvial diamond concentrations known in the vicinity of Bakwanga. But it remains doubtful that such primary sources will be discovered in the big Kasai gem diamond district although the presence of kimberlite is practically certain.

The kimberlitic origin of the biggest known industrial diamond deposit is now proved beyond doubt. At Bakwanga, the geological situation is similar to the classical South African diamond fields, except that the age of the kimberlite intrusions is probably per-Karroo (pre-Triassic).

It is to be expected that spectacular mining developments will be seen at Bakwanga in the near future. In the opinion of the author, no shortage of the supply of industrial diamond has to be feared for many years to come. The single Bakwanga deposit can meet any increased demand.

Geological conditions in the Belgian Congo are similar to those of South America, where no true diamondiferous kimberlites have been discovered so far as I know. The Bakwanga discovery should encourage a new search for hidden kimberlite pipes in the South American diamond districts.

The Bushimaie Valley

A NEW TECHNIQUE
FOR GEMSTONE IDENTIFICATION

by

ROBERT M. SHIPLEY, Jr.

NOEL S. ALTON

RESEARCH directed toward extension and simplification of known procedures of gemstone identification and diamond grading has been in progress for the past year.

The aim has been to develop methods and equipment to fit the following specifications; (1) capable of being easily and quickly applied, (2) simple enough to permit use by jewelers and others with relatively little mathematical background, and (3) applicable to cut stones, both mounted and unmounted. It is now possible to report some advances in the technique of identification of gems, together with relatively simple and inexpensive equipment to implement this technique.

Three newly developed pieces of equipment form the basis of a revised system of gem identification. These are the *Analyzing Refractometer,* the *Gemological Microscope,* and the *Sortagem.* Equipment is available in a rather wide price range: the total cost varies from $78.50 to $715.00.

THE GEM REFRACTOMETER

The newly developed Gem Refractometer provided the basic requirement necessary in perfecting the Analyzing Refractometer mentioned above. While the Gem Refractometer is but a simplified version of the Abbey Refractometer, it represents a very significant advance in gem testing instruments, for it fills a definite need for a refractometer which, though very inexpensive, is highly accurate and easy to use. In order to produce an instrument which could be manufactured inexpensively, a rather novel design was adopted. The housing consists essentially of two plates, each, one eighth of an inch wide, and separated by only one eighth of an inch. Between these are held the optical elements of the instrument, thus providing an optical system one eighth of an inch wide throughout. The dense glass element is a hemicylinder rather than a hemisphere or prism as in most refractometers, it being found that certain aberrations common to the hemispherical element were thus eliminated. The scale is produced photographically and is inserted into opposed arc-shaped recesses in the side plates. The curved shape of the scale reduces to a minimum the parallax and the lack of sharp focus found in the usual jewelers' refractometer design. Instead of a prism, a first surface mirror of .050 glass is inserted in slots in the side plates. The screw focusing eyepiece is mounted on a yoke which pivots around an axis located at the apparent center of the glass hemicylinder, as projected through the reflecting surface of the mirror. Optical parts are thus reduced to a minimum, hence eliminating many of the basic errors of this general type of refractometer. The result is an instrument

which gives readings which are both more intense (as a result of the reduction in the number of glass-air surfaces) and at the same time more accurate than those from any comparable refractometer of more conventional design. The Gem Refractometer, complete with instructions for use, contact liquid, and box, sells for the remarkably low price of $29.00.

THE ANALYZING REFRACTOMETER

The clarity and accuracy of readings of the Gem Refractometer have made possible a significant extension of the use of the refractometer in gem testing. As a course of investigation the authors undertook to combine the principle of the refractometer with that of the polariscope in the hope of obtaining a further analysis of the refractive index readings. This combination had been tested some ten years ago, with negative results on the refractometers then available. Also, it had been used by Cutler West in 1938 to obtain sharper readings from thin plastic films. When the polariscope principle was combined with the newly developed Gem Refractometer the anticipated results were achieved. The new instrument resulting from these developments is called the Analyzing Refractometer; it enables one to

make the following determinations for any gem whose refractive index is not over 1.80:

1) Refractive Index of isotropic material, w and e indices for uniaxial minerals, α, β and γ indices of biaxial gems.

2) Isotropic or anistropic or cryptocrystalline.

3) Presence of anomalous double refraction.

4) Birefringence (accurate within .002 in most cases).

5) Birefringence of cryptocrystalline material.

6) Optic character (uniaxial, biaxial, positive or negative).

7) Estimate of $2V$ in special cases.

The above determinations may be made on *opaque* as well as transparent material, mounted or unmounted, and hence furnish information heretofore unobtainable with any other gem testing instruments. Not all of the above information can be obtained with cabochon cut gems, but at minimum the accurate R. I. and approximate birefringence of cabochon stones can be obtained. The above information is sufficient to identify over 95% of all gems, without further tests other than ascertaining that the gems are neither synthetic nor assembled.

It has long been known that the shadow edges seen in the refractometer are produced

The New Gem Refractometer

by light which has been modified in the specimen being tested. This was pointed out as early as 1906 in Pockel's *Lehrbuch der Kristalloptik,* and reemphasized by Schlossmacher in his 1932 revision of Bauer's *Edelsteinkunde.* The explanation of this modification of the shadow edges by the specimen and the further modification occurring in the Analyzing Refractometer are too complex to be attempted in this paper; however, the results obtained with the Analyzing Refractometer are easily explained and interpreted.

Crossed polarizers, one before the aperture of the Analyzing Refractometer and one over the eyepiece, furnish an extinction position comparable to that achieved with the crossed polarizers in a polariscope. When a doubly refractive specimen is placed in suitable contact with the surface of the dense glass of the Analyzing Refractometer, the effect is that of a light bar between two dark fields; i. e., the two indices (of the fast and slow rays) are joined by a bright area of light. This bar shows directly both the high and low indices and the birefringence of the gem for that particular orientation. Furthermore, the behavior of the bar of light, when the stone is rotated on the glass surface, allows the determination of optic character. When no bar is seen, the specimen is either isotropic or is a doubly refractive substance with an optic axis lying in the plane of contact with the dense glass and parallel to the optic axis of the refractometer. The reading almost disappears as the shadow edge can be seen only faintly. However, with many singly refractive stones, enough anomalous double refraction is present to produce a light line at the normal position of the refractive index shadow edge. As would be expected from an analysis of the nature of anomalous double refraction, the bright line in this case is too narrow to measure, proving the presence of double refraction, but with birefringence approaching zero.

When, upon rotation of the specimen, one side of the birefringent bar remains fixed in all positions of the specimen, the material is uniaxial. If the lower index side of the bar (the fast ray of the mineral) is fixed, the fast ray is proved to be the ordinary ray, and the mineral is positive in sign. When the higher edge of the birefringet bar is fixed during rotation, the ordinary ray is the slow ray and the sign is negative.

When both edges of the birefringent bar shift during rotation of the specimen, the mineral is biaxial. During a rotation of 180° a low point for the low index and a high point for the high index will be reached. These points may be at the same rotational position of the specimen, or at 90° from one another, depending upon orientation. In either case, the lowest reading seen during rotation is α and the highest is γ. The second reading seen in each position of the stone represents an intermediate index of refraction; of the two intermediate readings thus obtained one is β and the other β_1 or "false β." If it is desired to determine the optic sign of a biaxial mineral, it will in some cases be necessary to use a second facet at as great an angle as possible from the first and obtain a second series of readings. In this second position, α and γ are again obtained by rotation, as are β and β_2. α and γ will be identical with these obtained in the first position, and of the four readings for β thus obtained two will be identical and will be the true value for β If this value of β is nearer that of α, the sign is positive, if nearer that of γ, the sign is negative.

For most minerals used as gems, $2V$ is a relatively small angle, and the values of *both* β and β_1 will lie nearer α than γ, or vice versa. Hence, a valid analysis of sign is obtained from a single contact surface. The writers have found this to be generally true even for such stones as feldspar and chrysoberyl, for which optic sign

is difficult to obtain by ordinary methods with the refractometer. However, if β is nearer α and β_1 nearer γ or vice versa, then the two facet method must be used.

If a translucent or opaque stone is being tested and neither edge of the bar shows any motion when the specimen is rotated, the material is most likely cryptocrystalline without regular orientation of individual crystal grains. In this case optic character obviously cannot be determined, but the width of the bar is valid as a measure of birefringence. The Analyzing Refractometer is of particular value in cases of opaque cryptocrystalline material, since no direct proof of the doubly refractive nature of such cut stones can be obtained by any other known means. Chalcedony, nephrite, and other such gem materials are in this classification.

Inasmuch as the shadow edge seen in the refractometer is determined by the refracted ray which lies in the plane of contact between the specimen and the surface of the dense glass of the instrument, and is oriented along the long axis of the refractometer, non-characteristic readings may be obtained if the specimen is oriented so that a principal crystallographic axis lies in this plane. A variant of as little as 1° from exact orientation will nullify this effect so these conditions are of relatively little concern in applied gemology.

However, an understanding of these special conditions is essential if absolute accuracy is desired. There are two such directions in a uniaxial mineral and three in a biaxial mineral, as would be expected. If a uniaxial mineral is cut so that the principal or axis lies exactly perpendicular to the plane of contact, the maximum birefringence of the stone will be read at all points during rotation, i. e., there will be no variation in the birefringent bar. Determination of optic sign must be made by using a second facet in order to get a variation of the birefringent bar, or by removing the polarizer from the system and identi-

fying the ordinary and extraordinary rays by means of their vibration directions as shown by the analyzer alone. If the C axis lies in the plane of contact, rotation of the specimen through 90° will bring the birefringent bar from its maximum position to zero. Since this orientation gives the most diagnostic result it is to be welcomed rather than avoided.

With a biaxial mineral, if the plane containing the optic axes (the XZ plane) corresponds with the contact surface, the result is extremely interesting and valuable. A complete rotation of the specimen will cause the birefringent bar to show four positions of disappearance or nulls, which correspond to the four "ends" of the two optic axis. In this orientation an estimate of $2V$ may be obtained since the acute angle between two such nulls is a direct measure of $2V$. Furthermore, the birefringent area, as the stone rotates past extinction, will shift from a bar below the null point to a bar above the null point. The two maximum width bars represent the readings for α and β and the readings for β and γ, the null occurring at the true reading of β. When

The Polarizing Microscope
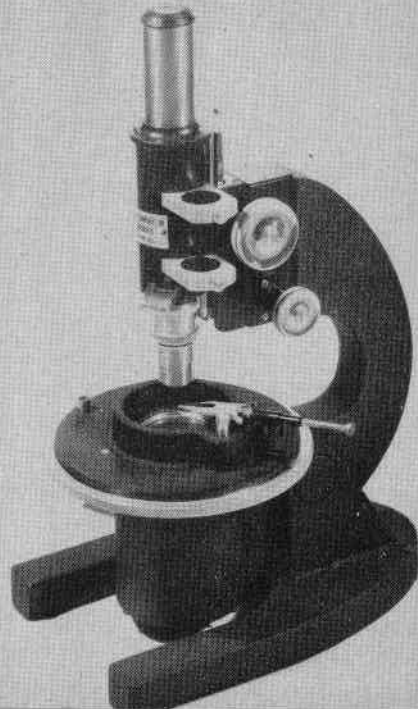
the contact surface of a biaxial stone corresponds with the XZ or the YZ plane, (that is with one of the two principal planes which lie at right angles to the plane of the optic axes or XZ plane) the motion of the birefringent bar is similar to that in a uniaxial mineral, in that one edge of the bar remains fixed. As pointed out above, such specific orientations are rare even in the most accurately fashioned gemstones; however, if possible it is advisable to use a second facet and obtain confirmed readings before making positive identification of the mineral.

