Vol. VI No. 3 July, 1957

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C. 2

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

(Originally founded in 1908 as the Education Committee of the National Association of Goldsmiths, reconstituted in 1931 as the Gemmological Association)

THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. VI No. 3 JULY 1957

RUBY AND SAPPHIRE

by ROBERT WEBSTER, F.G.A.

IT is often difficult for the uninitiated to realize that ruby, with its red colour, and the blue sapphire are one and the same mineral—corundum, and that an impure form of the same mineral is abrasive emery. Both ruby and sapphire have been coveted as gems over the centuries, even when fine quality specimens were more plentiful than they are to-day.

Legend

The legend and lore of ruby and sapphire are quaint. The lucky owner of a fine ruby was said to be assured of a life lived in peace and concord with all men—neither his land nor his rank would be taken from him, and his house and garden would be saved from damage by tempests.

Ruby has been claimed to be the most precious of the twelve stones God created when he created all creatures, and this " Lord of Gems " was placed on Aaron's neck by Christ's command. The high esteem placed on ruby is further indicated by the names applied to ruby in Sanskrit. These were *ratnaraj*, which may be translated as " King of Precious Stones " and *ratnanâyaka*—" Leader of Precious Stones." The Hindoo peoples described the glowing hue of the ruby as an inextinguishable fire which burned within the stone, and asserted that this inner fire could not be hidden and would shine through the clothing or through any material wrapped round the stone. If placed in water the inner heat was communicated to it causing the liquid to boil.

Ruby was said to preserve the mental and bodily health of the wearer, for it removed evil thoughts, and, although considered to be associated with passion, it was also thought to control amorous desires, to dispel pestilential vapours and to reconcile disputes.

Some Indian beliefs were that he who made offerings of rubies to the images or gods in the worship of Krishna would be reborn as a powerful emperor ; or if with a small ruby he would be reborn a king. Rubies, and other red stones whose colour suggests that of blood, were thought to be a remedy for haemorrhage and inflammatory diseases. Such stones were believed to confer invulnerability from wounds, but the Burmese said that it was not alone sufficient to wear the stones, but that they must be inserted into the flesh and thus become, so to speak, part of the wearer's body. Those who in this way bear a ruby about with them believe they cannot be wounded by spear, sword or gun. Ruby is the natal stone for the month of July.

The gem of the soul, and of autumn, sapphire, the natal stone for September, was said to preserve the wearer from envy and to attract divine favour. Fraud was banished from its presence and necromancers honoured it more than any other stone, for it enabled them to hear and understand the obscurest oracles. The ancients thought sapphire to be endowed with the power to influence spirits, to be a charm against unchastity and capable of making peace between foes and protecting its owner against captivity. The Sinhalese respect the star-sapphire as protection against witchcraft.

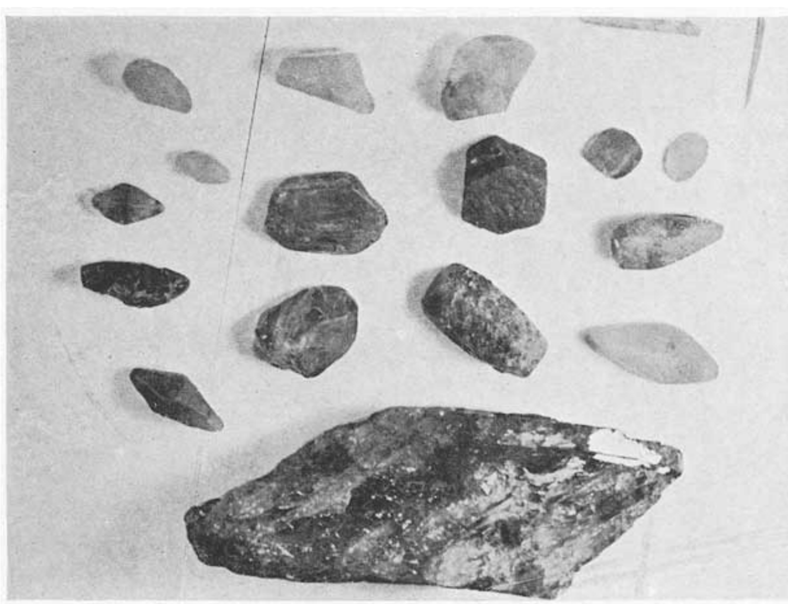
Tradition is that the law given to Moses on the Mount was engraved on tablets of sapphire, but from Pliny's description the tablets were more probably made from the stone we now know as lapis-lazuli. The religious significance of sapphire was further enhanced in the 12th century, when the Bishop of Rennes lavished encomiums upon the sapphire and began the use of this stone in ecclesiastical rings.

The names ruby and sapphire mean red and blue respectively; the first is derived from the Latin *ruber* and the second from *sapphirus*, the latter being derived from a Greek word of similar spelling. Similar words are found in Persian and Hebrew, and the primary derivation, though uncertain, may have been Sanskrit.

Properties

The mineral corundum, of which ruby and sapphire are the most highly prized varieties, is simply a crystallized form of aluminium oxide (Al_2O_3), and if pure is colourless. Like so many other things in nature a very small trace of impurity will alter a comparatively uninteresting material to one of striking beauty and increased value. A small trace of chromic oxide is the cause of the blood-red colour of perfection ruby, and the oxides of titanium and iron give to corundum the rich blue which alone can be seen in the lovely sapphire.

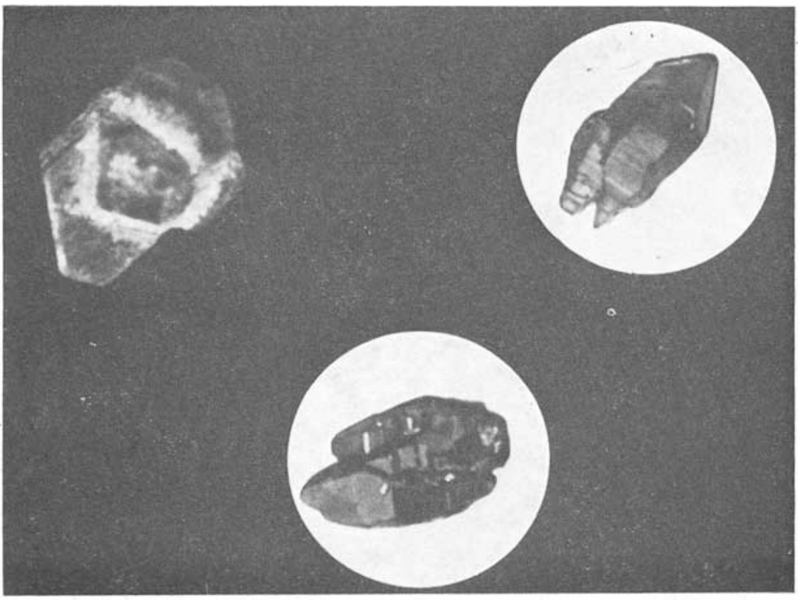
Corundum crystallizes in the rhombohedral division of the hexagonal system of crystal architecture, but the habit varies greatly, not only by locality, but by variety, ruby crystals usually showing



Group of corundum crystals.

a different habit from that of sapphire. Ruby from Burma usually takes the form of a hexagonal prism terminated at both ends by a basal plane at right angles to the faces of the prism, with more or less well-developed rhombohedral faces at alternate corners. These rhombohedral faces may be partly or entirely absent, specially in the large, and usually opaque, crystals from Tanganyika and Madagascar. In many crystals the prisms are very much flattened and although they may be of large diameter, are relatively thin, and such crystals often present a stepped or platy appearance, as though the crystal were composed of a number of thin plates, each a little smaller in certain directions, superimposed on each other. The basal planes of many of the crystals are traversed in three directions by fine parallel striations, which take the form of hair-like lines crossing each other at an angle of 120° and dividing the area up into small equilateral triangles.

Sapphire, and in some cases ruby, usually takes the form of a hexagonal bipyramid of twelve triangular faces, six above and six below, meeting at a girdle. This general habit may occur in



Corundum crystals.
Top left, ruby from Tanganyika. Top right and centre, sapphire from Ceylon.

different combinations of three bipyramids of different inclinations, with sometimes the girdle formed by a narrow hexagonal prism, and the ends of the crystal are often capped by the flat basal face. These forms are aptly described as having a " barrel-shaped " habit. The hexagonal bipyramid habit is common in the sapphire from Ceylon, and in this form the faces are often deeply striated horizontally, due to repeated oscillation between different pyramids. The sapphires from Montana on the other hand tend to take a rhombohedral and tabular habit.

Ruby may vary from the very palest shade of pink, through all shades of red to a very deep crimson, sometimes known in the gem trade as " black." The sapphire may likewise vary from nearly colourless through all shades of blue to a very dark indigo which to the eye appears black. Gem corundum may, indeed, have any colour, such as violet, green, brown, yellow and colourless, which, however, in natural stones is never completely water-white. The pink corundum may be considered as a pale ruby, but there is a decided difference in tint between a pink sapphire—all coloured corundums other than blue and red being termed sapphire with the colour as prefix—and a pale ruby, and this difference the experienced eye can detect. An attractive, although somewhat rare, shade in corundum, is an orange-red colour from Ceylon. This stone has been called *padparadscha* from the Sinhalese word meaning lotus colour, though some authorities contend that there is no need for such a term.

The trace of chromium oxide (Cr_2O_3), which causes the colour of ruby, enters the crystal lattice as a small scale isomorphous replacement. The amount, about 0·4% of chromium oxide, determines the depth of colour, but the presence of iron in the ferric state also modifies the tint, giving to Siam rubies that brownish tinge which is so typical of stones from Thailand. The most highly prized shade of colour for ruby is the so-called " pigeon's blood," a red slightly inclining to purple. There seems little doubt that titanium oxide and iron oxide are the cause of the blue colour in sapphire, although it is considered by some authorities that a trace of chromic oxide can take part in the coloration. This theory gains some credence because a greenish-blue glass can be obtained by the use of the oxides of chromium and iron. There is some reason for assuming that two types of coloration may be encountered in blue sapphire, for some blue sapphires lose colour on heating and some do not. Titanium and iron are known to be present in sapphire in the form of ilmenite ($TiFeO_3$), and this compound is not isomorphous with alumina, and the ultra-microscope has revealed that the colouring agents are in the form of colloidal particles. This also provides an explanation of the irregular distribution of colour in sapphire. The production of a blue colour in synthetic sapphire by the addition of the oxides of iron and titanium gives added confirmation of the Fe/Ti coloration. There is, however, an added complexity in that the synthetic blue sapphire shows no iron band in its absorption spectrum. Iron is included in the powder used to make sapphire but it tends to volatilize in the heat of the oxy-hydrogen blowpipe flame. The part that iron plays in the coloration is therefore not clearly defined, and, further, benitoite, a barium titano-silicate, a mineral which has a colour so like sapphire, appears to have the coloration due to titania alone, for analyses (by Blasdale) give no iron, and absence of iron is further indicated by the typical fluorescence shown by benitoite under short-wave ultra-violet light.

The density of the purest corundum, that is the colourless sapphire synthetically produced, is 3·989, and the refractive indices for such pure material are ω 1·7687 and ε 1·7606, giving a birefringence of 0·0081 which is negative in sign. The density of ruby and sapphire approximates to 3·997 and there is little variation for specimens of different localities, although the iron-rich types from Australia may go up to about 4·00. The refractive indices do not vary much from the values given for the pure material—slightly higher in most cases—but only in the iron-rich green sapphires do the values reach as high as 1·77-1·78. The hardness of corundum is 9 on Mohs's scale and is the standard for this number. The lustre is vitreous to nearly adamantine and the velvety lustre of perfection sapphires is said to be due to the colloidal nature of the colouring.

The fracture of corundum is conchoidal to uneven and stones need to be handled with some care for they are brittle and if dropped on to a hard surface or given a sharp blow tend to develop internal flaws and cracks. There is no true cleavage in corundum, but there is a false cleavage, or parting, parallel to the basal plane, and two less distinct partings parallel to the prism and rhombohedral faces.

Some authorities contend that these partings are really true cleavages, and other theories are that they are due to pressure and lamellar twinning on these faces, or to weakness caused by incipient decomposition along these planes.

The dispersion of ruby and sapphire is only 0·018, between the B and G lines, hence corundums have little " fire," the beauty of the stones being in their colour nuances only. The dichroism is moderate in most coloured corundums, except in the yellow stones where it is rarely seen. The most attractive colour in both ruby and sapphire is that of the ordinary ray. These are a deep blue colour in sapphires and a deep purplish-red in ruby. In order that a stone may show the best colour it is necessary for the stone to be cut with the table facet at right angles to the vertical crystal axis.

The absorption spectrum of ruby is characterized by fine lines in the red, the strongest being a close doublet with wavelengths at 6942 and 6928Å. Other weaker lines are at 6680 and 6592Å which are more in the orange part of the spectrum. There is a broad absorption band which cuts out the yellow and green light, and another band cuts out the violet end. Therefore the blue light is transmitted and in this " window " there are three narrow lines, a close doublet with wavelengths of 4765 and 4750Å and another line at 4685Å. The doublet in the red, with a mean of 6935Å, is characterized by its reversibility, for under certain conditions it will show as a bright line. This fluorescence line, as it is called—and indeed the fluorescent effects of ruby are due to it—is best seen when light is scattered from the surface, and this is spectacularly seen if a flask of saturated copper sulphate solution be placed in front of the incident light. Then the bright lines are well seen on a black background. This fluorescence line indicates that the chromium, which is the cause of the absorption spectrum, is incorporated in the crystal lattice.