The Analyzing Refractometer is available in three different models varying in accuracy and cost. The simplest of these is a combination of the Gem Refractometer with a polarizing eyepiece and a set of three filters consisting of two polaroid filters with parallel and 45° vibration directions, and a red filter which gives sharper shadow edges and easier reading of the birefringent bar. The eyepiece and set of filters sell for $6.00, and the minimum set of Analyzing Refractometer equipment therefore costs $35.00.

An intermediate instrument is the Gem Analyzing Refractometer. This instrument consists of a built-in light source, with a slide to shift from white light to red light for observation of the birefringent bar, and a rotating disc on the shaft of the refractometer to permit rapid shift from ordinary light to light polarized parallel to the surface of the dense glass hemicylinder or at 45° to the hemicylinder surface. The analyzer on this instrument is set on a ring which forms part of the yoke of the refractometer. Zero points for positioning the analyzer with respect to the parallel and 45° positions of the polarizing filters are marked on the ring, and the vibration directions of the filters are marked on the rotating filter ring. These features permit much more accurate orientation of the analyzer with respect to the polarizer, and the instrument

in its complete form is more accurate than the basic refractometer with the added filter set. The Gem Analyzing Refractometer sells for $65.00

The most accurate form of this device is the Gem Master Analyzing Refractometer. It is essentially the same as the Gem Analyzing Refractometer except for the addition of a built-in sodium vapor lamp, which serves as a monochromatic source of light. This instrument also has the same rotating filter disc and analyzer as the Gem Analyzing Refractometer. The Gem Master Analyzing Refractometer gives readings so sharp that estimation of .001 of refractive index is possible. Therefore, the measurement of birefringence and the analysis of optic character and sign are possible even when the birefringence is as small as .005. The Gem Master Analyzing Refractometer sells for $135.00.

THE GEMOLOGICAL MICROSCOPE

For many years gemologists have used modifications of the standard petrographical microscope for gemstone identification. Even with special attachments made to handle cut gems, such equipment has never proved entirely satisfactory because it is designed for use with prepared thin sections of minerals and rocks. In order to make available a microscope which will permit the use of standard procedures of optical mineralogy with cut stones, and even with mounted stones, the *Gemological Microscope* was developed. This is a very versatile instrument; when used properly, the optic constants of any unmounted transparent gem are readily obtained. and the majority of mounted stones can be handled with reasonable efficiency. The instrument contains a built-in light source which gives a large area of illumination and a relatively high working point. This feature avoids the severe limitations imposed by the condensing system of a standard petrographical microscope. The gemological microscope also incorporates rotating stage, centering

objective mounts, accessory slot and quartz wedge, and slide-in analyzer and Amici-Bertrand lens, as found in petrographical equipment. It can therefore be used as a normal petrographical microscope, and gives excellent results with the usual rock and mineral sections. For gem use it has the additional features of the Gemological Institute's stone holder, together with a support arm embodying sufficient relief to permit 360° rotation of the stage with the stone holder in place. A particularly valuable feature is the special immersion cell, which also permits use of the stone holder. This cell is equipped with a "bath tub drain" feature which allows the user to empty the liquid directly from the cell into a tank below the stage of the instrument. This saves a great deal of time, and eliminates the mess which is unavoidable when a large bath of liquid is lifted off the stage of the instrument.

The gemological microscope as set up for work with fashioned stones includes objectives of 3X, 10X, and 21X. Objectives of higher magnification may be used but the writers have found that they are seldom or never required. Oculars are standard Huygens 5X and 10X. The instrument also incorporates a calibrated fine adjustment,

by means of which the Schaulnes method of refractive index determination may be employed.

The writers have found the following order of procedure preferable: (1) Locate and classify inclusions. Usually relative low magnification (50X) will suffice, although higher magnification is sometimes necessary. (2) Pleochroism, if any, can be noted by rotation of the microscope stage. (3) By using the 21X objective and slipping the analyzer and Bertrand lens into place, an interference figure is obtained and "tracked" by motion of the isogyves; optic character and sign are then analyzed.

The stone holder is of particular value at this point since it permits rotation around one axis directly and the stone can be shifted manually in the jaws in order to rotate it around an axis at right angles to the first. By means of these two motions the optic axis figure is readily located in most cut stones. If, however, the fashioning of the stone will not allow light to pass through it parallel to an axis, preventing the obtaining of an axis figure, immersion in a liquid whose index approaches that of the specimen will remedy the situation. The writers have found that the use of only two liquids gives satisfactory results in every case. Pure

The New Gem Analyzing Refractometer
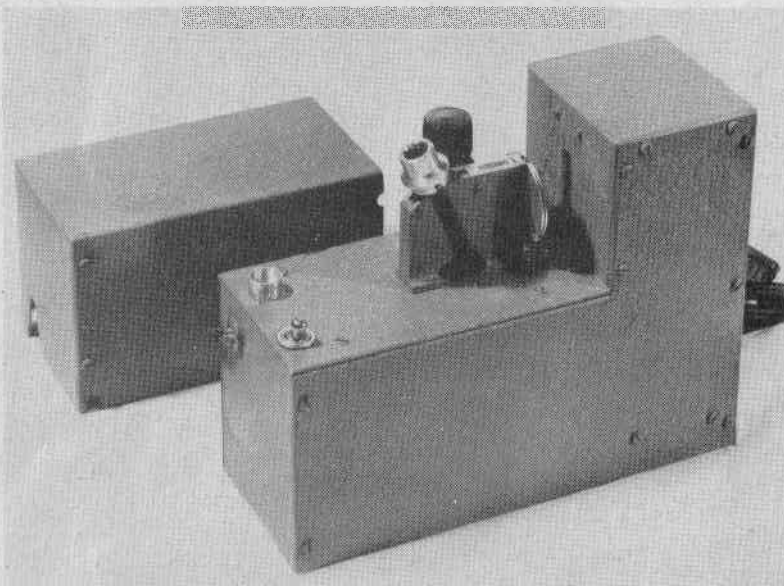
methylene iodide is used for all gems whose refractive index is over 1.65, toluene for those below 1.65. If greater accuracy is desired, or if a demonstration is being made to a user less versed in the analysis of interference figures, it is of occasional value to mix liquids to the index of the specimen. However, such mixing of liquids is time consuming and is not of great value since the non-parallel faces of a gem will produce aberrations in the interference figure even when the specimen is immersed in a liquid of exactly its own index.

The gemological microscope sells at a basic price of $401.50, with 5X ocular, 3X, 10X, and 21X objectives, and stone holder. The complete instrument has in addition to the above, quartz wedge, immersion cell, centering nosepiece, a 10X ocular, and sells for $558.00, almost $200.00 below the cost of any other comparable equipment.

THE SORTAGEM

The third device which has been developed is a simple key-sort system for identification. It consists of 110 cards, each covering a mineral species which may appear as a fashioned gemstone. The Sortagem has been found of great value since it affords rapid and accurate correlation of the optical constants obtained with the Analyzing Refractometer and/or the gemological microscope. This is particularly true since the properties employed in making up the Sortagem are those for typical gem quality material. Extended mineralogical tables incorporating some of these constants may of course be used, but all such tables known to the writers have several defects: (1) they include constants for all minerals, are not limited to gem species, (2) they cover all types of each mineral,

not the relatively constant gem varieties, (3) each property is tabulated separately, and coordination of a series of properties is difficult.

The Sortagem system is based primarily on refractive index, birefringence, optic character and sign. In general, the first test made on a cut stone will be determination of refractive index. The Gem refractometer permits indices to be obtained even from cabochon gems, and gives a positive indication when an index is over 1.8. When index is over 1.8, or for some reason cannot be obtained, further sorting is done on the basis of single or double refraction, color, transparency, and metallic or non-metallic luster. In case these readily-obtained properties prove inconclusive, a series of slots permit a sort to be made on the basis of .05 steps of specific gravity. Any of the foregoing properties may be used for the first sort if desired. If the Analyzing Refractometer is used, the second sort will usually be on the basis of birefringence. Optic character and sign may be used for the third and fourth sorts if identification is not conclusive after the second test. Major gemstones can be sorted out quickly, as can gems showing phenomena such as asterism, chatoyancy, etc.

The manipulation of any key-sort system results in a series of segregations of the cards. With the Sortagem a recommended procedure is to lay these individual "sorts" in separate piles; eliminations which were made on the basis of any measurement whose accuracy is questionable can thereby be checked very rapidly by reviewing the proper pile of cards. The Sortagem sells for $25.00, complete with case and handle-type sorting rod.

On the Alexandrite Color
of Crystal

by

S. V. GRUM-GRZHIMAILO

translated by

GEORGE TUNELL, Ph. D

DISCOVERED in the preceding century, alexandrite has attracted attention by its special property of changing color depending on the illumination: by day it is green, in artificial light, rose-colored.

The nature of this phenomenon is explained in a series of works; nevertheless, until the present time, no detailed investigation of the alexandrite color has been carried out. In the present work the results of such an investigation of a crystal of alexandrite are given. For the study, a plate 1.68 mm in thickness was cut from a crystal parallel to the plane of the optic axes, that is, parallel to the face (010).

Transmission curves for eaves with vibrations in the directions Z and X[2] were measured with a Konig-Martens spectrophotometer. They are presented in the lower part of the figure (full lines). Along the axis of ordinates in the figure $1/1_0$ is plotted (1_0 intensity of light incident upon the crystal, 1 i n t e n s i t y of light transmitted through the crystal), along the axis of abscissae the wave length is plotted. Maxima in the absorption spectrum, corresponding to minima in the transmission curve, occur in the yellow and violet parts of the spectrum.

The curves show that the color of alexandrite is caused by the red rays (beginning approximately at 620 and the bluish-green rays (from 530 to 460), for which the crystal is transparent.

With this distribution of regions of transmission in the spectrum, the color is very sensitive to change in the relative intensity of blue-green rays in the light illuminating the crystal. The latter differs markedly for daylight and electric light, which appears to be the cause bringing out the change in color of alexandrite. With illumination by daylight, the blue-green rays play a dominant role in the perception of the color, and the crystal appears green. With artificial light, poor in these rays in comparison with daylight, its color depends principally on the red rays, the result of which is that the crystal appears rose-colored.

As is well known, three color coordinates can be determined from the absorption curve by calculation, and thus the color tone characterizing the color of the object can be found. Carrying out such calculations, it can be shown that the color of alexandrite must change with changing illumination.

Curves of natural alexandrite for both waves were calculated by the method of selected ordinates, treated by Hardy and Pineo[3], for a source of light A (gas filled

1. Originally published in the Memoirs of the Russian Mineralogical Society (Zapiski Vserossiskogo Mineralogicheskogo Obshchestva, second series, volume 75, pages 253-255, 1946); Translated by George Tunell.
2. The curve for the wave with vibrations along Z has a minimum at 580 mu, that for the wave with vibrations along X has a minimum at 560 mu.

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lamp with color temperature 2848°K) and for a source C—"daylight" (color temperature 6500°K).

Calculations for source A showed that the color tone for waves vibrating along Z corresponds to a wave length of 675 mμ (red), and for waves vibrating along X, 591 mμ (yellow-orange); the color saturation and brightness are nearly the same in the two cases. These values correspond very well with the color of alexandrite as observed under the microscope in polarized light with artificial illumination. It is rose-colored for light vibrating along Z and yellowish for light vibrating along X.

Calculations of these same curves for source C give quite different values. The brightness is the same for both waves; the saturation differs markedly, which is confirmed by observations under the microscope with daylight. The results for the color tone are close together—about 568-570 mμ, which corresponds to a yellow-green color of the object, although it actually has a green color. This discrepancy can be explained by the incomplete coincidence in the distribution of energy in daylight and in light source C and by some inexactness of the results of the calculation, caused by the fact that the points on the curve for the short wave part of the visible spectrum were not measured, but found by extrapolation, which, according to what was said above, should affect the results of the calculations for daylight more than those for artificial light. Still, notwithstanding this discrepancy, the results of the calculations indicate sufficiently convincingly, that with artificial light the color of the crystal has a tone corresponding to a longer wave part of the spectrum than with daylight, as is actually observed.

The color of the investigated specimen of alexandrite is caused by chromium (it contains 0.34% Cr_2O_3); it contains no vanadium.[4] It does not follow that the alexandrite color is a specific property of crystals of $BeO.Al_2O_3$ (colored by trivalent chromium in sixfold coordination). The chromium ion can produce the alexandrite color in other crystals possessing a structure differing from that of alexandrite.

Thus, for example, a crystal of corundum containing about 30% Cr_2O_3 also changes its color—from greenish in daylight to rose-violet in electric light.

Crystals of $Cr_2O_3.Al_2O_3$ have the spectral transmission curve characteristic of Cr^3+ (coordination number 6), which with increasing concentration of chromium gradually shifts toward the red end of the spectrum.[5] A crystal having a concentration of chromium for which the maximum and minimum on the curve correspond to the same wave lengths as in the case of a crystal of alexandrite, has the alexandrite color. As an example, the curve (dotted) in the figure pertains to a specimen with 29.2% Cr_2O_3 and 70.8% Al_2O_3, which appeared as a baked, finely crystalline mass, annealed at 1750°.[6] The specimen was measured in reflected light on the Pulfrich ore photometer (a barite plate serving as a standard).

The alexandrite color also does not appear to be a peculiarity associated solely with the presence of trivalent chromium. Thus, for example, it can be obtained in the case of corundum if certain other coloring ions are introduced. Abroad, where synthetic gems are manufactured, artificial alexandrite is produced. It is corundum, colored, according to Brauns,[7] by vanadium and cobalt.

It should be mentioned that by the method of Verneuil by which corundum is synthesized, large boules cannot be ob-

3. N. G. Fedorov, Obshchee Tsvetovedenie, 1939, P. 150. (A. C. Hardy and O. W. Pineo. The computation of trichromatic excitation values by the selected ordinate method. Journal of the Optical Society of America, volume 22, page 430, 1932; the original article of Hardy and Pineo is more accessible to American readers than the Russian textbook by Federov. Translator).

4. S. V. Grum-Grzhimailo, Trudy Laboratorii Kristallografii Akademii Nauk SSSR, volume 2, p. 73, 1940.

5. S. Grum-Grzhimailo (Grum-Grzhimailo), Acta Physicochimica URSS, volume 20, number 6.

tained with a content of chromium sufficient to give the alexandrite color (a series of experiments showed that the boule does not grow when the content of chromium exceeds a few per cent).

In order to determine what is the coloring agent in artificial alexandrite (the data in patents being often inexact), we carried out an investigation of an imported boule of alexandrite, which had a light green color in daylight and a light rose-violet color in electric light, similar to natural alexandrite. Spectral analysis of the artificial alexandrite, carried out in the All Union Institute of Mineral Raw Materials, showed the presence of a large quantity of Al and the complete absence of Be. Its color, according to this analysis, must be attributed to the content of Cr and V (tenths of a per cent). Other impurities present in the specimen, judging from the appearance of its curve, do not play a role in its coloration. In the specimen traces of Fe, Si, Ti were detected, also a little Mg; no other basic elements were present.

By the introduction of two coloring ions in the crystal investigated, giving transmission curves very similar in appearance, a disposition of the curve is attained similar to that of natural alexandrite (see figure, curves 1, measured on the spectrophotometer); the plate, cut almost parallel to the optic axis, was approximately 1.5 mm. thick.

The regions of transmission occur at approximately the same wave lengths as in the case of natural alexandrite. A difference is the absence of the peculiarity characteristic of color caused by chromium—the displacement of one maximum of absorption (minimum on the curve) in relation to the corresponding maximum 4 for the other of the two waves propagated in the crystal.

The general similarity of the curves of artificial and natural alexandrite cause their characteristic change of color with change of illumination.

Thus the alexandrite color does not appear to be a characteristic property of crystals with the structure of alexandrite, and it is not caused solely by the trivalent chromium ion.

Institut Kristallografii
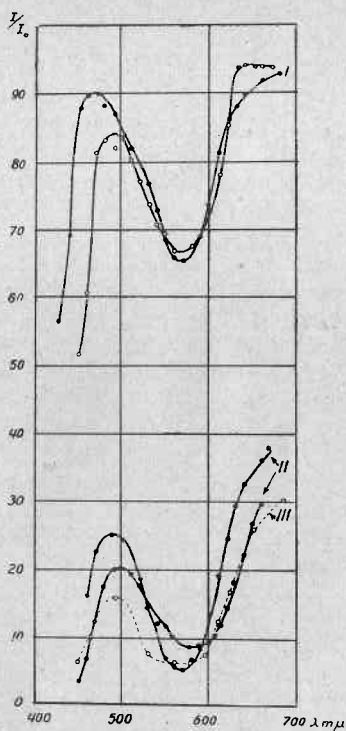Akademii Nauk SSSR

Figure 1. Transmission curves of crystals with the alexandrite color. I) Synthetic alexandrite; II) Natural alexandrite; III) Crystals of composition 29.2% Cr_2O_3 and 70.8% Al_2O_3.

6. The specimen was prepared in the Leningrad State Ceramic Institute by N. K. Antonevich.
7. Brauns, R. Centrallblatt für Mineralogie, Geologie and Paláontologie, Abteilung A, 1926, page 233.

CHRYSOBERYL

Chrysoberyl, in its several varieties, is one of the most beautiful and costly of all gems. In spite of this, it is not well known to the layman and has not attained the popularity it deserves.

Chrysoberyl is an oxide of beryllium and aluminum. It crystallizes in the ortho-rhombic system and the crystals are twinned so as to have a hexagonal appearance. This is well illustrated in figure A of the color plate. The hardness of chrysoberyl is 8½, placing it third in hardness among gems, being exceeded only by corundum (ruby and sapphire) and diamond. Its specific gravity ranges from 3.65-3.68 and refractive index from 1.746 to 1.755.

There are three gem varieties of chrysoberyl, chrysolite chrysoberyl (B), alexandrite (C and E), and cat's eye (D). Chrysolite chrysoberyl is yellowish green in color, and is the most common and least costly variety. Alexandrite is the rarest and most highly prized variety because of its remarkable property of possessing different body color under different lighting conditions. In daylight a fine alexandrite is emerald green in color, while under yellow artificial light it is columbine-red. Cat's eye is also very rare and unusual because of its fine chatoyancy, resulting in a very sharp "eye." Chrysoberyl cat's eye is also sometimes called cymophane.

The term chrysoberyl means golden beryl while chrysolite chrysoberyl alludes to chrysoberyl having the color of chrysolite (an obsolete name for peridot). Alexandrite was named in honor of Alexander II of Russia. Cymophane is derived from two Greek words meaning wave and to appear, in allusion to its chatoyancy.

Most gem chrysoberyl comes from alluvial deposits in Brazil and Ceylon; the finest alexandrites come from the Ural Mountains.

Gemologist Diplomas Awarded Twenty-Four

Students of the Gemological Institute of America who may now call themselves gemologists, and who have received their diplomas in the "Theory of Gemology" from the G.I.A. since the first of the year, are:

Joseph W. Beauregard
Irving B. Gerson
Thomas J. Hummel
Douglas N. Letendre
Frank E. Mabry
Harold D. MacRitchie
Richard Moriarty
Darwin R. Neumeister
Wesley Savage

B. H. Shields, Jr.
Jared E. Wootten
Mary (Mrs. Geo.) Beattie
Maurice Brodman
T. C. Brown
Jack Cohen
Everett Hardy
Harold Hyde Hubbard
Russell Mastin
E. N. Nelson
Edward Novy
Franz Pulver
Harry Robinson, Jr.
Walter E. Singer
John Young
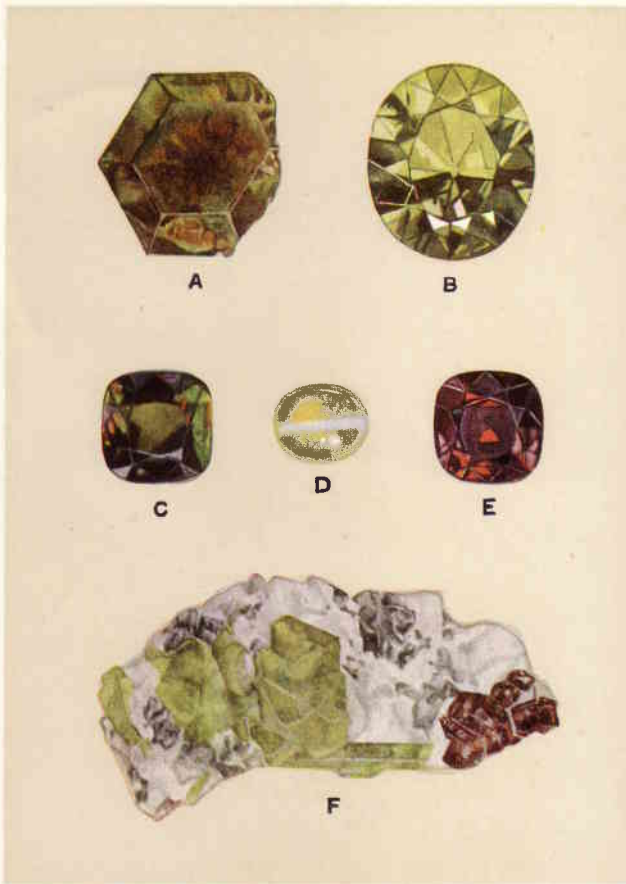
CHRYSOBERYL

One unfamiliar with characteristic crystal forms could be confused with the chrysoberyl crystal at (A). Although this Russian chrysoberyl appears to be hexagonal in form, it is really a twinned crystal of the orthorhombic system. It is known as a psuedo-hexagonal form in which chrysoberyl frequently occurs. Chrysolite chrysoberyl is shown at (B) while (C) and (E) show a fine alexandrite under daylight and artificial light respectively. (D) is the well-known precious cat's eye. The rough specimen at (F) contains chrysolite chrysoberyl, garnet, and other minerals. Specimens from the collection of British Museum (Natural History), London.