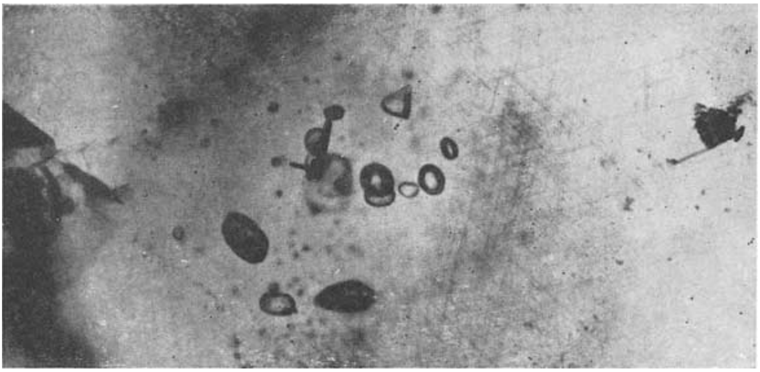
The absorption spectrum of sapphire shows bands due to iron in the ferric state, and the spectrum shows considerable difference in intensity with a decrease of iron content. In the iron-rich green, greenish-blue and greenish-yellow stones there are three evenly spaced absorption bands in the blue region. These are centred at 4710, 4600 and 4500Å, of which the 4500Å band is the strongest and most persistent. This 4500Å band is sometimes so wide that it merges with the 4600Å band giving a two band aspect to the spectrum. With decrease of iron content these bands, usually known as the 4500 complex, decrease in intensity until in the case of the rich blue sapphires only the 4500Å line may be seen and that often only with difficulty, even with the aid of the copper sulphate filter before the light source, which filters out the brighter light from the longer wave end of the spectrum. Many Ceylon sapphires show the bright red fluorescent line at 6935Å, due to a trace of ruby, and the 4500Å sapphire line is only seen in them with great difficulty.

The other colours of sapphire have an absorption spectrum reminiscent of the colour nearest to it, such as the pink and violet sapphires which show the spectrum of ruby, although the lines in the blue may be much weaker. Colourless and brown sapphires do not exhibit an absorption spectrum which can be observed in the spectroscope. Unlike stones from other localities, the yellow sapphires from Ceylon do not show the 4500Å complex, iron apparently not being the colouring agent in this case. The absence of iron is borne out by the unusual fluorescence shown by this variety of sapphire. In one case only, that of an orange-red stone from Burma, has a line at 4750Å been seen. This line, which is attributed to vanadium, is diagnostic for the synthetic sapphire coloured to imitate the alexandrite.

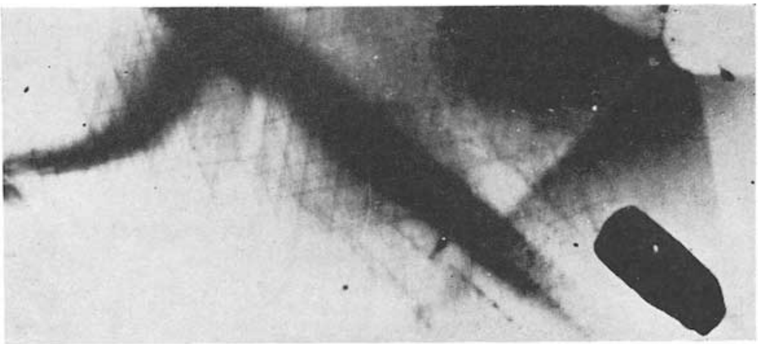
The luminescence of the chromium-coloured corundums, ruby, pink and violet sapphires, shows when bombarded with long- or short-wave ultra-violet radiations, or X-rays, a strong crimson light. This is due to excitation of the chromium ion, the glow being due mainly to the intense emission from the doublet at 6935A. This red glow can be seen spectacularly when viewed between " crossed filters "—that is, by placing the stone in a beam of blue light which has been passed by a copper sulphate filter and viewing the stone through a filter which passes only the red rays. The stone then appears glowing red on a black background. This is because blue light will also excite the chromium ion. If this fluorescence light be examined with a spectroscope the bright lines are the same as seen in the absorption spectrum. This discrete spectrum only occurs when electronic shifts, to which the luminescence is due, are sufficiently screened by an outer electron shell so as not to be too greatly interfered with by the surrounding atomic field. This effect appears to occur only with chromium, rare earths, and diamond ; in the latter case, however, the mechanism is somewhat different. When rubies are viewed through the Chelsea colour filter this fluorescent red may be seen and this is a convenient method to adopt when picking out rubies from a mixed parcel of rubies and garnets, the latter not fluorescing.

The fluorescence of ruby has been suggested as a test for distinguishing between rubies from Burma and those from Siam—and for distinguishing synthetic stones from natural rubies. Experiment has shown that it is impossible to pick out the synthetics with any degree of certainty from a mixed parcel of synthetic and Burma stones. Owing to the damping of the fluorescence by iron content, rubies from Siam show a much weaker fluorescent glow than those from Burma, which glow brightly. This effect has been suggested, and used, as a distinction between the two sources of ruby. While this usually operates in typical cases it is apt to fail in precisely those cases where it is most needed, such as in the case of a deep-coloured Burma ruby and an exceptionally fine Siam stone. It should be mentioned at this stage that the gem trade refers as Burma rubies to stones of a typical red colour, and as Siam rubies to all those stones which are darker, or show a slight brownish or violet tinge, and do not approach the " ideal " red. Ceylon rubies to the trade are those lighter coloured rubies approaching the pink sapphire. True localities may not necessarily be meant, although the designation may be correct in eighty per cent of the cases.

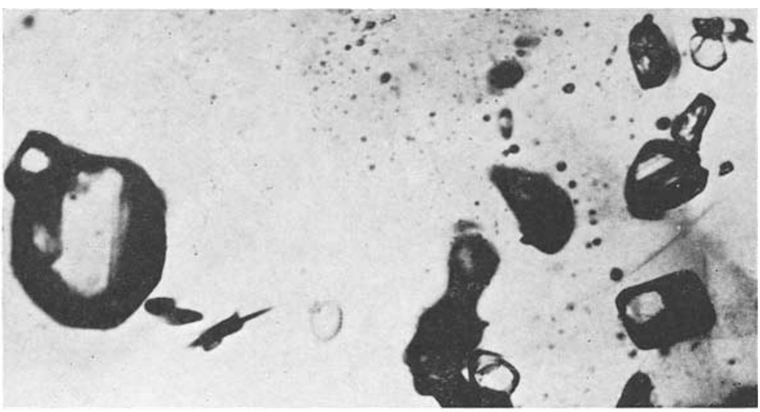
In the case of the blue sapphires the luminescent glow is practically non-existent. An exception, however, is the Ceylon sapphires which contain a trace of chromium. These show a red or orange glow under long-wave ultra-violet light. Under short-wave ultra-violet light some blue sapphires show a weak blue glow, an interesting observation in view of the bright blue glow shown by the titanium mineral—benitoite—under the short-wave lamp, while it is practically inert under the long-wave rays. Most sapphires are inert under X-rays, except the Ceylon, Montana and some Indian (Kashmir) stones which may show a dull red or yellowish-orange glow. It has been reported that under bombardment by cathode rays (fast moving electrons) Kashmir sapphires show a greenish-blue glow, Burma stones a strong dark purple, Siam stones a weak dull red, and sapphires from Ceylon a vivid red fluorescence,



Inclusions and silk in a Burma ruby.



Large crystal and silk in a Burma ruby.



Inclusions in a Burma ruby.

The iron-rich green and yellow sapphires show no luminescence under any of the aforementioned radiations, but the yellow stones from Ceylon show a strong apricot-yellow glow under ultra-violet light and X-rays. The cause of this particular luminescence does not appear to be known. Such stones when bombarded by X-rays turn to a rich topaz-colour, however weakly yellow they were originally. This colour is not permanent for the colour reverts on exposure to about 3½ hours sunlight or quickly when the stone is heated to a temperature of about 230°C. Colourless sapphires may also suffer this change of hue by X-ray bombardment, but the shade of yellow attained is usually lighter ; and further some blue sapphires will change to a dirty amber colour.

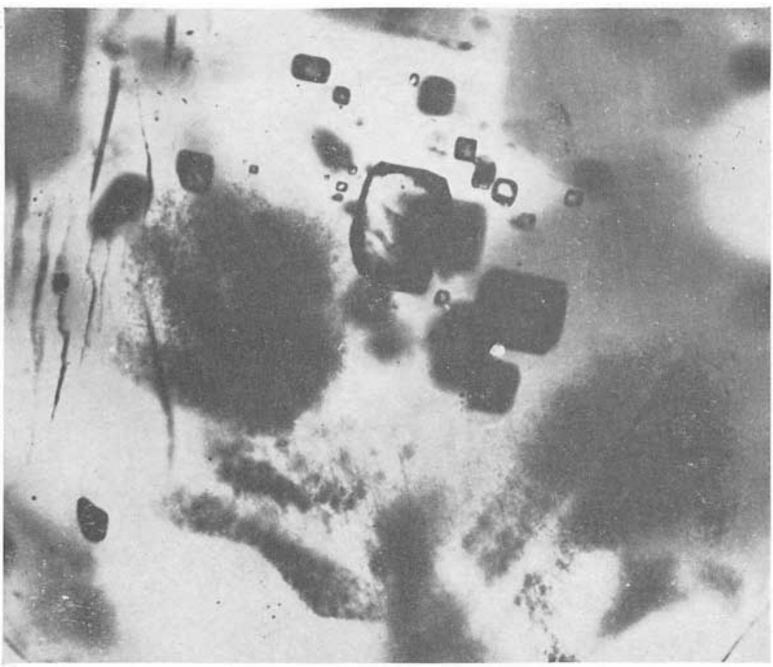
Much work has been carried out, particularly by E. Gübelin in Switzerland, on the nature of the inclusions in corundum, with a view to identifying the locality from which the stone emanates. It is the writer's opinion that while in some cases the evidence so obtained is sufficient to give an indication, in many cases there are insufficient grounds to formulate a satisfactory conclusion, and, apart from other factors, this is the primary reason why most gem-testing laboratories refuse to certify the locality of a stone.

Burma stones, especially rubies, show a system of short rutile needles arranged in three directions parallel to the faces of the hexagonal prism, that is crossing each other at angles of 60° and 120°, and these lie in planes at right angles to the principal axis of the crystal. To these needles, which may in some cases have decomposed leaving canal-like cavities, is due the shimmering whitish sheen popularly known as " silk." Stones from Burma may show included well-formed crystals of rutile, octahedra of spinel and mica platelets. Rounded crystals of corundum, zircon and garnet make up the general picture of corundums from this source. The rich bright red colour of Burma rubies is often to be seen in swirls, rather like the effect seen when treacle is stirred, hence this colour swirling is sometimes known as " treacle."

Siam stones usually show " feathers " consisting of large loop-like systems of a reticulation of fine canals which often enclose swarms of hexagonal shaped " slabs." Quite commonly these " feather " systems contain a conspicuous black inclusion. Siam stones often contain tubes or tube-like liquid inclusions in cross-joined parallel arrangement producing a script-like design. Other common features are flat cavities of brownish colour and twin planes, the latter often in two sets at approximately right angles producing a checkered design. These are more pronounced when the stone is viewed between crossed nicols.

Corundums from Ceylon show rutile needles which are characterized by being longer and more widely spaced than in the stones from Burma. They often traverse the whole stone. Very characteristic of Ceylon stones are inclusions of zircon crystals, each of which is surrounded by a " halo " of brown colour due to stresses caused in the host mineral. The well-defined " feathers " seen in stones from this island consist of large networks of irregular liquid-filled cavities. Clearly defined colour-zoning is common in Ceylon stones.

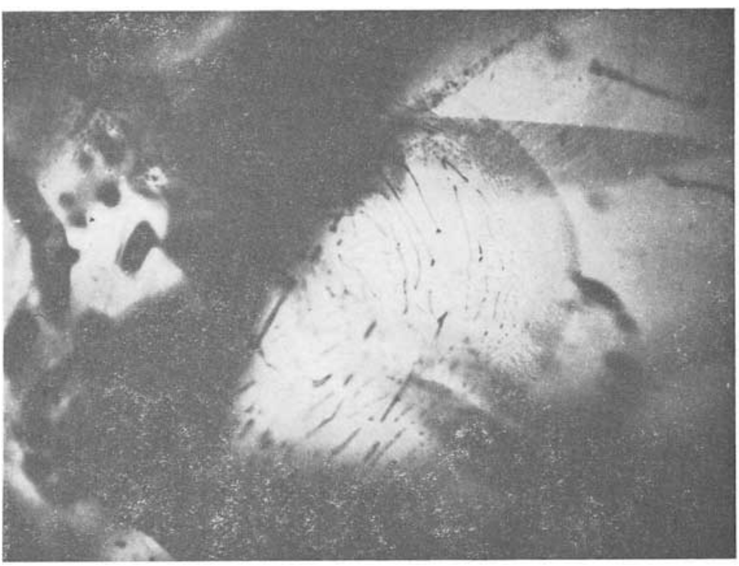
The sapphires from Kashmir owe their attractive milky or hazy appearance to a fine veil-like formation of hazy lines oriented at 120° to each other. The " feathers " in such stones usually



Zonal silk and large crystals in a Burma ruby.