PLATE XVIII
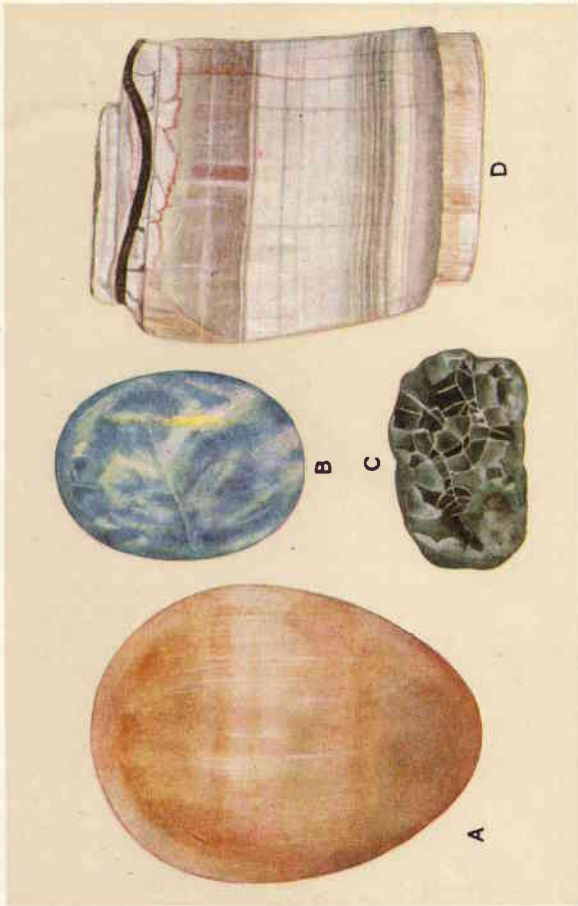
SATIN-SPAR, LAZULITE, CHLORASTROLITE

Figure (A) shows a fine specimen of the translucent fibrous, silky gypsum better known as satin-spar from Perm, Russia. The blue stone at (B) is lazulite, often confused with lazurite, Zematt, Switzerland. The light bluish green mineral at (C) is chloastrolite. In addition to its mottled appearance it possesses a chatoyant effect that readily identifies it. The Isle Royal in Lake Superior is the principal source of this material. The fibrous specimen at (D) is calcite, satin-spar, from Alston Moor, Cumberland. Specimens from the collection of British Museum (Natural History), London.

PLATE XIX

STANDARDIZING THE

NOMENCLATURE OF GEMS [1]

by

EDWARD H. KRAUS, Ph.D.

It has long been the practice to give minerals and gems names that indicate either some characterizing physical property, an important chemical constituent, or the locality where first found; also some mineral names honor a scientist or the discoverer of the mineral. Thus, we have azurite because of its characteristic color; zircon because it is a compound of the element zirconium; feldspar from the German word feldspath meaning a mineral found in the field; vesuvianite, because it was first found on Mount Vesuvius; brazilianite, the recently described gem mineral from Brazil, and smithsonite, honoring James Smithson, who founded and endowed the Smithsonian Institution in Washington, D. C.

Many names are the heritage of the distant past, and are well established and cannot easily be replaced by more accurate scientific names. For example, amethyst from the Greek meaning "without drunkeness," because the gem was supposed to be a remedy for intoxication. I do not suppose that this ancient belief is ever mentioned today to a prospective buyer. Then, too, many popular names have been in use for a long time. Some of them are desirable and should be retained. This is especially true of gem minerals which occur in many varieties, thus the ruby and sapphire varieties of corundum, and the varieties of beryl known

as emerald, acquimarine, morgenite, and goshenite. There are, however, other popular names which are designed to increase the sale value, whereby a cheaper stone is given a name resembling or suggesting that of a more valuable gem. For example, the red pyrope garnet has frequently been called by such misleading trade names as American ruby, Arizona ruby, Cape ruby, and the like. Rose quartz has often been designated as Bohemian ruby, and the somewhat misleading term rubellite is applied to red or pink tourmaline. These terms, which are long standing, as well as some of more recent date such as starlite, introduced by George F. Kunz for the blue zircon the result of heat treatment, should be discontinued.

During the past 20 years much progress has been made in Europe and in the United States and Canada towards standardizing gem names. In 1928 the National Association of German Jewelers, Goldsmiths, and Silversmiths, the Chamber of Industry and Commerce in Idar adopted a nomenclature which was especially designed to meet the needs of the trade and of science. The nomenclature was compiled by Professor R. Brauns of the University of Bonn, Professor K. Schlossmacher of the University of Koenigsberg, and O. Holstein in charge of the Technical School at Idar. The list gives the mineral

names, the various varieties, and the terms commonly used in the trade. The gems listed are classified as follows: 1) precious stones, 2) semi-precious stones, 3) synthetic stones, 4) doublets, and 5) imitations. Although the list does not attempt to indicate acceptable terms or those that should be discontinued it was nevertheless a valuable step forward.

Later it was proposed that this nomenclature be adopted internationally, and accordingly it was referred to the Bureau of the International Association of Manufacturers, Wholesalers, and Retailers of Jewelry and Gold and Silverware. This Association is commonly known as the B.I.B.O.A. using the abbreviation of the French name of the organization. It was organized in 1926 at Amsterdam and has its headquarters at the Hague, Netherlands. To obtain the cooperation of the various countries, members of the B.I.B.O.A., it was obvious that certain changes and modifications must be made. Professor H. Michel of the Museum of Natural History in Vienna and B. W. Anderson, in charge of the Diamond, Pearl, and Precious Stone Trade Section of the London Chamber of Commerce, rendered valuable assistance in revising the nomenclature and gem descriptions. Representatives of Great Britian, France, and Italy assisted in translating the material into different languages. At the Congress of the B.I.B.O.A. held in Rome in 1933, the nomenclature was adopted and a year later, 1934, the Congress at The Hague entrusted Professor K. Schlossmacher and G. Gobel of Paris with the task of preparing the manuscript for the printer. The publication known as the B.I.B.O.A. nomenclature or list was issued in 1935. Thirty-nine mineral species used as gemstones are listed, as are also pearl, coral, and amber. Futhermore, reference is made to synthetic ruby, sapphire, and emerald, colored stones, reconstructed materials, doublets, and imitations.

In 1936, the National Association of Goldsmiths of Great Britain approved for the trade standard gem descriptions. These were adapted from the B.I.B.O.A. list for use primarily in Great Britain. Also in 1936 a very helpful contribution entitled *Edelsteine* (Precious Stones) was published in Switzerland. It contains concise information concerning gems in general, and a list of the names and descriptions of those gemstones commonly encountered in the trade. Here too, the recommendations of the B.I.B.O.A. are followed and accordingly the term *semi-precious* is not used, gems being classified as *precious* and *ornamental.*

In 1938 at Lucerne, Switzerland, at the meeting of the B.I.B.O.A. there was further discussion concerning the practice of classifying some gemstones as semi-precious. It was revealed that this unfortunate term was introduced in the trade during an economic crisis and for purely commercial reasons. At that meeting it was decided to discard the term semi-precious and that instructions to that effect be sent to the members of the B.I.B.O.A. It was also agreed that this action should be stressed at the next international meeting to be held in Prague, Czechoslovakia in 1939, but unfortunately that meeting did not take place.

In 1945, the Precious Stone Dealers' Association of New York adopted a single list of Preferred Names for twenty gemstones. I believe the organization is now called the American Stone Importers' Association but that the list continues to be known as the P.S.D.A. list. During the same year, 1945, two dictionaries appeared, namely the *Jewelers' Dictionary,* issued by the Jewelers' Circular-Keystone, and the *Dictionary of Gems and Gemology* by R. M. Shipley and others. These dictionaries are very important contributions. They are very complete and have many cross references which aid greatly in their use. As is the case with all dictionaries, the definitions do not always agree, for they tend to reflect the opinions of the editors.

Although the recommended preferred and non-acceptable names are not assembled

in lists in these dictionaries, as was done by the organizations referred to earlier, these publications contributed very valuable information concerning the usage and acceptability of names and the correct descriptions of the various stones.

More recently the Gemmological Association of Great Britain revised the earlier British list which was adopted in 1936. The new list was published in April, 1948 number of the Journal of Gemmology. Thirty-two gemstones are described in one list as to mineralogical species, varieties, color, and correct trade names. As only one list is used there is no reference whatever to *precious* or *semi-precious* stones. There are special cautions, which are printed in italics; for example, under chrysoberyl and "quartz cat's-eye;" and under zircon it is used on its own, but qualified by the name of species, i.e., chrysoberyl cat's-eye, or "quartz cat's-eye"; and under zircon it is indicated that "the terms *jacinth* and *hyacinth* should not be used."

At the annual meeting of the Educational Advisory Board of the Gemological Institute of America in 1947 a committee 'of the American Gem Society asked the Board to recommend a nomenclature. Accordingly, at the time of the Conclave held in Washington in 1948, a sub-committee on nomenclature was appointed by the Board. This committee was asked to consider the topaz-citrine question and especially the suggestion from the Precious Stone Dealers' Association that the descriptive name *topaz-quartz* be an acceptable synonym for citrine and that the term *quartz-topaz* be abandoned, and that it would then be optional to use either citrine or topaz-quartz as a name for the transparent yellow variety of quartz.

Professor C. B. Slawson, Chairman of the Sub-Committee, submitted a statement to the Educational Advisory Board which was read at its meeting in New York on November 13, 1948 in which he reported that "The matter was informally discussed after the meeting of the Educational Advisory Board and it was the general conclusion that this designation should be considered acceptable but that no formal action was taken by the Sub-Committee." After considerable discussion of this report, a motion was adopted by the Board that *topaz-quartz* be accepted as a synonym for citrine, as the term topaz has long been in general use to designate a color. It should be stated that the vote on this action was not unanimous. Moreover, during the past two decades the Germans and the B.I.B.O.A. admitted the use of topaz-quartz, but the 1936 Swiss list did not recognize the term. The recent 1948 British nomenclature does not list topaz-quartz; it also indicates that quartz-topaz is incorrect. Only citrine is admitted.

Furthermore, at the meeting of the Educational Advisory Board it was voted that the Gemological Institute of America should prepare a complete nomenclature list and submit the same for consideration to the Educational Advisory Board. It was hoped that this could be done so that it might be reported at the Boston Conclave. It was also suggested that in preparing the list serious consideration be given to the desirability of classifying gemstones as 1) *precious,* 2) *synthetic, and* 3) *imitation,* and that the term *semi-precious* be omitted.

Due to the very heavy load being carried currently by the Gemological Institute of America at its headquarters in Los Angeles and the development of the Eastern headquarters in New York, the preparation of the list is still underway. It is expected that the list may be completed and be ready for consideration at the next meeting of the Educational Advisory Board and subsequently be transmitted to the American Gem Society.

A study of the various nomenclatures clearly indicates that very serious attempts have been made to approve names which express as accurately as possible the true character of gem stones and that all mis-

leading and meaningless terms be discarded. Naturally, there are and always will be honest differences of opinion as to the proper terms and descriptions which should be used not only within a given country, but also between different nations. These differences are readily detected when one compares the nomenclatures referred to, as well as the usages followed in the various books on gems and gemology which have been published in recent years. There is, however, one very striking and important recommendation, namely that the term semi-precious be discarded. The American Gem Society is to be commended for adopting at the Washington Conclave its Ruling A-7, which reads, "Members shall not employ the term 'semi-precious' in referring to any gem stones."

This is not the time or place to discuss in detail which terms should be approved in the proposed standard nomenclature or which ones should be discarded. That can best be done by comparing the various lists and then making decisions which meet to the best advantage the requirements of science, the trade, and the general public. It is hoped that at the next Conclave a standard nomenclature may be presented which may receive the general approval of the various groups represented at these meetings. It is also to be hoped that through the cooperation and exchange of ideas with the gemological groups in various parts of the world, before long, a truly international nomenclature may be adopted. In fact, it is of great interest to know that at the conference of the B.I.B.O.A. held in Paris in October, 1948, action was taken to have the B.I.B.O.A. list restudied. This is being done by Monsieur George Gobel, Paris; Mr. B. W. Anderson, London; Dr. E. Gubelin, Lucerne, Switzerland; Dr. J. Bohnan, Hilversum, Netherlands; and Dr. F. Schlossmacher, Idar Germany. It is the desire of the officers of the B.I.B.O.A. that a list be prepared that may be adopted by as many national associations as possible, and thus be truly international.

G.I.A. GRADUATES RECEIVE DIPLOMA

Six new graduates of the G.I.A., who were recent recipients of the diploma in the "Theory and Practice of Gemology," are:

Lester B. Benson, Jr.
Ward H. Cook
G. R. Crowningshield
Robert Fudge
Robert Spratford
O. F. Stoops

Each of the six has completed the four Correspondence Courses and passed all examinations of the G.I.A. In addition to attending Resident Classes A and B, they also had to pass final stone examinations at their close.

DR. HURLBUT REVISES DANA'S BOOK

In the third edition of Dana's *Minerals and How to Study Them,* reviser Cornelius S. Hurlbut, Jr., member of the G.I.A. Educational Advisory Board and Professor of Mineralogy at Harvard University, has written the chapter describing mineral species to conform to the almost universally accepted chemical classifications.

Welcomed by amateur collectors will be the author's suggestions for starting a well-rounded mineral collection. Also added are two appendixes, one listing the common minerals according to prominent elements and the other indicating minerals which are most important for a small collection.

Published January, 1949, John Wiley & Sons, Inc., New York City. $3.90.

IN NEXT ISSUE

Radioactive Diamond by John A. Hardy; *Reconstructed Rubies,* Basil Anderson; Dr. Gubelin and Dr. Alexander; *Vegetable Ivory* by Robert Webster; *Idar-Oberstein* by Dr. Schlossmacher; and others.
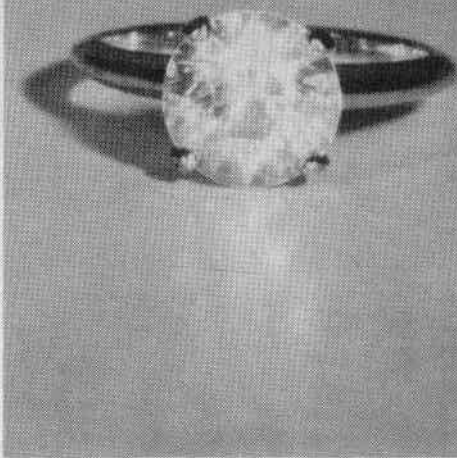
American Synthetic Crystals

SAPPHIRE TO TITANIA

by

A. K. SEEMANN

LINDE AIR PRODUCTS CO.

Editor's note: The following article is the principal parts of a talk delivered by the author before the 1949 Conclave of the American Gem Society in Boston.

In 1944 the writer was privileged to address the American Gem Society relative to the establishment of a synthetic crystal industry in the United States. Since that time this country has emerged from World War II and has accomplished the transition from a war to peacetime economy. It will be observed that in a few short years American synthetic crystal developments have not only caught up with Europe, but have advanced into new fields, as exemplified by the star stones and, more recently, titania. Of equal importance are technological advances of a fundamental nature which add to the knowledge of crystals and to the successful manufacture of new physical forms for commerce and the arts.

This paper will describe the process by which many of these crystals are grown, their composition, properties, crystal habits, and commercial importance. An attempt will also be made to review the significant technical advances made by American industry.

The process for the production of synthetic corundum crystals was first described by A. Verneuil, in a French paper published in 1904. Up to that time "reconstructed" or "Geneva" rubies, made by fusing together

Titania

small chips of natural ruby, had been the nearest approach to a man-made ruby gemstone. The early crystals made by Verneuil were in the form of small balls weighing two to three grams. In spite of the fact that carrot-shaped and later cylindrical-shaped crystals weighing over 100 grams each have been produced, the crystals made by the Verneuil technique are still called boules, corresponding to the original French designation.

As it is known today, a corundum boule is a single crystal of alpha aluminum oxide, normally produced in diameters of $\frac{1}{2}$ to 1 inch and in lengths of 1 to $2\frac{1}{2}$ inches. The clear, uncolored crystal is usually designated as clear or white sapphire. If the boule is colored red by the addition of chromic oxide, it is ruby with essentially the same chemical composition as the natural stone. Alternately, the addition of small amounts of titania and iron oxide results in a blue sapphire crystal.

Synthetic spinel boules (MgO in Al_2O_3) are also grown by the Verneuil process. These crystals can be made either clear or colored in a wide variety of tints and shades

by the addition of small percentages of the oxides of cobalt, chromium, titanium, nickel, iron, and vanadium. Perhaps the most popular colored spinels for gemstones are the blue and aquamarine.

The basic process for growing corundum and spinel boules has changed little from that first developed by Verneuil.

The powdered oxides are held in a hopper with a fine mesh screen bottom. Tapping the hopper causes the powder to feed intermittently into the oxygen stream and to be carried down through the center tube of the diffusion-type oxy-hydrogen burner. Hydrogen is fed to the flame through an annular passage surrounding the oxygen-powder tube. The tip of the oxy-hydrogen powder burner discharges the flame into a cylindrical ceramic furnace, usually split down the middle for easy opening and with a small rectangular slot in one side for viewing the boule during the growth process. The boules are grown on a ceramic pedestal, centered in a refractory furnace. and supported by a table with a vertical screw adjustment. Fig. 3 shows such a split furnace opened up with the finished boule still standing on its ceramic pedestal.

At the start of the boule growth process, the powder feed rate is adjusted somewhat higher, and the flame intensity lower than for the steady boule growth condition. The powder feed-rate is varied by changes in the tapping frequency and amplitude of the hammer blow. The flame intensity is varied by adjusting the oxy-hydrogen gas ration and precise regulation of the actual volumes of these gases fed to the flame. The powder falling through the flame builds up a sintered mass on the end of the ceramic pedestal, and if the flame conditions are favorable, a single crystal soon begins to emerge from the mass. By careful control of the flame intensity, this single crystal is made to grow out of the sintered mass until it forms a rod about the diameter of a match stick and $\frac{1}{4}$ inch long. At this point, the adjustment is changed and a

small ball is made to form on the end of the rod, which is progressively broadened to resemble a mushroom. When the diameter is increased to the size desired for the boule being grown, the growth conditions are adjusted to give a uniform diameter cylindrical section. These steady conditions of powder feed, flame intensity, and boule lowering rate, are maintained until the boule is of the desired length, and then the growth process is stopped.

As a general rule, the clear stones are easier to grow than the colored ones; the greater the amount of coloring agent added, the more difficult the fusion and the greater the probability of the boule cracking when the flame is shut off at the end of the growth cycle. Fig. 2 shows the boules in various stages of growth.

The alumina and alumina-magnesia spinel powders used as starting materials in the boule process are prepared by the calcination of aluminum ammonium sulphate and magnesium sulphate for the spinel crystals.

The alums are formed by precipitation from hot, aqueous solutions. While spectrographic analysis is used to control quality in the various steps of powder preparation, it has been our experience that one is never really sure of powder quality until after a boule has been grown. Some impurities, such as iron, magnesia and silica, can be detected immediately by eye in a clear sapphire boule in concentrations as low as a few parts per million. The fact that spinel boules contain about 12% magnesia, complicates the preparation of corundum and spinel powders in the same plant.

Calcination of the alums to the alumina or spinel powders is effected in muffle furnaces. At the end of the calcining cycle, the boule powders are removed from the furnace and allowed to cool in still air. For clear sapphire, the alum crystals are calcined are prepared by adding the proper amount directly to alumina powder. Colored powders of colorant solution to the alum before it is placed in the calcination furnace. The fact

that the alum melts in its water of hydration during the early stages of calcination insures the uniform distribution of colorant in the alumina powder.

After cooling, the alumina in the calcination dishes is in the form of a light, friable cake, which is then screened to provide the powder used in the boule growth apparatus.

The crystallographic form of the boule powder is gamma alumina. On calcination at higher temperatures, the powder is transformed to alpha alumina with a substantial increase in tultimate particle size.

The alpha alumina powder has found extensive application as an improvement over levigated alumina for metallographic polishing. Direct calcination at carefully controlled temperatures insures a uniform particle size not obtainable by levigation. This polishing powder is used to advantage in the polishing of some of the softer gemstones.

The synthetic corundum crystals are of considerable interest as gemstones. However, the hardness of the crystals and their ability to take a high polish exhibiting low friction recommends them as a bearing material for watches and instruments. Therefore, it is not a mere coincidence that the production of synthetic corundum crystals for a long time was centered in a relatively small area in southeastern France and Switzerland, near to the tremendous watch industry. It was not until the demands of modern instrument warfare forced the United States to develop its own industry that facilities for growing corundum crystals were established here as a war measure in 1941 and 1942.