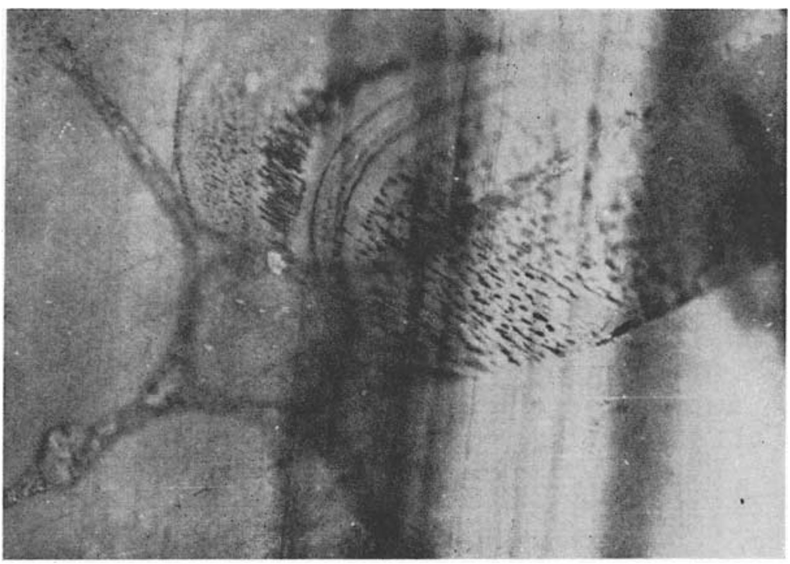
consist of thin films of yellow or brown colour with the edges terminated by an irregular system of liquid-filled canals. The stones from Montana, U.S.A., contain negative crystals surrounded by, or in near proximity to, extremely flat liquid films. Typical inclusions in such stones are long rods or tubes with projections making them appear rather like feather quills. The many accessory minerals seen in corundums from oriental localities do not appear in Montana stones. In Australian stones the " feathers " are liquid-filled cavities and dark flat cavities, and zonal structure is most pronounced.

Bound up with the internal features of corundums are the star-stones, or asterias, which to many have such a fascinating appeal. Much consideration has been given to the reasons for the production of the star-like effect seen in these attractive stones, and the theories have been summed-up, and added proof deduced by the work of Alice S. Tait. The " silk " which has been previously mentioned may so impregnate the stone that the tubes or fine needle-like crystals running in three directions parallel to each pair of prism faces completely fill the crystal. If a stone be cut in the



Feathers in a Ceylon sapphire.

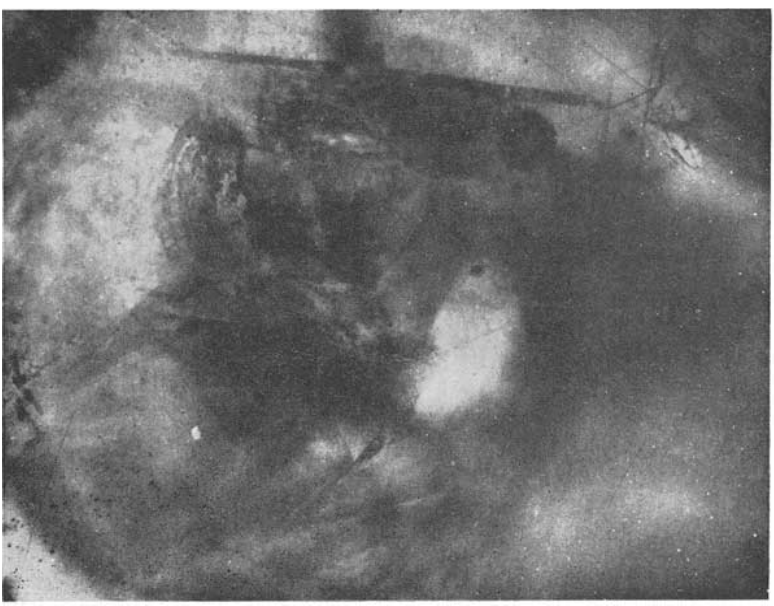
cabochon form from such material, so that the base of the cabochon is at right angles to the vertical crystal axis, that is parallel to the basal plane, three rays of white light cross the stone at right angles to the direction of the needles, thus producing a six-pointed star. This light is by reflection from the fibres and is termed epiasterism. If only one set of needles be present, as occasionally may happen, just one ray of light will be seen in a suitably cut stone, therefore under these conditions a corundum cat's-eye will be produced. Rarely, a six-rayed (12 pointed) star is seen in asteriated corundums. This effect is understood to be due to oriented needles not only conforming to the prism faces of the first order prism, but to the addition of a second set of three parallel to the faces of the second order prism which lie at 60° from those of the first order. Thus, there will be not only the three rays of light from the needles parallel to the first order prism faces, but a second set of three rays due to the needles parallel to the faces of the second order, thus producing a six-rayed, or twelve-pointed, star. Tait has found, from the shape of the needles and by spectroscopic examination of the material of the needles, that they are rutile crystals. It



Feather and zoned silk in a Burma ruby.

should be mentioned that in order to see the star effect (called *asterism*) to the best advantage, the stone should be viewed by light reflected from a single overhead light ; a room with a multiple number of lights destroys the effect. Star-stones may be of any colour, but the red-coloured material (star-ruby) is the most prized, and the fine blue (star-sapphire) next in value, but much depends upon the brightness and symmetry of the star and the body colour of the stone. Pink, violet and brown colours are common, but a stone with a nearly black body colour makes a most lovely asteria.

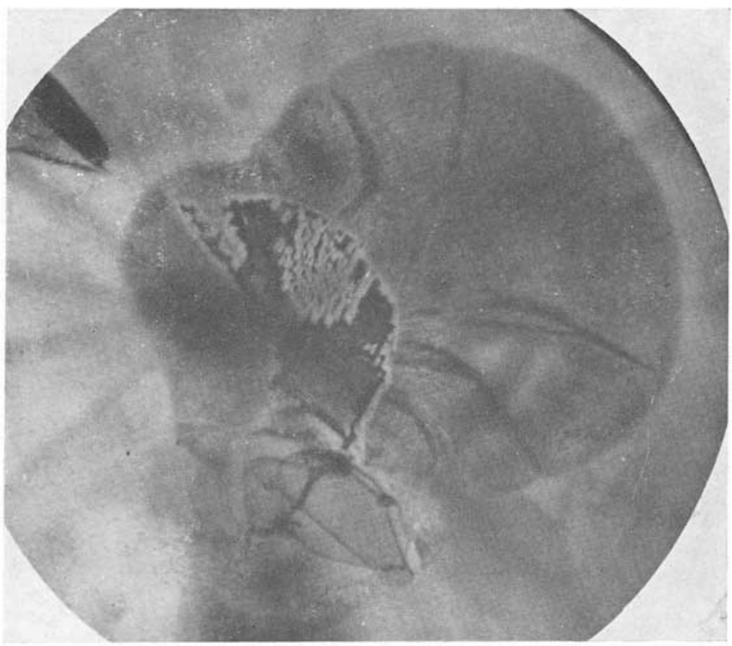
There are few true rubies with an individuality, and except for the Chhatrapati Manick so charmingly described by V. Clarke, the 43 carat " Peace ruby " a crystal found in 1919, another crystal, but not of true gem quality, the 167 carat Edwardes ruby in the British Museum (Natural History), and the 100 carat De Long star ruby in the American Museum of Natural History, there are no rubies to which names have been applied. The historical " Black Prince's ruby," which graces the front of the Imperial



Inclusions in a Siam ruby.

State Crown, and the "Timur ruby" which is also part of the Crown Jewels, are both red spinels.

Among sapphires there are a number of fine stones, among them the St. Edward's sapphire and the Stuart, or Charles II's sapphire, both of which are companions to the Black Prince's ruby in the Imperial State Crown. The American gem dealer, Harry Winston, has, or had, in his possession several lovely large sapphires, one the so-called Catherine the Great's sapphire and another gorgeous stone weighing 337·10 carats. In the American Museum of Natural History is a 536 carat star sapphire known as the Star of India and a smaller black star called the Midnight Star, weighing 116 carats. That sapphires can attain a large size is amply illustrated by the work of Norman Maness, who spent 1,800 hours carving a 2,302 carat sapphire into the form of the head of Abraham Lincoln.



Large feather in a sapphire.

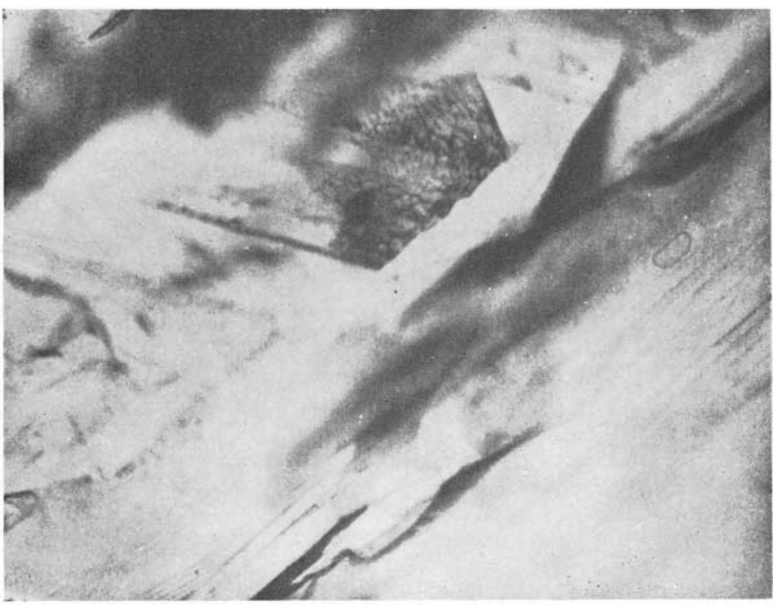
Burma

The most famous locality, and maybe the only locality for fine rubies, and much fine sapphire, is the district around Mogok in Upper Burma. This so-called Mogok Stone Tract is an area of some 400 square miles, but the area now being spasmodically worked is some 25 miles from the town of Mogok itself.

When the Burma ruby mines were first discovered is quite unknown. The earliest that is heard of them is in a Burmese legend of untold age, which relates of an inaccessible fever-stricken valley in the Chinese Country, into which human beings could not descend, but into which lumps of raw meat were flung from the surrounding hills, to be retrieved by the vultures, and from which the adhering rubies were picked off. This legend corresponds with the writings of Marco Polo (1254-1323), and he must have picked this up during his wanderings in Cathay (China). On this legend is based the story of " Sinbad the Sailor." A further proof of the great age of the mines is the comparative abundance of prehistoric implements both of stone and bronze age found amongst the detritus of the mining.

The first real record of the mines is that early Burmese history records that they were taken over from the Chinese in 1637, in exchange for Mong Mit (Momeit) and that mines were then in full operation in the valley. The country, covered with dense forest, was so notoriously unhealthy that there was a shortage of labour, and to alleviate this King Bodawgyi sent thousands of captives from Manipur to work in the mines. This was about 1780, and subsequently the place became the place of exile for those who had incurred the king's displeasure. Shortly afterwards the district was placed in charge of Governors or So-Thuygis (So's) who allowed mining on payment of a tax, with a stipulation that all stones mined of an individual value of two thousand rupees and over were the property of the king without payment. This went on for some years and the So's enriched themselves greatly by oppressing the miners and forcing them to sell their stones for little or nothing to themselves. As they held absolute powers of life and death, the So's were very well placed to terrorize the unfortunate miners. Things went from bad to worse, and the miners deserted their villages and left the district.

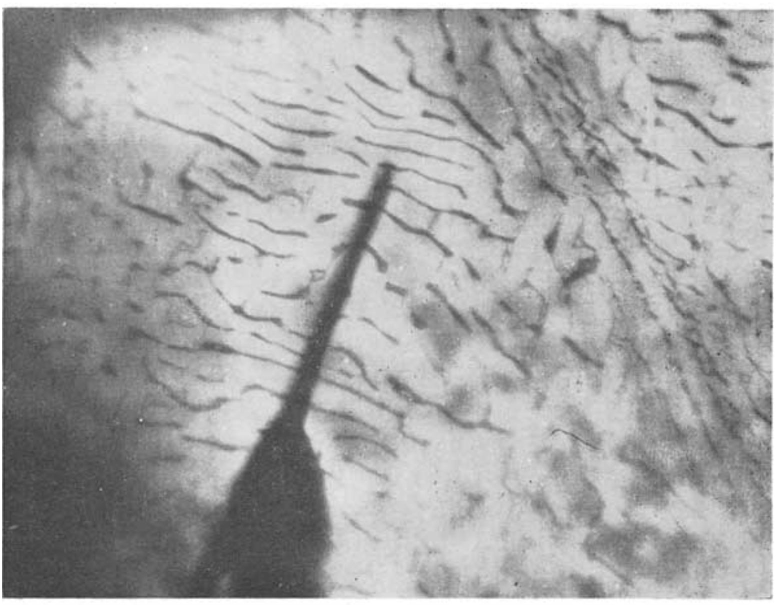
King Mindoon Min then took over the district and control of the mines but made such a bad job that in 1863 another Governor was appointed with the responsibility of collecting a tax of some £5,000 a year from the miners, to be paid directly to the king, beside what the So could collect for himself. Under this arrangement matters became much worse and a rebellion took place, the whole Stone Tract being beset by gangs of fierce robbers, and practically deserted by peaceful miners. As the king was getting no revenue he made mining free to everybody, and the miner had the right to sell all stones under 2,000 rupees in value—the king taking all stones above this value—to anyone within the Stone Tract, but not outside of it. All stones not sold in the Stone Tract had to be sent under seal to a central ruby mart in Mandalay. Here they were offered for sale, and if sold the purchaser paid 10% and the owner 5% on the price by way of tax. If no sale took place the owner paid 10% on the valuation and was then free to sell the stones anywhere. This restored prosperity for a time, but abuses again became apparent, mainly on account of the king's demand for more revenue, not only from the mines but from the Governors, which



Inclusions in a Siam ruby.

they obtained by again oppressing the miners and swindling the traders who came to the mines to buy. These demands for more money grew apace and in 1885 King Thebaw appointed a Governor whose business it was to find no less a sum than £16,000 per annum. This was the last straw, and the district again entered a state of chaos. The villages were raided daily by gangs of robbers forcing the villagers to go about in armed bands for self-protection. The road from Mogok to the river was infested with robbers, three local bandits establishing a convoy system down the road, demanding as much as ten rupees a head for a safe passage ; if travellers did not pay they were simply robbed or murdered. At this time King Thebaw was negotiating with a French syndicate for a lease of the mines, and this was one of the deciding factors which led to the annexation of Upper Burma by the British in 1886.

After the annexation, Streeter, the Bond Street jeweller, who was said to have been negotiating with Thebaw, obtained a concession from the British Government to work the mines. The



Liquid-filled feather in a Ceylon sapphire.

Burma Ruby Mines Limited was immediately floated and the issue was over-subscribed in a few minutes and double the amount, £300,000, could have been easily raised.

The British Government's annual rental for the mines was fixed at the tremendous sum of £30,000 plus 30% of any profits, in return for which the Company were to have the right to work any unoccupied land with the use of machinery. The native miners were to be allowed to continue working by purely native methods, on payment to the Company of 30% of the value of their declared finds. It was thus considered that the Company would have a monopoly of rubies and would be able to control the price of them. This was a mistaken idea as was soon evident ; for the native miner naturally concealed the greater part of his finds and produced absurdly small parcels for valuation. The smuggling of the concealed stones was a simple matter and quite impossible to check, and these stones coming on the market stopped any regulation of the price of rubies. Subsequently new arrangements were made whereby the native miner paid a fixed monthly fee of twenty rupees a month for each workman he employed. This fee went to the Government but was collected by the Company, who received 10% of the total for their services. The annual rent for the mines was reduced by 50%, and was subsequently abolished altogether in view of the open market created by the native miners selling their stones.

At the beginning the Company's engineers were confronted with a task of great magnitude. The ruby bearing alluvials were found to lie deep down under heavily water-logged valleys, and a considerable portion of the ruby-bearing ground was under the town of Mogok itself. This entailed purchasing the buildings and re-erecting the town on another site. Heavy machinery and pumping plant had to be brought for sixty miles over a rough mule-track through dense fever-stricken jungle infested with wild animals, from tiger to elephant, and passing over mountains five thousand feet high. It took over a year to make a road passable by very light bullock carts, which took three weeks to make the journey and could not travel at all for seven months of the year. Rinderpest was a scourge, and machinery lay abandoned on the roadside for months owing to lack of transport. These difficulties were eventually overcome and a good road constructed. At the mines a 400 kilowatt hydro-electric power station was opened, a low-level drainage tunnel constructed for a mile through a mountain range at a cost of £40,000 and five large washing mills, each dealing with some thousands of tons of earth per day, put into operation. Subsequently, three more mills were erected eight miles away near Kyatpyin, and the mines entered on a period of prosperity.

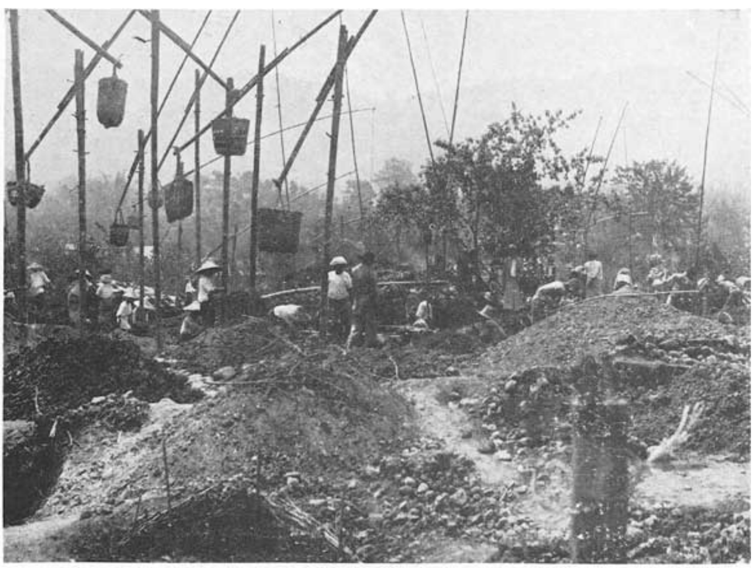
The mines were worked by the open-cast method, there being no underground working at all. The first process was to take all the earth from grass level to bedrock and truck it away to large washing mills by hand labour and rope haulages. This method was subsequently superseded by a system of washing the earth down by large jets of water (monitor jets) under high pressure and passing the earth through a series of sluice-boxes, to which it was elevated by large gravel pumps, which made a great saving in mining costs.

All went well with the mines and the Company was paying dividends until 1908, when the synthetic ruby was placed on the market, causing an immediate panic and making rubies difficult to sell. At the same time America was passing through a depression and the prices of fine rubies fell, while the depreciation in lower grades was much greater. It was the beginning of the end for the company, although all through the lean years of the First World War Burma Ruby Mines Limited struggled on. The company fought a losing fight until 1925, when it went into voluntary liquidation, only to struggle on further until 1931, when it finally surrendered its lease to the Government.

On the cessation of activities by the Burma Ruby Mines Limited the mining was carried on by native miners working by their primitive method. Up to the commencement of World War II these miners paid a monthly fee of ten rupees per workman to the Government, but for an enhanced fee were allowed to use water and explosives. In order to obtain a licence to mine in Burma it is necessary that one's name should be on a very arbitrary list of Registered Miners, but those on the list are often willing to lend their names to the less fortunate for a consideration. A licensee usually employs three workmen, who receive as payment 50% of the total profits of the mine for the month to share between them. Every market day they draw a very small advance for the purchase of food, and if the month's work shows a loss that amount is wiped out, and they receive no further payment. If the mine shows a profit this sum is deducted from the 50% of the total profits of the mine.

In the dry season these men mine by sinking a shaft on to the layer of *byon* (the name applied to the gem-bearing alluvial gravel) ; if there is little or no subsoil water these pits are merely small round holes just large enough to allow a man to descend into them. They are sunk very rapidly and contain no timbering. The pits are called *twinlon* and are usually from twenty to forty feet deep. After this depth they are often unsafe, but in very favourable ground may go down to one hundred feet. At this depth a second shaft is sunk parallel to the first, and is connected with it by openings at intervals for the purposes of ventilation.

One workman simply squats at the bottom of the shaft and loosens the earth with a tiny spade, and then presses it into a small bamboo basket with his hands. This basket is hauled to the surface by the second workman by means of a balance crane constructed of three bamboos, and a basket of heavy stones, or other weight



Twinlon workings, Mogok Stone Tract.

known as a *maungdaing*. Light is reflected to the workman below by means of a piece of tin set at an angle above the hole. Until the *byon* is reached the earth removed is thrown away, after which side tunnels are driven by two workmen along the *byon* in every direction for about forty feet. Every scrap of *byon* is carefully removed from the entire area. The tunnels are allowed to fall in when finished with, but are consolidated so as to provide support for the top whilst the other galleries are being driven.

If the ground contains water a *twinlon* would not stand so a square pit known as *lebin* is put down. This has sides two foot each way and is lightly timbered with brushwood and leaves held in place by thin sticks to keep the wet earth in place. Such pits may go down for over two hundred feet. Larger pits with sides of four and a half feet are known as *kobin*, while still larger ones with sides of twenty to thirty feet are known as *imbye*. These large heavily timbered pits need a number of men to operate them and are expensive to work.

Water is removed from the wet pits by bailing with fuel-oil cans tied to the *maungdaing* or by the use of an ingenious bamboo

Washing the byon, Mogok Stone Tract.

pump, which is best explained by reference to the illustration. Effective down to a depth of twenty feet, the pumps are arranged in relays for greater depths.

In the rainy season when the pits cannot be worked the hillside deposits are tackled. The miner makes a cutting into the hillside washing the loose earth away by means of sprays of water falling from bamboo pipes placed at a height above the working. The light earth is allowed to wash away to waste while the heavier sands and gravels are led away to narrow water courses, where the heavier portion, containing the gems, is trapped in holes made in the channels and is sorted by hand. This method of mining is known as *hmyawdwin* and may be of any size from an insignificant cut to an enormous opening. The water to work the mines is often brought from long distances by channels cut in the rock, and even through tunnels, being carried over valleys on high bamboo aqueducts in bamboo mats luted with clay.

The deposits in the interior of the hills are contained in the cracks and crevices in the rocks, which often open out into large caverns of great beauty. These caverns are reached by long tortuous passages, so small that a man can scarcely worm his way along them, and such mines are called *loodwins* or *loos*. Some of the finest stones are found in such *loos*.

The local streams are worked for the gems by rudely damming them with logs and brush wood and the gravel held up by this being dredged out by hand and small baskets. The return from this source is usually poor.

The *byon* removed from the mines is placed in a pear-shaped washing place called a *yebangwet* and is then broken up with water by men using hoses. The slurry formed is allowed to fall into a channel from the narrow end of the *yebangwet* where the heavy gravels are trapped in a series of holes dug in the floor of the channel. This heavy concentrate is removed and more highly concentrated by hand in small round bamboo trays. This residue is then sorted by hand for the gems.

In all the streams poor women armed with round bamboo trays may be seen scraping up the gravel from the bed, and sorting it for rubies. This is a hereditary right for women only and is known as *kanase*. It is free of all fee and licence and the women must not be interfered with. Usually their finds are small.

What goes on in Burma to-day is to some extent conjecture, for the Mogok Stone Tract became part of the battleground of the 14th army and the Japanese invader. Burma is now no longer a British possession and it is not known what fine sapphires and rubies now emanate from Burma.

The Burmese ruby occurs embedded in a mother rock of white dolomitic granular limestone, or marble. This is a common rock of the district and is said to be originally a sedimentary limestone, which has suffered metamorphism by contact with intrusions of igneous rock causing the calcium carbonate to recrystallize out as marble, and its contained impurities to crystallize out as other minerals including corundum. The sapphire from the Burmese locality is, however, not found *in situ* in the marble, but in a feldspathic rock. It is in the alluvial deposits derived from the weathering of the parent rocks that the gem corundums are mostly found ; this is the *byon*. Rubies predominate around Mogok, whilst sapphires are more common at a site some eight miles away, near the village of Kathe, which is some 100 feet higher than the Mogok valley. At Bernardmyo, at an elevation of some 300 feet above Mogok, rather dark-coloured stones are found in a hard black iron-cemented conglomerate.

Siam

The next most important occurrence for rubies and sapphires is Siam, where the rubies are rather a brownish-red and somewhat dark in colour, while the sapphires are of excellent quality. The main occurrence covers a considerable area in the neighbourhood of Chantabun, where rubies predominate, and Battambang, important for sapphires, and the deposits spread over the border at Phailin in Cambodia. The stones are found in a coarse yellow or brown sand, overlaying a bed of clay or basaltic rock. The beds are mostly within six to eight feet or less from the surface, but some of the mines are over twenty feet deep. The Siam deposits have only been worked to any extent in comparatively modern times and at one period were worked under a concession by an English company. The mining is by native methods and the miners are mostly Burmese.

Kashmir

Sapphires of a magnificent colour, possessing a fine milky lustre, often of a fine cornflower-blue with a slight milky appearance, are found in the Zanskar district of Kashmir. The mines are near the village of Soomjam (Sumsan) in the Pader District. The deposits were said to have been first discovered by an avalanche laying them bare in 1881, but there is reason to believe that the local inhabitants knew of them much earlier. The deposits lie in a small valley about half a mile long by a quarter wide in the Kanskar Range of the north-western Himalayas. The valley, on a tributary of the Chenab, lies approximately midway between Srinagar and Jammu at an elevation of 14,950 feet, and except for a few months of the year is under deep snow. The stones occur in a pegmatite vein in association with tourmaline, garnet, kyanite and euclase. The pegmatite veins penetrate lenses of actinolite-tremolite rock in crystalline limestone ; the sapphires are often found in pockets of kaolin derived from the pegmatite. When first discovered the sapphires were extracted from the face of a precipice at the head of the valley, and it was not until some years afterwards that the whole floor of the valley was found to be covered with a thin layer of white pegmatite overlain by a few feet of ordinary earth which carried sapphires in immense quantities. Mainly due to the severity of the climatic conditions the work was carried on in a desultory way until 1924, when the mines were re-opened after the deposits came under the notice of the Kashmir Mineral Survey. The crystals are well-formed and often of large size when found in the rock, but the stones found in the valley are water-worn and rarely show crystal form. The crystals are said frequently to enclose green tourmaline. Cut stones, which make excellent night stones, often contain " silk," and according to some reports also contain inclusions of green mica. Little is known of the mining methods. The mining must be primitive, for the stones are picked out by hand, a very crude form of ground sluice being used.

Ceylon

In the south-west part of the island of Ceylon are found corundums of many colours—blues (usually rather pale), violet, yellow, white, green and pink, which often attains a quality comparable, to that of ruby and is, if a rich enough rose-red, called a Ceylon ruby. Star-stones, too, are plentiful in this island but as a rule have not a colour which can be said to be fine. Pit-mining is carried on in Ceylon in a similar manner to the Burmese system. The miner searches for the small and scattered localities by observing the surface for signs of rolled pebbles. These localities are often in the rice paddies, and having found what he hopes will be a good spot, the miner sinks a pit which goes down, maybe, fifty feet to reach the gem-bearing strata known as *illam*, which is a blue and yellow mud. Sometimes the gems are found embedded in boulders of semi-decomposed gneissic rock. If the miner is not successful with his first pit he must fill it in and start another somewhere else. If he strikes gem gravel, then it is brought to the surface and panned by the use of a finely woven basket. The gravel is washed by placing it in the bottom of the basket and being broken up by water, the light mud separating off through the fine meshes of the basket and the heavy concentrate sinking to the bottom. This is then searched for gems, which are subsequently sold by auction. Much of the gem material won from the *illam* is cut and polished by native craftsmen on the island. Squatting outside his cottage, or in a back alley, the cutter fashions the corundum gems on a small wooden wheel mounted at the end of a horizontal shaft which is rotated by a drawstring bow which he saws back and forth. For polishing, a chamois leather pad is fixed over the vertical lap, and the stone is usually held in the hand while being cut and polished. The Sinhalese cutter aims at getting the most weight out of a stone, so that the proportions are wrong by European standards, the base being overweight and often not symmetrical. Much blue sapphire from Ceylon is parti-coloured and the wily native cutters cut such stones with the blue colour at the bottom of the pavilion, so that by total internal reflection the stone when viewed from the top appears a good blue colour ; such stones looked at sideways are found to be colourless at the top and the patch of blue near the culet. Some blue sapphires from the island contain a trace of ruby (chromium) and although they are a good blue colour in daylight they tend to turn purple when seen in artificial light. In common with many stones of other species that are found in Ceylon the corundums from this locality often show as inclusions small crystals of zircon surrounded with circular dark areas where stresses from the zircon have affected the surrounding host mineral. These inclusions are usually known as " zircon haloes."