While the general information on the production of synthetic corundum and spinel boules was available to the embryo United States industry in the form of a few widely scattered technical papers, details of the European plant equipment and process control were closely guarded trade secrets. Thus, it took several years for this country to reach the frontiers of knowledge in the boule growth process and to manufacture these boules on a large scale for the war effort. The first years of research and development effort in the United States were directed toward reaching these frontiers. However, it is the primary purpose of this discussion to present some of the technical advances which have been made in the art of American industry. Briefly, these include

Figure 1. A bank of boule production furnaces used in the manufacture of Linde Synthetic Crystals.
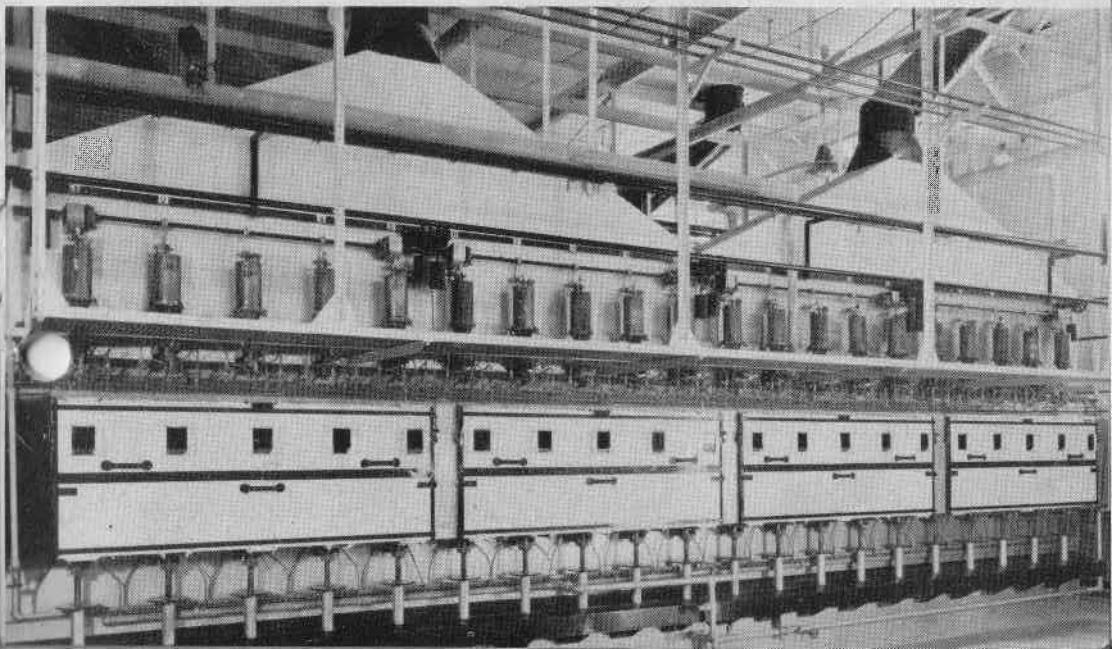
single crystal rods up to 2/10 inch in diameter and up to 18 inches in length; annealed whole boules which do not split down the middle in the manner of the conventional European product; sapphire balls 0.040 - 0.750 inch in diameter, ground to precision ball bearing tolerances; and star ruby and blue sapphire gemstones. In addition, the process has been adapted recently to the production of rods and boules of titania (TiO_2), a material with very interesting optical and electrical properties.

In making jewel bearings for watches, etc., from split boules, the common practice is to slice the boule into thin, half-moon wafers; to cross-hatch these wafers into tiny squares; and then to grind the squares into circular discs. This process is tedious, time consuming, wasteful of materials and above all, expensive. The advantages in starting with a cylindrical rod of about the right diameter for the jewel bearing, are obvious. Only one slicing operation would be required to arrive at the same point obtained by the many operations on boules.

Once the frontiers of knowledge on the boule process were reached, it was only natural that the above thinking should direct the research and development efforts toward the growth of corundum crystals in the form of rods. This has now resulted in the development of apparatus and techniques for growing corundum rods which do not split down the middle in the manner of conventional boules.

In the early development of rod, it was found that some rods split longitudinally along the plane common to the growth axis and c-crystallographic axis, while others did not. This plane in the crystal is the same as that on which all boules split. A study of this factor revealed a close correlation between cracking tendency and crystallographic orientation of the rod. It was found that rods with a c-axis orientation (angle between c-axis and growth direction) of less than 30 degrees usually would split longitudinally when subjected to the slightest stress. Rods with a c-axis orientation greater than 75 degrees tended to develop notches and flat sides causing them at times to be subject to transverse cracking. The first rods were grown from crystal seeds cut from boules with little regard for crystallographic orientation. The previously mentioned effects observed in rods led to a systematic study of the orientation of boules grown with random seeding.

The peak of the frequency distribution curve as a function of c-axis orientation was found to correspond with the most stable rod orientation; i. e., 50 to 70 degrees. However, at this point unexpected correlation between rod length and c-axis orientation was observed.

Since our rod growing equipment was not designed for growing rods of infinite length, the curve is obtained by cutting off the rod after 1 to 2 feet of growth and seeding the next rod with the top section of the preceding one. It should be noted that the rate of orientation change is highest at the smallest angles between c-axis and direction of growth. This rate of change slowly decreases with increase of the orientation angle until it becomes asymptotic for an orientation of 90 degrees. The curve forms the basis for orientation control of rods in production.

The availability of sapphire rods in long lengths permitted the investigation of a whole new series of phenomena not possible with boule sections. For example, while single crystals of corundum exhibited remarkable strength and rigidity at high temperatures, if the temperature is made to approximate the melting point of 2050°C., corundum rod can be bent into a helix. This bending process is related to the crystallographic orientation of the rod. Experience indicates that the bending is a combination of slippage on the basal plane, and actual crystal lattice distortion. The best c-axis orientation in rod for bending has been found to be 45 degrees. Rods with an orien-

tation of zero and 90 degrees are almost impossible to bend. The above analysis, shows that the rod bends easiest in the plane containing the c-axis and the growth axis.

It has also been found possible to stretch sapphire rod heated to temperatures approximating the melting point. Here again, rods with a c-axis orientation of 45 degrees are easiest to stretch, since it is believed that the elongation takes place as a result of slippage on the basal plane. This hypothesis, regarding the mechanism of the bending and stretching phenomena, is given some confirmation by the fact that the stretched section changes from a circular to an elliptical cross section. The minor axis of the ellipse corresponds with the c-axis growth-direction plane of the rod.

The availability of long lengths of corundum rod permitted, for the first time, the observation and study of the phenomena of flame polishing. A cylindrical rod about 0.100 inch in diameter can be given an excellent polish by slowly moving it through an oxy-gas flame at such a rate that the surface heals over all of the grinding surface marks.

The flame polishing operation is comparatively inexpensive and fast, as compared with diamond polishing, and has found commercial application in such widely diversified objects as ruby rod gemstones and thread guides. The flame polishing technique has also been found to be particularly ap-

plicable in forming the tip of a sapphire phonograph needle. The high polish and uniformity of curvature on the tip obtainable with the flame process were especially desirable.

Tests indicate that the life of a sapphire phonograph needle is markedly affected by the crystallographic orientation of the needle tip. The useful life of a sapphire needle can be varied by an order of magnitude by controlling the crystallographic orientation of the tip with respect to record groove. In order to obtain maximum needle life, a twofold control of the needle tip orientation is necessary; (1) the plane defined by the c-axis and the normal to the record face must be nearly parallel to the tangent to the record groove at the point of contact and (2) the angle between the c-axis and record face should approach zero. For practical purposes a tolerance of $\pm$ 15 degrees is recommended for these two controls.

Once the process for growing small diameter sapphire rods was an accomplished fact, research attention was directed toward the problem of growing rods greater than 0.125 inch in diameter which would not split. There are very few articles of commerce made from sapphire which could not be made better and more economically from a whole cylinder rather than a half boule. Annealing of the sapphire boules at very high temperatures has yielded encouraging results in this problem. It is now possible to anneal whole boules, as large as ¾ inch

Figure 2. Steps in the growth of a Linde synthetic ruby boule.
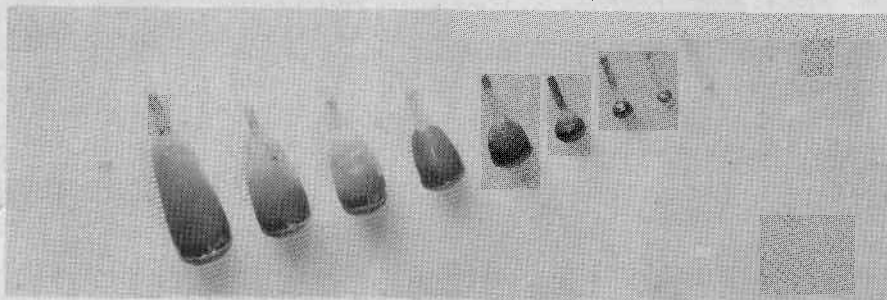
in diameter and several inches long, so effectively that the boules can be sawed, drilled and polished without fracturing, and the finished articles perform as well in service as those previously cut from half boules. The annealing process is carried out in a specially designed oxy-gasfired high-temperature furnace with a maximum temperature in the order of 1900°C.

The constant search for new industrial applications for corundum quite often leads into fields where the physical and chemical properties of sapphire are fine, but the physical shape and form are not available. This was true for sapphire balls desired last year for use in the ballpoint fountain pens. Some 1 mm. balls of sapphire were available from Switzerland, but the diameter and sphericity tolerance of these imported balls were not good enough for the pen application. Since sapphire shows a considerable difference in hardness as a function of crystallograhic orientation, it is not surprising that the first attempts to grind sapphire balls resulted in miniature models of the crystal habit shapes shown in the standard crystallographic text books. However, after considerable process and machine development work, we are now able to manufacture 1 mm. sapphire balls to a sphericity tolerance of 0.000010 inch. In addition to the small 1 mm. size, a process for making sapphire balls up to $\frac{3}{4}$ of an inch in diameter has been developed. Here again, as in the case of flame-polished rods, an industrial development contributes to the jewelry field. Small ruby balls are used as melee in fraternity pins and other jewelry pieces.

At the present time spinel boules in a variety of colors are available in this country. They include white, ruby, garnet, golden, blue, pink, green, topaz, and aquamarine. Additional colors will be made when a sufficient demand develops. Several of the crystals are supplied as whole, annealed boule. This materially reduces fabrication costs and obviously increases the yield of finished carat weight. It has also been an

object of our research to develop colored boule of greater homogeneity. It is characteristic of certain colored varieties that the colorant segregates at the outside of the boule and thereby creates additional difficulties for the lapidary desiring to fashion the most attractive gemstones. Some success has been attained in improving this condition.

Probably the most startling contribution of American technology was the announcement a little more than a year ago of the synthesis of the star sapphire and star ruby. Since their introduction there has been much speculation as to the method by which they are manufactured but, unfortunately, the technique cannot be disclosed at this time. Patent applications are pending and upon their issuance the story will become public. They are sapphire and the asterism is caused by rutile needles. While some of the stones are not completely asterated, a better understanding of the factors influencing asterism has greatly increased the percentage of completely asterated material. Basically, star sapphire and star ruby are unsuited to mass production techniques so that there is very little chance that they will ever fall into the category of common synthetics. They are a custom made laboratory product and will remain so.