Australia

Corundum, mainly blue, green and yellow colours, but some ruby, is found in Queensland and New South Wales, Australia. The Queensland sapphire fields are located around Anakie and extend for some two hundred square miles. Ruby Vale is a prominent locality for Queensland corundum and at Willows, some 212 miles west of Rockhampton, a 28 pennyweight yellow sapphire was found in 1946. The Anakie deposits, discovered in 1870, are along the banks of creeks and not in the beds of the present streams, the stones being found in a clayey, or loose and friable, alluvium. Owing to the arid nature of the area, sluice-boxes are not often used and the mining is carried on by hand-picking and by the use of hand-sieves. The New South Wales deposits, which are centred around Inverell, west of the New England Range, lie in the north-east part of the state. The sapphires are found in an alluvial deposit of recent age, and here the mining is carried on by dredging and the sapphires reclaimed by the use of sluice-boxes and pulsators. Australian sapphires are usually rather dark blue and somewhat inky, the yellows are of an attractive greenish-yellow, and Australia produces probably the best of the green stones. The greenish tinge of the stones is due to iron, and this is shown by the strong 4500Å complex seen in the absorption spectrum, by the slightly higher constants and by the lack of luminescence when under a beam of ultra-violet light. Australian corundums usually show dark " feathers," but also show strong colour-zoning. Some sapphire is found, too, in the north east part of the island of Tasmania.

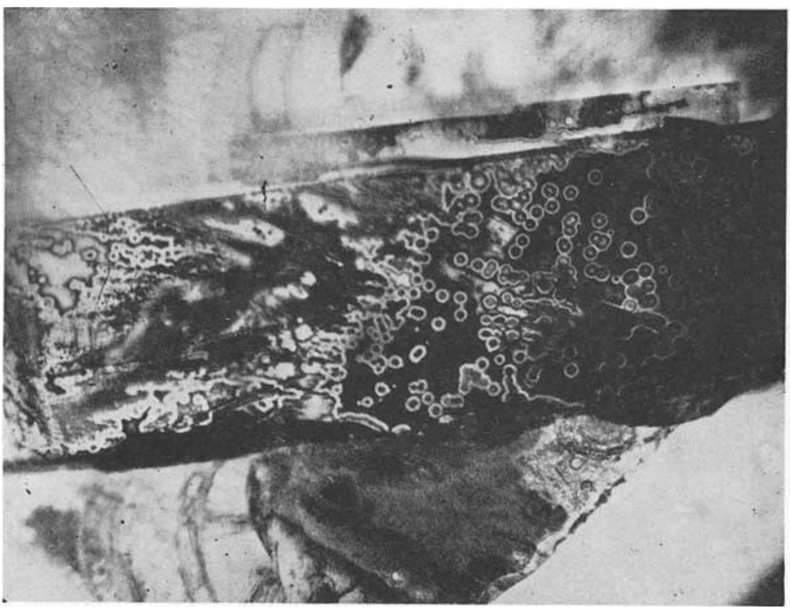
U.S.A.

The only important locality for gem corundum in the United States is in Montana, where it is found as water-worn pebbles in the gravel bars of the Missouri river, and at Yogo Gulch, near Utica, where flat gemmy crystals, pale in colour but with a curious metallic lustre, are found in nearly vertical and much weathered dark-coloured fine-grained igneous dykes. The crystals are small and only furnish stones suitable for calibre work, or for instrument jewels. The blue stones have a decided greenish tint and a bright metallic lustre ; ruby is not common, and the same may be said for star-stones. Montana sapphires make attractive night stones. Small rubies of fair quality have been found in Macon County, North

Carolina, the stones being found in the sands of Cowee Creek. Blue sapphire is said to occur in Colorado and Idaho.

Other Occurrences

Corundum is of wide-spread occurrence, but the above-mentioned occurrences are the important gem localities. There are a few minor sources of gem material which have little commercial significance. There is a small deposit of ruby at Jagdalak in Afghanistan, some thirty miles east of Kabul, and small corundums of various colours are found in the Somabula Forest in Southern Rhodesia. About 1952 a number of large ruby crystals of excellent colour but rather opaque were found by A. G. Clough in the Matabatu Mountains of the Northern Province of Tanganyika Territory. The short prismatic ruby crystals are found, sometimes as aggregates, in a bright apple-green zoisite rock. At the same period, possibly found in the local alluvium, were small water-worn pieces of ruby which were transparent enough to cut ; and some of these



Feather or flaw in a Burma ruby which has " boiled out " owing to overheating by a blowpipe flame.

stones were cut and, it is believed, marketed. These cut specimens were a rich colour, as good as much Burma material, but the stones were not so transparent and were extremely chrome-rich. Similar red crystals are found in Madagascar at Gogogogo, east of the Linta River in the south western part of the island. The matrix here is said to be a green mica schist. Sapphire is also reported to have been found in Madagascar. Gemmy corundum has been mentioned as occurring in Czechoslovakia, the U.S.S.R. (Ural Mountains), Rumania and Borneo, and as a matter of interest, small blue sapphires, of no use for gems, are found embedded in the rocks of the Isle of Mull, Scotland.

Rubies and sapphires may be faceted in many different styles; mostly the mixed-cut is used, the brilliant-cut crown being backed with a step-cut pavilion. For fine stones the step- or trap-cut is often employed, and if the material be poor in quality or much flawed it may be cut into beads or even carved. Star-stones are cut cabochon in order to exhibit the attractive optical effect of asterism. Pale stones are often mounted with a closed setting and the back of the stone sometimes foiled with a suitable colour. Bingley states that it was formerly the practice, in the case of blue sapphires, to place under the stone the blue part of a peacock's feather instead of foil.

Synthetic Corundum

Ruby has a value so high that it was one of the first stones to warrant experiments in an endeavour to make the stone synthetically. These experiments leading to successful synthesis were essentially a French endeavour, and to-day there is an industry in France and neighbouring Latin-speaking countries.

The first experiments were carried out by Marc A. A. Gaudin, who, whilst at the Bureau of Longitude, was the first to melt quartz and produce silica glass by the aid of the oxy-hydrogen blowpipe. Gaudin, using a similar technique, attempted to make rubies by fusing a mixture of alum and a little potassium chromate, but although crystals of corundum were formed, they were opaque on cooling and did not take the colour as expected. In 1847 Ebelmen, using borax and boracic acid as a type of flux, made ruby from alumina and chrome oxide. These crystals were in the form of thin hexagonal lamellae.

In 1885, or perhaps three years earlier, a number of rubies came upon the gem market and at first were accepted as genuine. Soon their natural origin was questioned, and it transpired that the stones had been made by the direct fusion of small fragments of well-coloured natural ruby. These so-called "reconstructed rubies" were said to have been made by an enterprising priest in a small village near Geneva and were known as " Geneva rubies."

The trouble that these stones caused at the time is well illustrated by the abridged abstract from a trade paper of 1890 :— " A Berlin jeweller has just been the victim of a curious hoax. He recently received a circular from a Zürich firm offering rubies at remarkably cheap rates, and thereupon entered into negotiation for the purchase of some. He bought 25 rubies, for which he paid 4,500 marks (£225) receiving a guarantee from the firm that the stones were genuine. Shortly after, the jeweller heard that false rubies were being manufactured so cleverly as to deceive connoisseurs, and, becoming alarmed, sent those he had purchased to Paris to be examined by the Syndicate of Dealers in Precious Stones, who are considered unimpeachable authorities. They reported that the stones were not imitation, but were real rubies, which were small, and consequently of small value, fastened together so cleverly as to render detection difficult. The jeweller then wrote to Zürich requesting that the firm take back the stones. This they refused to do, on the ground that their guarantee only ensured the genuineness of the gems and contained no mention of their size."

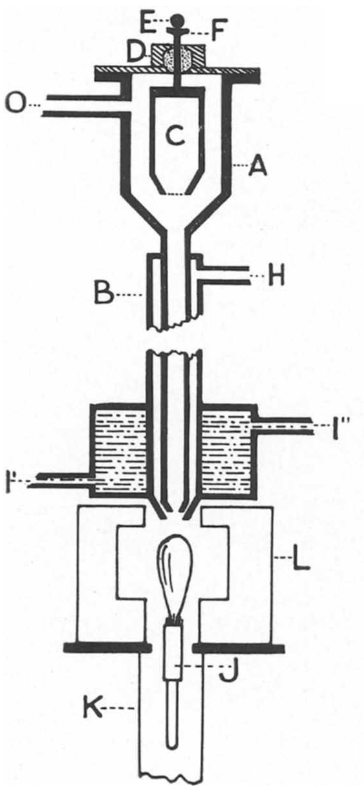
In 1895 the French chemist Michaud developed a technique employing the fusion, or rather sintering, of poor quality Siamese rubies in a platinum crucible under an oxy-hydrogen blowpipe, adding bichromate of potash to enhance the colour. As the process became well known and other people commenced making them—even in London's Hatton Garden—the price dropped so that manufacture became uneconomic, and with the introduction of Verneuil's method of synthesis these " reconstructed rubies " were no longer made. These crucible-made stones, with their fine cracks and other imperfections, which often appear like " silk," have an appearance nearer to that of natural ruby than the much cleaner modern synthetic stone.

During the time that the reconstructed ruby held sway the French chemists had not been idle. In 1877 E. Frémy, in partnership with C. Feil, worked on the problem of ruby synthesis and successfully produced ruby and other colours of corundum. This synthesis was reported in the French journal *Comptes Rendus*, and an abstract was made in the *Mineralogical Magazine*. The abstract makes most interesting reading:—" Frémy and Feil have lately succeeded in preparing artificially variously coloured crystallized corundum and emerald (? green corundum) of such a size and transparency as to be suitable for the purposes of the jeweller and watchmaker. Several methods of preparation have been adopted, but that which is said to give the best results is to dissolve alumina in oxide of lead at high temperature in an earthernware crucible. After the solution is complete, the temperature is maintained for about twenty days. The silex of the crucible is gradually dissolved and by replacing the alumina causes it to crystallize out very slowly. The remarkable success obtained is mainly due to the Authors having used as much as twenty to thirty kilograms and having command of large furnaces. The various coloured specimens of corundum have the same specific gravity, hardness and crystalline form as the natural mineral. The artificial ruby was coloured, as is the natural, by oxide of chromium ; but the artificial sapphire was coloured by oxide of cobalt and they probably differ from the natural. Very blue sapphire does not give a spectrum at all like that due to cobalt. The true nature of the colouring substance is somewhat doubtful."

Later another young French chemist, by name Auguste Verneuil, a name which has since become a byword in gemstone synthesis, joined as Frémy's partner in place of Feil. Their work progressed, and it is noteworthy to recall that in a trade journal of 1890 mention was made of the synthesis in these words :— " More valuable than mere theory was the fact that these chemists exhibited, for the benefit of the Paris Academy of Sciences, some hundreds of the specimens of the glittering red crystals they had succeeded in producing—the only regrettable part of the business is that owing to the high price of the chemicals required and the difficulty of manipulation, the artificial rubies cannot be produced at a price cheaper than the natural precious stones." Some of these small rubies were used as watch jewels and a few were cut as small gemstones. A year later Moissan, of diamond fame, published particulars of a process of fusing alumina in his electric furnace.

The crucible method of making ruby was never a success commercially, but Verneuil had learned much from the experiments which had gone before, particularly that the fusion must be carried out in the hottest part of the flame richest in hydrogen, but not hot enough to cause boiling ; he had also learnt to produce the mass of corundum by superimposed layers from bottom to top and lastly to limit the contact of the melted product to an extremely small surface. In 1891 Verneuil had deposited with the Paris Academy of Sciences a sealed account of a new and revolutionary process for ruby synthesis, and this he published freely to the world in November, 1902.

The Verneuil inverted furnace consists of two iron tubes, A and B in figure. Tube A is widened into a circular chamber at the top, the lower and thinner end passing down the centre of the tube B, into which it is tightly screwed so as to form a gas-tight joint. Both tubes are constricted to nozzles at the lower ends, that of A being situated close to, but inside and above that of B. Pure oxygen under pressure is admitted to tube A through the pipe O. Within the upper chamber of A is placed a small basket or canister with a base of fine wire mesh (30 to 80 mesh have been reported as having been used) C, which is rigidly fixed to a metal rod passing upwards through a block of resilient rubber D contained in a cylinder which forms part of the chamber lid. In some cases a phosphor-bronze diaphram is employed instead of the rubber. At the top of the rod is placed an adjustable cam-shaped head F, which may be adjusted to regulate the force with which the small hammer E will strike it. This hammer, which is operated either by an electro-magnet or a cam rotating on a shaft (not shown in the drawing) may also be regulated to give a regular series of gentle taps. Hydrogen under pressure is admitted to the tube B by means of the pipe H. This meets and mixes with the oxygen at the orifice, where it is ignited. Owing to the intense heat generated, some 2,000°C, it is necessary to protect the pipes against fusion and this is done by placing around them a water jacket G with cold water continually running in at I′ and out at I″. Below the orifice is placed a fireclay support J (usually known as the " candle ") carried on an iron rod connected to a stand K fixed to the bench or floor, and provided with screw and sliding adjustments not shown in the drawing, whereby J may be centred below the orifice of the burner, and may be raised or lowered as



A & B.	*Iron Tubes.*
C.	*Mesh basket.*
D.	*Rubber block.*
E.	*Hammer.*
F.	*Cam-shaped head.*
H.	*Hydrogen-pipe.*
I' & I''	*Coldwater inlet and outlet to water jacket.*
J.	*Fireclay support.*
K.	*Stand.*
O.	*Oxygen pipe.*

Verneuil inverted furnace.

the *boule* grows. *Boule* is the name given to the pear-shaped single crystal which forms. This name is derived from the French word for ball, for the small specimens first grown by Verneuil were ball-shaped. To protect the growing *boule* from cold draughts and to maintain a regular temperature around it, a divided fireclay chamber L is provided, in front of which is held a red screen, so that the growth of the *boule* can be watched.