The latest contribution to American gemstones is a synthetic titania or, as it is known mineralogically, rutile. Titania is titanium dioxide and is found in nature in many localities but seldom in large single transparent crystals suitable for gemstone purposes. Titania is of great commercial importance as a pigment material for the same reasons that it bids fair to become a popular gemstone material—high refractive index and high dispersion. This tetragonal crystal has a refractive index of 2.616-2.903 and chromatic dispersion of 0.155-0.205. When compared with the diamond—refractive index 2.417 and dispersion 0.063—it is at once apparent why the gemstone varieties possess such popular appeal. The crystal is

grown by a modification of the well known Verneuil technique from very pure titania powder. The boule size varies up to 300 carats and probably could be very much larger. To date no colorless varieties have been grown. The nearest are tinged with yellow. Many beautiful shades, including red, blue, green, brown, and yellow can be made so that a whole new series of gemstones will be offered to the public. Titania is a comparatively soft gemstone material and there were grave questions regarding its durability. Fortunately however, it is rather tough and field testing of titania rings indicates that while the material will scratch, its brilliance will probably assure several years of wear before repolishing is necessary.

Synthesis of titania is unique in that the as-grown boule must be heat-treated to obtain a transparent material. As-grown the boule is black and opaque—similar in appearance to carbon. In this form the material is not completely oxidized, the oxygen deficiency being in the order of 0.01%. When treated in an oxidizing atmosphere at elevated temperature, the transparent form results. This change is reversible and is accompanied by a profound change in electrical resistivity. The oxygen deficient titania is a semi-conductor, while the fully oxidized form is highly resistant. This suggests the commercial employment of titania

Figure 3. **Close-up of a boule furnace opened for photography.**
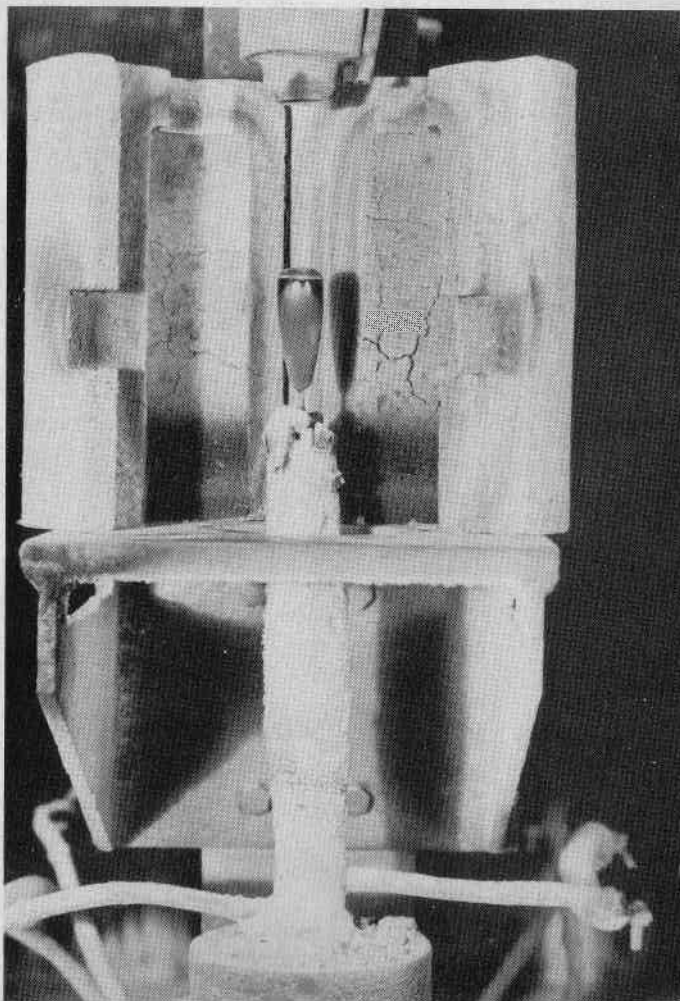
crystals as continuous recorders of the oxygen content of furnace atmospheres. On page 151 is shown a titania gemstone.

The very high refractive index and dispersion of titania, plus the fact that the crystal is dichroic presents a problem to the lapidary who is unappreciative of the effects of these properties in the finished stone. Only too often is the comment made that the polished stone—usually diamond cut—is opalescent and lacks the favorable characteristics of similar high index stones, such as the diamond and zircon.

Titania loses much of its beauty if the table of the stone is not normal or parallel to the c-axis of the crystal. The boules which we furnish are grown at zero orientation, i.e., the growth direction and c-axis coincide within a few degrees. It is only necessary that the table of the stone be a longitudinal or transverse cut of the boule.

To achieve the most pleasing gemstones it is obviously necessary to hold facet angles to close tolerances in accordance with recommendations established by several recognized authorities. For the round stone these are:

*Crown*: Main, 30°; Star, 15°; Girdle, 35°.
Pavilion: Main, 40°; Girdle, 41½°.

These are angles to the table. The cut used is the standard round brilliant having 57 facets—24 pavilion and 33 crown, including the table. The table has usually been made 0.6 the diameter of the girdle.

However, a slight improvement in appearance of finshed stones can be accomplished by cutting the table diameter 0.4 the girdle diameter. In this way the table is less noticeable.

Proper polishing techniques are quite as important as the aforegoing factors and

Figure 5. Top: Black, opaque, synthetic titania (reduced state), as it is produced in boule and rod form. Bottom: Almost colorless, clear, synthetic titania (after oxidation), in boule and rod form. This is the material from which the popular, brilliant, titania night stone is cut.
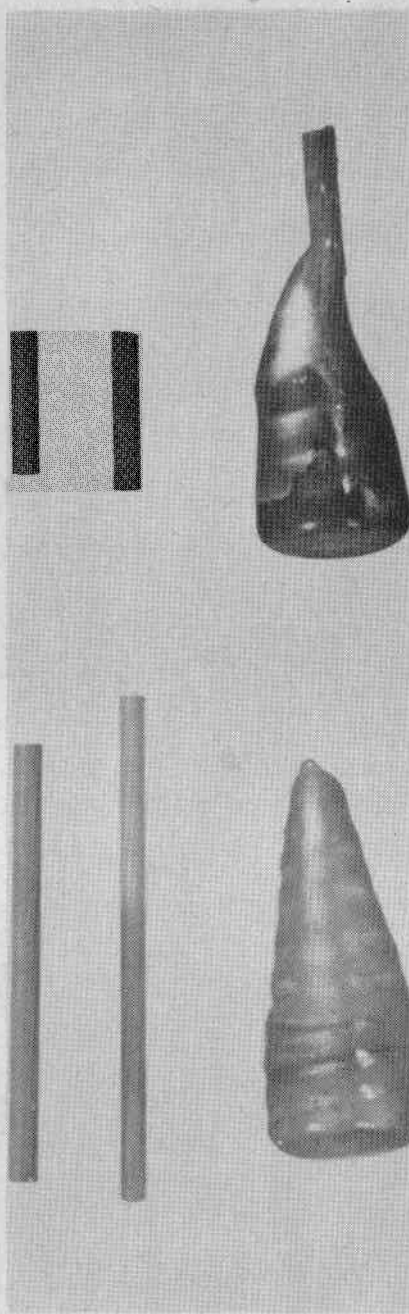
while specific recommendations can be made, they are by no means the final word. In order to retain plane facets and sharp facet intersections it is necessary to use a fairly hard lap. Present recommendations are for cutting on diamond (400 mesh) impregnated copper laps as for sapphire. Preliminary polishing is done with 10 micron diamond on a tin lap with olive oil lubricant. Final polish is with Linde "A" alumina powder on a 50-50 Tin-Lead solder lap. The Linde "A" alumina (with water) gives a good clear polish that has been impossible with diamond (even 0-1 micron).

For all facets, except the table, it has been found important to use flat, unscored laps both for diamond and Linde "A" alumina to avoid severe rounding, particularly of facet intersections, as this rounding detracts considerably from the appearance of the stone. Scored laps can be used for tables, where rounding is not severe because of the large surface. The scored laps will give an unscratched table which cannot be obtained with a flat lap. Scratching caused by the flat lap is not so severe on the smaller facets, and what little occurs must be accepted in order to obtain flatness of the facets.

Because titania is relatively soft, diamond polishing is not recommended. We have found our alpha alumina polishing powder to be quite satisfactory but continuing research on other polishing media may develop a better agent.

At this point a word of caution is appropriate. Because titania may be oxidized or reduced at elevated temperatures, lapidary work should avoid any high temperatures. This includes sawing as well as facetting and polishing. It is well known that high surface temperatures may be reached in the cutting and polishing operations with resultant unfavorable discoloration or even fracture.

NOTE: The term "Linde" is a registered trade-mark of The Linde Air Products Company, a Unit of Union Carbide and Carbon Corporation.
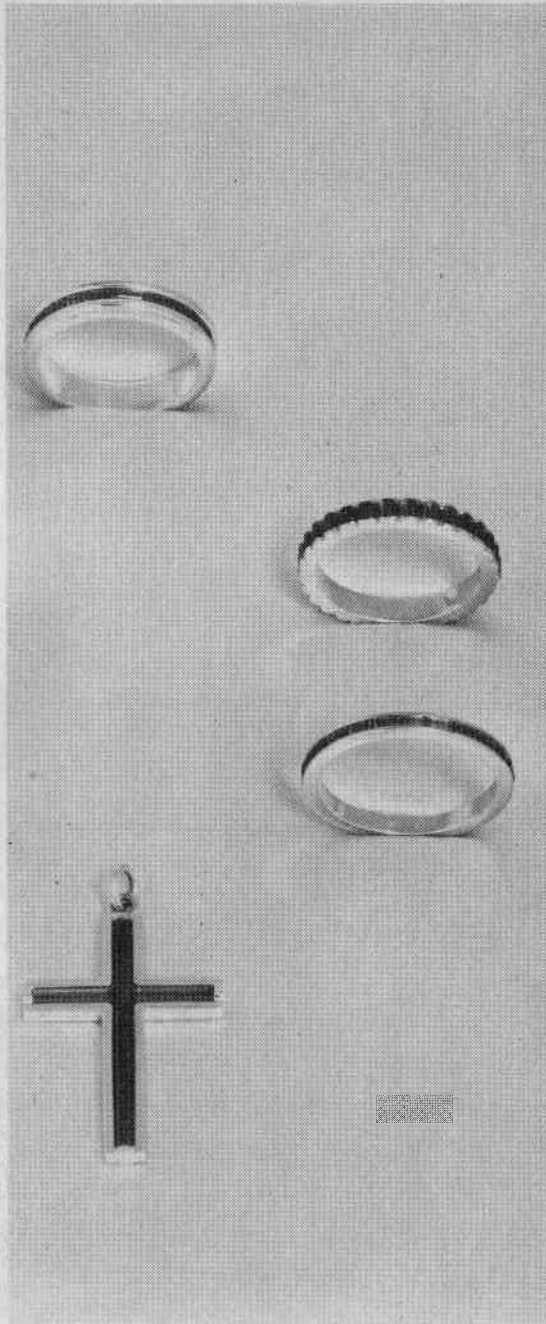
Sydney Hobart Ball

It was with extreme sadness that the Gemological Institute learned of the death of Sydney H. Ball, who passed away suddenly April 8, in his home in New York City. He was 71 years of age.