In the manufacture of synthetic stones by the Verneuil " flame fusion " method, as it is called, the gases and chemicals used must be of exceptional purity and have certain physical attributes. To-day most of the factories manufacture their own gases and chemical powders. To make the corundum gems—the ruby, colourless, blue and variously coloured sapphires—it is necessary to prepare a fine powder of alumina as the feed powder. This is done by calcining crystals of ammonium alum in silica trays in a muffle furnace at 1100°C for two hours. During decomposition the noxious gases generated are carried off by high chimneys and the charge swells up spectacularly to a meringue-like cake. This is an anhydrous (water-free) alumina in the so-called " gamma " form, and these cakes are then broken down to a fine powder by a tumbling process.

If ruby is required this snow-white powder has added to it about 8% of chromic oxide before calcining. It is then placed in the basket C at the top of the blowpipe. The hydrogen gas is turned on and lit at the nozzle ; then the oxygen is admitted, which with the already ignited hydrogen forms the intensely hot oxy-hydrogen flame. The hammer H is then started, at a rate which may be fairly fast—at some 80 per minute—causing a release of a sprinkling of the alumina powder at every tap—and this travels down the oxygen stream and fuses as it passes through the hottest part of the inverted flame, the melting point of alumina being 2050°C.

The molten powder is caught on the top of the ceramic " candle " J, which is about ¼ to 1 inch in diameter and is situated in the cooler part of the furnace. This fused alumina solidifies on the " candle " in the form of a small cone consisting of a number of small crystals of corundum. The tip of this cone remaining in the hotter part of the flame remains molten. By manipulation of the speed of tapping down of the powder and the amount delivered at each tap, which is controlled by alteration of the distance of the hammer from the top of the peg, and the gas supply, the single central part grows upwards, stalagmitic fashion, and opens out to mushroom shape, after which the speed of tapping is reduced in order to keep the *boule* diameter to about ¾ inch. This rate of tapping (for ruby) is about 20 per minute.

When the *boule* reaches a suitable size, about 2½ inches (60mm.) in length for ruby, and weighing 150 to 200 carats, the gas supply is cut off and the *boule*, a single crystal of alpha alumina, is allowed to cool on the furnace and when cool it is broken away from the " candle " and fritted cone of crystal aggregates. The stem of the *boule* is nipped with a pair of pliers, or given a slight tap with a hammer, when it splits longitudinally into two nearly equal halves, the flat faces of which are essentially plane.

Different manufacturers employ slightly different techniques, but the essentials are the same and little difference can be seen between these modern blowpipes and Verneuil's original. Even the arrangement of the banks of furnaces is similar. Quite recently an electrically driven slow-motion drive has been incorporated to lower the *boule* automatically during growth, this being carried out by periodic operation of a hand wheel in manually operated blowpipes. Further, the rate of tapping has been automatically controlled in these modern blowpipes by the use of photo-electric cells and electronic circuits.

It is interesting to recall that a French chemist, who had learned Verneuil's process before leaving Europe, started making synthetic rubies at the small lumber town of Hoquiam, Washington, the capital for the project being supplied by two wealthy lumbermen, Polson and Ninemire. Small *boules* were said to have been produced but the location was too far away from jewel markets, and the material was poor and liable to " crack-up," so the venture died. There does seem to be doubt, however, whether the process used was that of " flame fusion " by the inverted oxy-hydrogen blowpipe, or that of reconstruction by crucible.

Without colouring oxide the pure alumina powder will give clear water-white sapphire *boules*, and stones cut from them are the well known synthetic white sapphires. By the addition of other oxides many different colours are made.

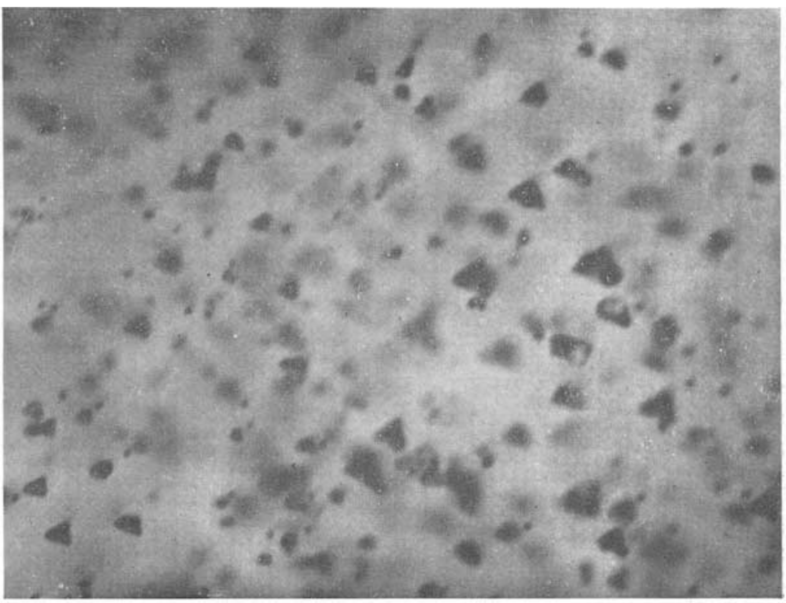
About 1907 attempts had been made to produce blue sapphire by the blowpipe method. The true nature of blue colouring in natural sapphire was still in doubt, and the logical use of cobalt oxide as a colouring agent was made. The *boules* produced from this alumina-cobalt oxide were found to be very patchy in colour, and at best the colour was a poor imitation of the rich blue of natural sapphire. In order to overcome this patchy colour the experimenters added magnesium oxide to act as a flux, and by this method did produce a blue boule of uniform colour, but still of a hue unlike that of sapphire. These stones were cut and marketed under the fanciful name of " Hope Sapphire." Examination of these stones showed that they had the characters of spinel and not those of corundum. It was this " accident " which led to the production twenty years later of the synthetic spinel in so many lovely shades of colour.

When scientific investigation had clearly shown that the cause of the colour in natural sapphire was due to a trace of titanium and iron, these oxides were used in the production of the synthetic blue sapphire with great success.

To-day synthetic corundum is manufactured in a great number of colours and shades of colour. A dark red is made to imitate the garnet and a light red or pink gives the synthetic pink sapphire. A deep pink-coloured material is termed " Rosaline," and a lovely lilac pink is the " Rose de France." An attractive orange colour is known as " Padparadscha," and this stone, presumably made to imitate the rare natural orange sapphire in the deeper shades does very much resemble fire opal of rich colour. At least two shades of yellow are produced, termed " Topaz colour " and " Danburite colour," but these stones also, of course, simulate the true yellow sapphire found in nature. Recently two rather attractive brown shades have been marketed under the names " Palmyra topaz " and " Madeira topaz." A good green which is like the natural green sapphire and a light green, which may imitate the peridot and is called " Amaryl," have been made. The true amethyst—the violet quartz—is imitated by a synthetically produced violet sapphire. And finally, although there seems no end to the shades of colour that the technician can produce, there is the synthetic corundum made so that in daylight it appears green, and in artificial light a red colour, presumably made to imitate the alexandrite chrysoberyl.

Up to 1947 any star-sapphire or ruby was bound to be genuine and it was confidently expected that such stones would never be produced synthetically. In that year the jewellery trade learned that such stones had been made. By the introduction of a percentage of titanium oxide into the feed powder, followed by heat treatment, synthetic asteriated corundum, both in red (ruby) and blue (sapphire) was produced. Many different colours of these synthetic star-stones have been produced but so far only the two colours mentioned have been marketed. The stones are made by adding to the gamma alumina powder, plus the necessary colouring oxides, not more than 0·3%, or less than 0·1% of titanium oxide (TiO_2). The *boules* formed from this feed powder are subsequently subjected to a temperature above 1,100°C, which precipitates needles of a titanium compound, most probably rutile, along the prominent crystal planes—that is, parallel to the faces of the hexagonal prism, which is the fundamental crystal form, even if it is rarely shown by the *boule* itself.

These synthetic star-stones, which were an American innovation, had the artificial " silk " confined to the outside of the boule and cabochon cut stones show concentrations of " silk " at the upper 2/3rds or 3/4ths of the stone, the rest being clear and showing all the characteristics of the normal synthetic corundum. It is due to this partial " silk " that the early synthetic star-corundums showed the arms of the star to only about 3/4ths of the way down the sides of the cabochon. Such stars are altogether too bright and the stones too strong in colour to make them really deceptive to the experienced eye. The more modern American synthetic asterias are much more opaque and although they make beautiful stones they still look unreal. A Bavarian firm has produced similar star-stones in synthetic corundum, which are much more like the natural stones and in which the star is more diffuse. All these synthetic asterias, however, show a " ground



Triangular-shaped two-phase cavities in a synthetic star-ruby. (Other parts of the stone showed many bubbles.)

glass " surface at the back, unlike the zonal structure shown by the natural star-corundums.

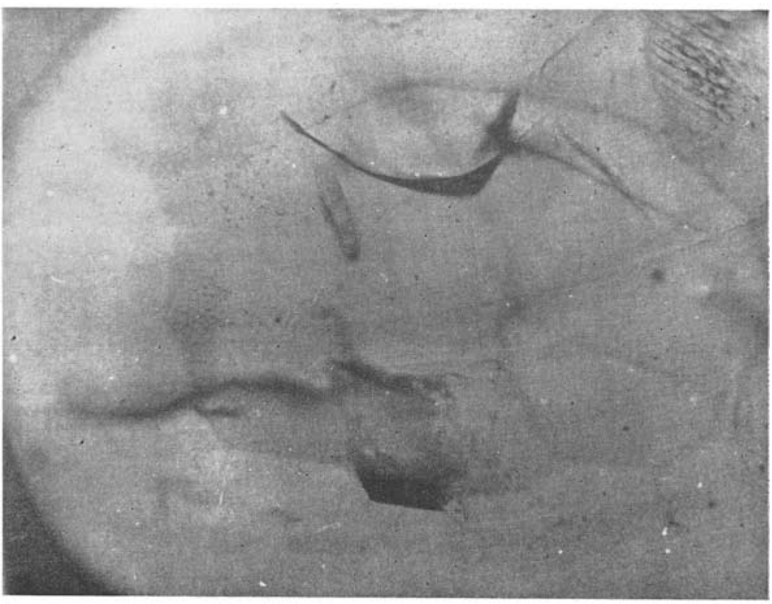
The physical and optical characters of the synthetic corundums are those of the natural stones, so neither density nor refractive index measurements will give evidence of their synthetic nature. Owing to their mode of formation being so different the structure differs from that of natural stones in a number of respects, and these are sufficient to distinguish between them. Synthetic corundum, owing to the shape of the top of the *boule* and the discontinuous nature of the feed powder—necessary in order that each increment of fused powder will have time to crystallize, and crystallize in conformity with the layers below it—shows, if coloured, curved structure lines, or bands when examined under the microscope. In the case of ruby, and some other colours including the " alexandrite " colour, these lines are fine and closely spaced and have been likened to the lines on a gramophone record. With blue sapphire these curved structure lines are wider and more widely spaced ; they take on the form of bands rather than lines. The synthetic corundums show included gas bubbles, either as clouds of small bubbles (which look like a mass of dots), round bubbles (often with a tail like tadpoles), or bubbles of flask-shaped or bomb-like outline. When large enough these bubbles show, when examined by a microscope, a bright centre with a dark outline. Often some of the feed-powder does not get completely fused whilst passing through the blowpipe flame and these angular-shaped dark pieces may appear to be natural, but they are never alone and the other features will assist a diagnosis.

In the case of synthetic blue sapphire the 4500Å absorption line is not present, due it is thought to the evaporation of the iron by the heat of the blowpipe flame. Therefore the presence of this absorption line, or the group of three forming the 4500Å complex, will prove a stone to be genuine. Further, the spectroscope will prove the nature of the synthetic sapphire made to imitate the alexandrite, for a narrow line in the blue at 4750Å, with absence of lines in the red, is markedly different from the absorption spectrum of the true alexandrite.

Owing, it is considered, to the purity of the synthetic corundums, more especially in that they contain no iron compound (and iron is universally found in natural gems), the synthetic corundums transmit ultra-violet light much more freely and further down in the range than natural stones. Natural stones cut the transmission at about 2900Å, whilst the synthetics pass the "light" down to about 2200Å. Thus, if a synthetic corundum be placed with a natural ruby or sapphire on a piece of photographic contact paper immersed in water in an open-topped cell and the stones given a short irradiation from a short-wave ultra-violet lamp (2537Å), the paper under the synthetic stone will darken more than where the synthetic stone has rested ; this, of course, shows on development of the paper. Recently Anderson has shown that by employing the immersion contact method of refractive index estimation fine curved structure lines have been revealed in synthetic corundums of blue and other colours. and that this method has revealed lines which were not observed by the usual microscopic examination.