His knowledge of precious stones and the diamond industry, his long and successful business experience, and his friendly interest in all things gemological were gifts which he gave gladly and freely. The loss of Sydney Ball as a friend and advisor of the Gemological Institute and to those students who profited by his knowledge and concern will long be felt.

Since 1933 he was a member of the Educational Advisory Board of the G.I.A. and his review of, and work on, the diamond courses was one of the many contributions he has made to the Institute. He leaves a vacancy on that Board which will be difficul to fill. With Dr. Edward Kraus and H. T. Dickinson he was made, in 1943, one of the three first Honorary Members of the Gemological Institute. In May, 1948 he was a member of the first Board of Visitors at the G.I.A. in Los Angeles. His interest in the work being accomplished was evidenced by the thoroughness of his three day study of the operation of all G.I.A. departments. He was also a member, since 1934, of the Examinations Standards Board of the G.I.A. He was one of five authorities comprising the Editorial Board of *Gems* and *Gemology*.

Born in Chicago, he studied at the University of Wisconsin, specializing in geology and engineering. Later, while with the United States Geological Survey he made extensive surveys of Idaho, Colorado, Nevada, California, Wyoming and Arizona, with much of the information collected still used as a guide for prospectors. He was also assigned to map geologically a large area in Southwestern Nevada and Southeastern California and the product of this research was the first accurate topographic and geologic mapping ever made of Death Valley.

Early in his career Dr. Ball had made a study of Tertiary dikes and Pleistocene glacial deposits, which for the first time recognized the existence of mountain glaciers of two distinct ages in the so-called Front Range.

In 1907 Dr. Ball became technical head of a prospecting expedition to the Belgian Congo. The party found a diamond in the area, which led to the opening of the Belgian Congo and the Angola diamond fields. For his service he was named *Chevalier de l'Ordre Royal du Lion* by the late King Albert I of Belgium; later an officer of the order; and in January, 1948, *Commandeur de l'Ordre de Leopold II*.

He was a member and former president of the Society of Economic Geologists, former president of the Mining and Metallurgical Engineers, and a governor of the Explorers' Club. For many years he also served in a consultative capacity for the *Societe Internationale Forestiere et Miniere du Congo,* the *Companhia de Diamantes de Angola,* and the United States Bureau of Mines. He was a founder of the House of Jewels at the New York World's Fair, and a member of the Jewelers Publicity Committee.

A prolific writer in his field, Dr. Ball was the author of the *Annual Review of the Diamond Industry,* published by the JEWELERS CIRCULAR-KEYSTONE, for the past 29 years. Since 1934 he contributed the chapter on gemstones to the *United States Bureau of Mines' Minerals Yearbook.* He was the author of many reports on the mineral resources of western states. In recent years his writings were largely devoted

Sydney H. Ball

Gemological Digests

NEW GIA BOARD MEETS IN MONTREAL

The first meeting of the newly elected Board of Governors of the Gemological Institute of America met April 24 at the Mount Royal Hotel in Montreal. Last meeting of the outgoing board was held April 5 in Boston.

New members of the G.I.A.'s governing body are Earl Jones, C. G., Jones Brothers Jewelers, Pekin, Illinois; Ernest Meyer, Meyer's, Grand Island, Nebraska; Glynn Cremer, C. G., La Crosse, Wisconsin; and Maurice Adelsheim, Minneapolis. Others continuing to serve on the Board are: H. Paul Juergens, C. G., Chairman, Juergens & Andersen, Chicago; J. Lovell Baker, C. G. Henry Birks & Sons, Ltd., Montreal; Charles H. Church Church & Company, Newark; Myron Everts, A. A. Everts Company, Dallas; Edward F. Herschede Sr., C. G. Frank Herschede Company, Cincinnati; O. C. Homann, C. B. Brown Company, Omaha; Geo. Carter Jessop, J. Jessop & Sons, San Diego; Lazare Kaplan, Lazare Kaplan & Sons, New York City; John S. Kennard, C. G., Kennard & Company, Boston; E. A. Kiger, C. A. Kiger Company, Kansas City; P. K. Loud, Wright, Kay & Company, Detroit; Charles D Peacock III, C. G., C. D. Peacock, Inc., Chicago; Leo J. Vogt, C. G., Hess & Culbertson Jewelry Company, St Louis; and Jerome B. Wiss, C. G., Wiss Sons, Inc. Newark.

Outgoing members on the board are: Paul S. Hardy, Hardy & Hayes Company, Pittsburgh; Burton Joseph, S. Joseph & Sons, Des Moines; C. I. Josephson, C. G., C. I Josephson Jewelers Moline, Illinois; and Fred Thurber, C G., Tilden-Thurber, Providence.

THE HOPE DIAMOND CHANGES OWNERSHIP

The Hope Diamond, owned from 1911 until the time of her death in 1947 by Evalyn Walsh McLean, was recently purchased by the firm of Harry Winston, Inc., New York City. Included in the collection purchased by Winston is the 100-carat pear shaped Star of the East.

Purchase price of the much publicized 44-carat blue diamond has not been revealed but it is stated that the gem with other stones in the collection were insured for $1,100,000 for their trip from Washington, D. C. to New York City.

SYDNEY BALL

to precious stones. From 1917 until his death he was a member of the firm of Rogers, Mayer and Ball, consulting engineers of New York City. He searched for minerals in the United States, Mexico, Cuba, Haiti, Peru, Chile, Venezuela, Greenland, Russia, Portugal, and Japan and has published many papers on economic geology of these regions. His latest writing was *A Roman Book on Precious Stones,* now at the printer's awaiting completion of printing. This book was the embodiment of his long cherished aim — to present an edition of Pliny's amazing 37th book on gems and minerals suitable for place among authoritative gemological volumes, without losing the fascination of a tale well told — the dramatic tale of gemstones and jewelry in Roman History. The book includes a modernized version of Philomen Holland's translation of the 37th book of *The History of the World,* written by C. Plinius the Elder in the first century.

Surviving is a daughter, Mary Virginia Ball. His wife, Mary Ainslie Ball, died in 1945.

Kokichi Mikimoto
Cultured Pearl Czar

by

WILLIAM F. FOSHAG, Ph.D.

Curator of Geology

U. S. National Museum, Washington, D.C.

Kokichi Mikimoto was born in Toba, Mie Prefecture, Japan, in 1858. Toba is a village near Ago Bay, an area well known from ancient times for its pearl fisheries. Mikimoto's family was engaged in the preparation and sale of macaroni. Mikimoto as a youth, however, was of an enterprising nature and traveled to Tokyo and other large cities selling pearls and other sea products of the Ago region.

At the national Exposition in Tokyo in 1890 Mikimoto exhibited a collection of natural pearls from Ago Bay. Among the members of the jury of awards was Dr. Kakichi Mitsurkuri, a well known Japanese biologist, who showed to Mr. Mikimoto a Chinese fresh water mussel shell with Buddha images coated with nacre on the inside of the shell, and suggested that similar growths could be grown in Japanese oysters. Mikimoto was much impressed by this suggestion and soon after began his experiments in pearl culture at Ago Bay. Using the old Chinese system of introducing a foreign body within the pearl oyster shell, he soon succeeded in producing half pearls attached to the shell and obtained a patent from the Japanese government for his process in 1896.

In 1908 Mikimoto obtained a Japanese patent for a method of producing completely round pearls. In 1916 Tokichi Nishikawa, a son-in-law of Mikimoto, obtained several Japanese patents for somewhat similar processes. Mikimoto's process involved completely surrounding the nucleus with epithelium tissue. Nishikawa simplified the process by using no more than a small piece of epithelium in contact with the nucleus. It is possible that Nishikawa's experiments were stimulated by the researches of F. Alverdes in Germany, in 1913, who induced pearl formation in *unios* by the introduction of a small nucleus and some epithelium cells into the body of the animal. It was, however, largely to Mikimoto's endeavors that pearl culture was brought to a high stage of commercial development.

The important production of round pearls began about 1920 and reached a maximum of 30 million oysters under cultivation in 1936-37.

Today, Kokichi Mikimoto, at 91 years of age, continues in active charge of his fisheries. Although others are similarly engaged in pearl culture, Mikimoto remains the dominant figure in the industry.

Contributions In This Issue

GEORGE TUNELL, Ph.D. (Harvard, 1930) is Associate Editor of the *American Mineralogist* and Associate Professor of Geology at the University of California in Los Angeles. In 1934 and 1937 he was sent to Europe by Carnegie Institution of Washington to visit a number of mineralogical laboratories and field localities. His travels took him to Norway, Sweden, Finland, Russia, Poland, and Germany. In Russia he met Miss Grum-Grzhimailo, visited her laboratory, and saw the work she was doing. Since no comparable work has been done in this country, he translated the paper appearing herein. He holds memberships in most important mineralogical and geological societies here and abroad.

HENRY EDWARD KRAUS, Ph.D (Munich, 1901), Dean Emeritus of the College of Literature, Science and Arts, University of Michigan, has been president of the Gemological Institute of America since 1947. In 1943 he became one of its first Honorary Members. He has long been recognized internationally as an authority in the field of crystallography and precious stones and his paper in this issue will be of interest to all readers. He is the author of a number of mineralogical books, the latest being *Gems and Gem Materials,* now in its 5th edition. In 1945 he was awarded the Roebling Medal by the Mineralogical Society of America, of which he was one of the founders.

A. K. SEEMANN (Colorado School of Mines, 1922), The Linde Air Products Company, has recently devoted most of his time and efforts to the development and production of Linde Synthetic Crystals. His previous experience included the introduction of two new oxy-acetylene processes to the metal industry and flame hardening and pressure welding. He has been associated with The Linde Air Products Company since 1925 and is currently Manager of the company's Synthetic Crystals Division. His article on Synthetics in this issue should be of extreme interest to our readers.

IVAN M. H. de MAGNEE, Ph.D.. was born in Hasselt, Belgium. He received all his higher education at the University of Liege and spent the following six years there as assistant. From 1936 to 1942 he lectured on Economic Geology at the University of Brussels; from 1942 to the present time he served that university as Professor of Economic Geology, Geophysical Prospecting, Ore-Dressing. He was founder and director of the "Centre belge d'etudes de Prospection Geophysique" (1942-1949). In 1938 he received his title of Advanced Fellow of the Belgian-American Foundation (Colorado School of Mines and travel). He has made numerous scientific missions and professional studies in Western Europe, Belgian Congo, United States, Canada, Iran, and Venezuela. His report of the kimberlite find in the Congo appears in English for the first time.