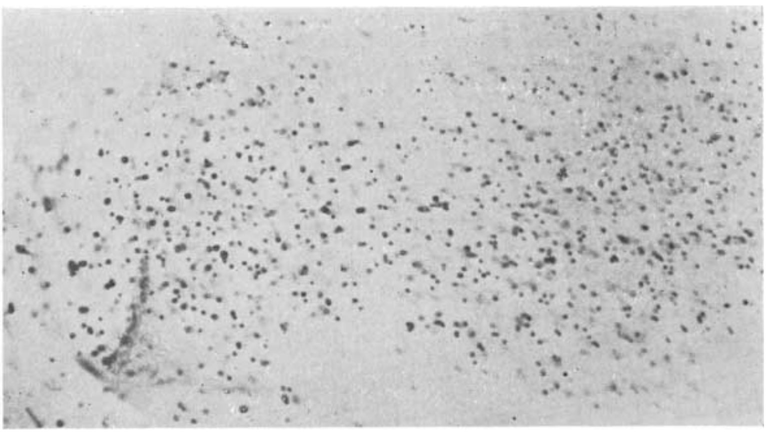
IMITATIONS

Apart from some natural stones, which may have a colour not unlike natural corundums, and which reveal themselves by normal

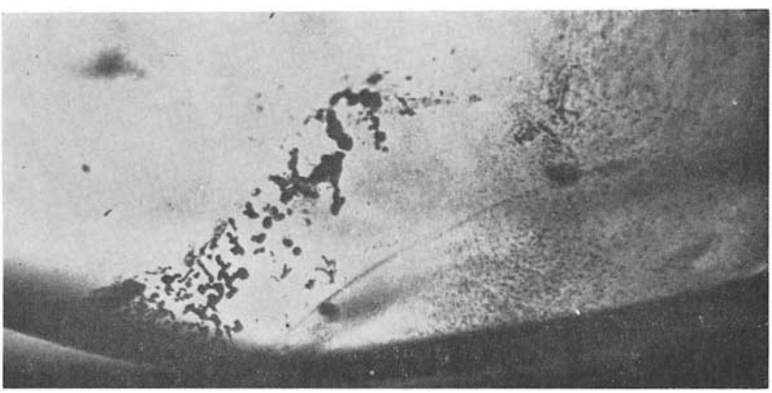


Deceptive crack-like markings (probably induced) in a synthetic ruby.

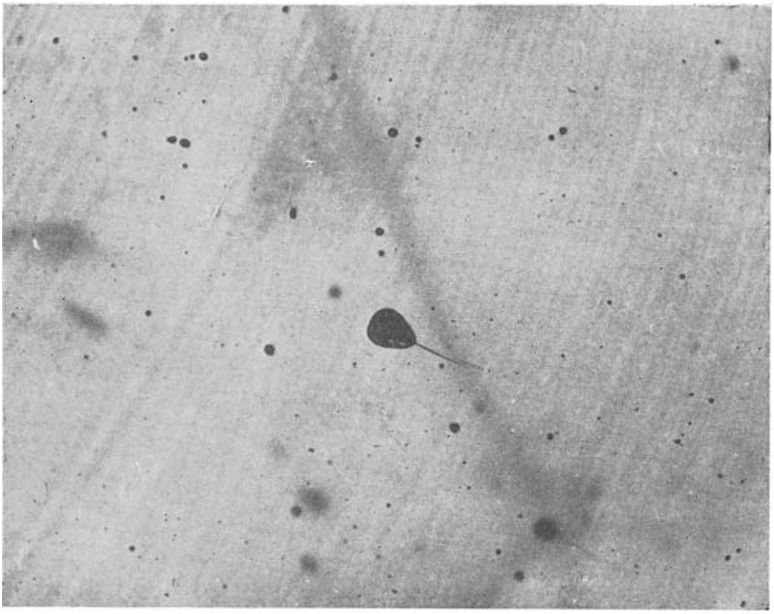
gemmological tests, the only common imitations are pastes of similar colour and garnet-topped doublets. Red pastes usually show an absorption spectrum which has a broad band cutting out the yellow and green, but, unlike ruby, they do not show the lines in the red and blue parts of the spectrum which are due to chromium; likewise the red garnet-topped doublets will exhibit a similar spectrum (due to the glass base) upon which is superimposed a weak almandine garnet spectrum. Neither of these show a " fluorescent effect " when viewed through the Chelsea colour-filter, nor will



Bubble cloud in a synthetic sapphire.



Bubble cloud and deceptive solid inclusions (probably alumina) in a synthetic ruby.

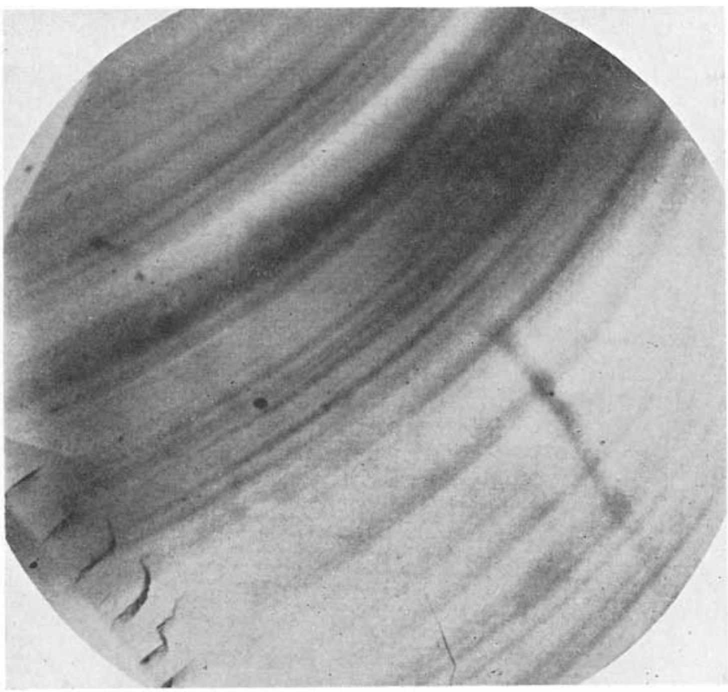


Curved (gramophone record type) lines and tadpole-shaped bubble in a synthetic ruby.

the crimson fluorescent glow shown by natural or synthetic ruby when bathed in either range of ultra-violet light be present with pastes or garnet-topped doublets. Most blue pastes show the cobalt spectrum of three broad bands in the orange, yellow and green of the spectrum, and no line at 4500Å ; further, such stones show a strong red when viewed through the Chelsea colour-filter. Some paler blue pastes, however, owe their colour to copper and do not show a characteristic spectrum or a red colour through the filter, so in this case reliance must be placed on the refractive index, lack of dichroism and the microscope.

The star-stone is, however, imitated by a special type of doublet—the star rose-quartz doublet. When a polished slice of a certain type of rose-quartz, which is cut at right angles to the optic axis of the quartz, is viewed from a single light source transmitted through it a bright star of light is seen. This is *diasterism* and the effect is used in the imitation of star corundums. A cabochon of rose-quartz cut with the base at right angles to the optic axis of the quartz is backed with a reflecting film or mirror, which has been suitably tinted, usually blue. This mirror on the base reflects the frontal light back through the stone making apparent the star effect due to diasterism and altering the pink colour of the rose-quartz to a bluish shade (only blue shades have been seen on the market). Such imitations, unlike the natural and synthetic star-corundums, in which the star is due to *epiasterism*, show an image of the light source at the crossing of the three rays forming the six-pointed star, and on moving the stone nearer to the light this image enlarges—no further test is needed. Another fake asteria consists of a cabochon of synthetic corundum, or even glass, on the flat base of which fine lines are engraved running in three directions at 120°. These imitations are not common and are only passably effective, distinction being easy when the base is examined by a lens.

It is in the species corundum, gemstones as highly prized as the regal diamond and the lovely emerald, that the truth is evident



Curved colour bands in a synthetic blue sapphire.

that synthesis can never completely undermine the true value of a stone which has had its genesis in nature.

REFERENCES

The list of references given below is of selected papers and does not include standard text-books on gemstones.

GENERAL

Alexander (A. E.). *Spectrophotometric and spectrochemical analysis of rubies and sapphires.* Journ. Gemmology, Vol. 1, No. 8, pp. 4–8, 1948.

Anderson (B. W.). *Crossed filters for the study of fluorescence.* Gemmologist, Vol. XXII, pp. 39–45, 1953 ; *Fancy sapphires.* Gemmologist, Vol. X, pp. 37–38, 1940 ; *More notes on immersion contact photography.* Journ. Gemmology, Vol. V, pp. 297–306, 1956 ; *The constancy of density of corundum.* Gemmologist, Vol. IX, pp. 119–121, 1940.

Anon. *Chatoyant phenomena.* Gemmologist, Vol. XII, pp. 9–10 and 14–15, 1942, repeated Gemmologist, Vol. XXVI, No. 309, pp. 69-75, April 1957; *Star sapphires in America.* Gemmologist, Vol. V, p. 110, 1935 ; *What colour is pigeon blood ?* Gemmologist, Vol. XII, p. 47, 1943 ; *World's largest star ruby.* Gemmologist, Vol. VII, p. 654b, 1938.

Bach (S. R.). *Notes on inclusions in gemstones.* Gemmologist, Vol. 9, pp. 97–99 ; 112–115, 1940.

Bingley (W.). *Useful knowledge, or a familiar account of the various products of nature.* Vol. I, p. 30, 1825. London. (*Backing sapphires with peacock's feathers*).

Dick-Larkham (R.). *Superstitions of ruby.* Gemmologist, Vol. X, p. 41, 1940.

Gravender (M. D.). *Sapphire.* Gems and Gemology, Vol. I, pp. 47–48, 1934.

Gübelin (E.). *Diagnostic importance of gemstone inclusions.* Journ. Gemmology, Vol. II, pp. 281–303 (ruby p. 285), 1950 ; *Differences between Burma and Siam rubies.* Gems and Gemology, Vol. III, pp. 69–72, 1940 ; *Gemstone inclusions.* Gems and Gemology, Vol. IV, pp. 142–149, 1943 ; *Gemstone inclusions.* Journ. Gemmology, Vol. I, No. 7, pp. 7–39, 1948 ; *Local peculiarities of sapphires.* Gems and Gemology, Vol. IV, pp. 34–39, 50–54, 66–69, 1943.

Klemm (R.), Wild (G. O.). *Zur Kenntnis des edlen Korundes.* Neues. Jahrb. Min. Abs. A, Vol. 53, pp. 266–270.

Krishnan (R. S.). *Raman spectrum of alumina and the luminescence of ruby.* Proc. Ind. Acad. Sci. Sect. A, Vol. 26, pp. 450–459, 1947.

Lensen (G.). *The cause of asterism in star sapphires and rubies.* Zeitschr. d. Deutsch. Gesell. f Edelstein, No. 8, pp. 7–10, 1954 (Abstr. Journ. Gemmology, p. 358, Vol. IV).

Mathews (C.). *Notes on ruby.* Gemmologist, Vol. I, p. 120/2, 1931 ; *Notes on sapphire.* Gemmologist, Vol. I, pp. 184–186, 1932 ; *The trade esteems Burma sapphires.* Gemmologist, Vol. V, pp. 97–98, 1935.

Ozerov (K N.). *Form of corundum Crystals as dependent upon chemical composition of medium.* Comptes Rendus (Doklady) Acad. Sci. URSS, Vol. 47, pp. 49–52, 1945.

Schlossmacher (K.). *Die Seltenheit des sapphirs.* Zeitschr. d. Deutsch. Gesell. f. Edelsteinkunde, No. 5, p. 8, 1953.

Spencer (L. J.). *Nation acquires large ruby.* Gemmologist, Vol. 2, pp. 176–178, 1933.

Tait (A. S.). *Asterism in corundum.* Journ. Gemmology, Vol. V, No. 2, pp. 65–72, 1955.

Thilo (E.), Jander (J.), Seeman (H.), Sauer (R.). *Über die Farbe des rubins.* Naturwiss, Vol. 37, p. 399, 1950.

Thomas (W. B. S.). *The beauty of star stones.* Gemmologist, Vol. XXII, pp. 34–37, 1953. (*Abstr. from Earth Science Digest*).

Thosar (B. V.). *The polarization of luminescence of ruby.* Phy. Rev. (Amer. Phys. Soc.), Ser. 2, Vol. 60, p. 616, 1941.

Walcott (A. J.). *Asterism in garnet, spinel, quartz and sapphire.* Field Mus. Nat. Hist. Chicago Geo. Surv., Vol. 7, No. 3, pp. 39–57, 1937. (*Abstr. Journ. Gemmology, Vol. IV, p. 318*).

Wild (G. O.). *Yellow sapphires.* Gemmologist, Vol. IV, pp. 273–274, 1935.

BURMA

Adamson (H.). *The material resources of Burma.* Bull. Imp. Inst., Vol. 16, pp. 74–75, 1918.

Anon. *A rare ruby from Burma.* Gemmologist, Vol. II, p. 220, 1933.

Bleeck (A. W. G.). *Rubies in the Kachin Hills, Upper Burma.* Rec. Geol. Surv. India, Vol. 36, pp. 164–170, 1908.

Brown (J. Coggin). *A geographical classification of the mineral deposits of Burma.* Rec. Geol. Surv. India, Vol. 56, pp. 65–108, 1924 ; *Ruby mining in Upper Burma.* Mining Mag., Vol. 48, pp. 329–340, 1933.

Cecil (G.). *Ruby mining in Burma.* Eng. Min. Journ., Vol. 126, p. 294, 1928.

Halford Watkins (J. F.). *Burma sapphires.* Gemmologist, Vol. XII, pp. 39–43, 89–95, 1935 ; *Rubies and groundnuts.* Gemmologist, Vol. V, pp. 63–69, 1935 ; *Rubies and sapphires in Burma.* Gemmologist, Vol. V, pp. 154–157, 1936 ; *The ruby mines of Upper Burma.* Gemmologist, Vol. I, pp. 263–272, 325–342, 1932. *Where are the priceless rubies now ?* Goldsmiths' Journal, pp. 358–360, June, 1936.

Pain (A. C. D.). *The gems of Burma.* Gemmologist, Vol. XII, pp. 37–40, 1943.

Scott (W. H.). *Ruby mines of Burma.* Summary of American Consulate Report (by Howell (D. H.)). Gems and Gemology, Vol. 2, pp. 3–6, 31–34, 1936.

Simpson (R. R.). *Notes on a visit to the Burma ruby mines.* Trans. Min. Geol. Ind. India, Vol. 17, Part 1, pp. 42–58, 1922.

SIAM

Anon. *Les mines du Cambodge ; Les mines de saphirs de Phailin.* La Vie Techn. et Ind. Special Indo-China Number, pp. 111-112, 1922.

Guhler (U.). *Studies of precious stones in Siam.* Siam Sci. Bull., Vol. 4, No. 1, pp. 1–39, 1947.

KASHMIR
Gaines (R. V.). *The sapphire mines of Kashmir.* Rocks and Minerals, Vol. 26, pp. 464–472, 1951.
Heron (A. M.). *The gemstones of the Himalaya.* Himalyan Journ., Vol. 2, pp. 21–28, 1930 ; *Abstr.* Min. Geol. Inst. India, Vol. 25, p. 374, 1931.
Middlemiss (C. S.). *Precious and semi-precious gemstones of Jammu and Kashmir.* Jammu and Kashmir Min. Surv. Rept., Vol. 9, pp. 4–50, 1931.
Parkinson (K.). *Kashmir sapphires.* Gemmologist, Vol. XXI, pp. 39–40, 1952. (*Abstr.* Journ. Gemmology, Vol. III, No. 6, p. 248, 1952.

CEYLON
Adams (F. D.). *A visit to the gem districts of Ceylon and Burma.* Canadian Inst. Min. Metall., No. 166, pp. 213–246, 1926.
Coates (J. S.). *The geology of Ceylon.* Ceylon Journ. Sci. (Spolia Zeylanica), Sect. B, Vol. 19, pp. 101–187, 1935.
Cohen (H.). *Mining sapphires in Ceylon.* Gemmologist, Vol. III, pp. 231–237, 1934.
Frazer (L.). *Rubies in Rangoon.* The Empire Review, May, 1934.
Gübelin (E.). *Characters of Ceylon rubies.* Gems and Gemology, Vol. III, pp. 121–124, 1940.
Wayland (E. J.). *Note on the sources of origin of Ceylon gemstones.* Econ. Geol., Vol. 18, pp. 514–516, 1923.

AUSTRALIA
Andrews (E. C.) *et al. The mining industry of New South Wales.* Dept. Mines N.S.W., pp. 302–309, 1928.
Anon. *Queensland's precious stones.* Mining Mag., Vol. 26, pp. 271–276, 1922.
Batchelor (H. H.). *Gems and Wildlife " Down Under " (refers to Tasmanian sapphire).* Gemmologist, Vol. XIII, p. 7, 1943 ; *Queensland sapphires.* Gemmologist, Vol. V, pp. 226–228 ; Vol. VI, p. 17 ; Vol. VIII, p. 42 ; Vol. X, pp. 105–107 ; Vol. XV, p. 64.
Chalmers (R. O.). *Australian gemstones.* Journ. Proc. Roy. Soc. of N.S.W., Vol. LXXXIX, pp. 90-108. Gems and Gemology, Vol. VII, No. 3, pp. 83–88, 1951.
Dunstan (B.). *Report on the sapphire fields of Anakie.* Brisbane, 1902.
Hart (R.). *Australian precious stones.* Gemmologist, Vol. XVI, p. 212, 1947.
Rowell (E.). *Queensland black star sapphire.* Gemmologist, Vol. XVII, pp. 232 and 300, 1948.
Stratton (V.). *Australia sapphire finds not fully exploited.* Gems and Gemology, Vol. VII, pp. 125–128.

NORTH AMERICA
Anon. *Sapphire in Idaho.* Gemmologist, Vol. XVII, p. 12, 1948.
Crocker (R. C.). *The Yogo Sapphire Mine.* Gems and Gemology, Vol. VIII, No. 11, pp. 323–330, 1956.
Field (D. S. M.). *Canadian gems and gem localities.* Journ. Gemmology, Vol. I, No. 8, pp. 21–24 ; Vol. 2, No. 1, p. 10, 1949.
Freeman (O. W.). *The sapphire mines of Yogo, Montana.* Min. Sci. Press, Vol. 110, pp. 800–802, 1915.
Pearl (R. M.). *The gems of Colorado.* Gems and Gemology, Vol. III, p. 40, 1939.
Rowe (J. P.). *Minor metals and non-metallic minerals of Montana.* Eng. Min. Journ., Vol. 125, pp. 816–818 (sapphire on page 817), 1928.
Smith (M.). *The rubies of Cowee Valley, North Carolina.* Rocks and Minerals, Vol. 25, pp. 474–180, 1950.

OTHER LOCALITIES
Game (P. M.). *Zoisite-amphibolite with corundum from Tanganyika.* Min. Mag., Vol. 30, p. 458.
Junner (N. R.). Report Geol. Dept. Sierra Leone. Ruby, p. 16 in 1927/8 ; and page 11 in 1929.
Kennedy (N. W.). *Gem minerals of the British Isles.* Journ. Gemmology, Vol. IV, pp. 91–92.

SYNTHETICS
Alexander (A. E.). *Genuine and Synthetic rubies and sapphires.* Journ. Chem. Education, Vol. 23, pp. 418–422 and 459, 1946 ; *The new synthetic star rubies and sapphires.* Gemmologist, Vol. XVI, pp. 307–308, 1947.
Anon. *L'examen des saphirs naturels et artificiels aux rayons-X.* Chimie et Ind., Vol 22, p. 636, 1929; *New method of production of Synthetic ruby.* Gemmologist, Vol. VIII, p. 180, 1939 ; *Synthetic gemstones.* Watchmaker, Jeweller and Silversmith, pp. 40–42, Nov., 1949 ; *Use of cathode rays to detect sapphires.* Min. and Met., Vol. X, p. 489, 1929. *Abstr.* Jew. Circ.-Keystone, p. 105, 18/7/1929.
Anderson (B. W.). *Gemstones from laboratory to factory.* The Times Science Review, Summer, 1955 ; *One hundred years of artificial gemstones.* Gemmologist, Vol. XVI, pp. 1–9, 1947.
Anderson (B. W.), Gübelin (E.), Alexander (A. E.). *Observations on reconstructed rubies.* Gems and Gemology, Vol. VI, pp. 184–190, 1949.
Anderson (B. W.), Payne (C. J.). *Absorption of visible and ultra-violet light in natural and artificial corundum.* Gemmologist, Vol. XVII, pp. 243–247, 1948.
Austen (R. L.), Anderson (B. W.). *A photomicrographic examination of the surface structure of synthetic corundum and spinel.* Gemmologist, Vol. VIII, pp. 81–85, 1938. *Abstr.* Deutsche Gold. Zeit, No. 5, p. 47, 1939.
Barnes (M. H.). *Synthetic sapphire and spinel production in Germany.* Field Information Agency, Technical (U.S.) British Intell. Rept. Report No. 655. *Abstr.* Gem. News (W. J. & O.), pp. 50–52, 1947.
Benson (L. B.). *Reconstructed rubies found to be synthetic.* Gems and Gemology, Vol. VII, pp. 139–144, 1952.
Chirnside (R. C.), Dauncey (L. A.), Rooksby (H. P.). *Synthetic sapphire.* G.E.C. Journal, Vol. XIII, No. 2, 1944 ; *Abstr.* Gemmologist, Vol. XIV, pp. 49–51 and 55–56, 1945.

Dollar (A. T. J.). *Fractures in synthetic corundum.* Gemmologist, Vol. VII, p. 553b, 1938.
Eppler (W. F.). *Synthetische steine.* Schweizer Goldschmied, Nr. 7 and 8, 1949.
Frondel (C.). *Commercial synthesis of star sapphires and star rubies.* Econ. Geol., Vol. 48, p. 325, 1953 ; *Abstr.* Trans. Amer. Inst. Mining. Metall. Eng., pp. 78–80, 1954.
Halford Watkins (J. F.). *Synthetic corundum.* Gemmologist, Vol. III, pp. 302–311, 333–341, 1934.
Kraus (F.). *Synthetische edelsteine.* 1929.
Leftley (H. T.), Cobden Turner (H.), Wadsworth (A.), Wheatley (C. C. H.). *Boule manufacture Wiedes Carbidwerk. Bavaria.* Brit. Intell. Objective Sub-Committee, Report No. 558.
Merker (L.). *The synthetic stone industry of Germany.* P.B. 77671. Office of Tech. Serv. Rept. U.S. Dept. of Comm.
Plato (W.). *Oriented zoning in synthetic corundum.* Edelsteine u. Schmuck, Vol. 1, pp. 193–194, 1949 ; *repeated in* Zeitschr. d. Deutsch. Gellsch. f. Edelsteinkunde ; *Abstr.* Gems and Gemology, Vol. VII, pp. 223–224, 1953 ; and Journ. Gemmology, Vol. II, pp. 157, 205, 207, 1950.
Pough (F. H.). *Synthetic corundum and spinel manufacture in Switzerland.* Jew. Circ.-Keystone, pp. 136–138 and 182, Aug., 1949.
Rooksby (H. P.). *Jewels and stones for industrial purposes.* Journ. Roy. Soc. Arts., Vol. XCIV, pp. 508–525, 1946.
Sandmeier (E. G.). *Synthetic corundum for jewel bearings.* Journ. Inst. Elec. Engineers, Vol. 72, pp. 505–514, 1933.
Seeman (A. K.). *American made synthetic crystals.* Journ. Gemmology (W. J. & S.), pp. 501–503, 1944.
Steindorf (G. E.). *Imitations of gemstones.* Gemmologist, Vol. XIV, pp. 34–35, 1945.
Syromyatnikov (F. V.). *Industrial production of synthetic rubies and sapphires in the U.S.S.R.* Trans. All-Union Sci. Res. Inst. Econ. Min. No. 146, pp. 5–15, 1939 ; *Abstr.* (by Behr (A.)). Gemmologist, Vol. XIII, pp. 1–2, 1943.
Verneuil (A.). Report on synthetic ruby and flame fusion process—by oxy-hydrogen furnace. *Ann de Chemie et Physique,* Vol. 3, 20, 1904.
Webster (R.). *Synthetic gemstones.* Watchmaker, Jeweller and Silversmith. Jan., 1936.
Webster (R.), Popley (A. R.). *Synthetic gem materials.* Gemmologist, Vol. IV, pp. 319–329, 1935.
Wild (G. O.), Biegel (H.). *The absorption of synthetic ruby and sapphire in the ultra-violet part of the spectrum.* Gemmologist, Vol. XVI, pp. 67–69 and 279–280, 1947.
Wooster (W. A.). *Synthetic materials.* Discovery, pp. 139–142, May, 1948.

NETHERLANDS RESEARCH INSTITUTE

On 26th April, 1957, the University of Leiden and the Netherlands Gold and Silver Federation established the Stichtung Ned. Institut v. Wetensch. Onderzoek van Edelstein en Perlen (Institute for the scientific research of gemstones and pearls).

The laboratory of the Institute is in the National Museum of Geology and Mineralogy at Leiden and the director of the Museum, Prof. I. M. van der Vlerk, is ex-officio president of the Institute. Members of the committee are: Ing. J. Hammes, F.G.A., secretary-treasurer, Prof. B. G. Escher, Prof. W. P. de Roever, As. Bonebakker, F.G.A., and J. J. Schoo, F.G.A. The director of the laboratory is Dr. P. C. Zwaan, who is also a Fellow of the Gemmological Association.

ASSOCIATION NOTICES

THIRD HERBERT SMITH MEMORIAL LECTURE

The third Herbert Smith Memorial Lecture was given at the Royal Institution, London, on Wednesday, 3rd April, 1957, by the President of the Association, Sir Lawrence Bragg, F.R.S. The title of the lecture was " The atomic structure of gem-stones and other minerals," and Sir Lawrence entertained over one hundred members and friends with an intensely interesting illustrated talk.

B. W. ANDERSON *writes* :—

Those Fellows of the Gemmological Association who, on April 3rd, attended the third Herbert Smith Memorial Lecture must surely have felt a sense of privilege as they took their seats in the famous lecture theatre in the Royal Institution to hear their President, Sir Lawrence Bragg, F.R.S., deliver his address. Sir Lawrence, with his father Sir William Bragg, was amongst the foremost pioneers in investigating the atomic structure of minerals by means of X-rays in the years immediately following Laue's famous experiment in 1912. In particular, he and his school of X-ray crystallographers in Manchester were chiefly responsible for elucidating the structures of the silicates, those chemically complex substances which embrace so many of the best-known gemstones.

In his lecture, Sir Lawrence, using simple language and many amusing analogies and metaphors, was able to show how this apparently hopelessly complex series of compounds can be grouped and classified on the basis of their structure into quite a few fundamental types of crystal.

The lecturer began by recalling " The Ethics of the Dust "—a book written for young people by John Ruskin in the middle of last century (1866). In this book Ruskin tells his young audience how, had they eyes which could see the infinitely small, they would realize that when they walk along a muddy road they are walking on " gems "—tiny crystals, in each of which the atoms were arranged in a beautiful pattern. Thus Ruskin, writing nearly fifty years before X-rays had revealed for us the structure of crystals, had, with a poet's imagination, understood their fundamental nature. The mineral world, said Sir Lawrence, showed order and perfection, in contrast to the animal and vegetable world, which showed disorder and untidiness, and added " order and perfection spell death : disorder and muddle spell life."

The lecturer stressed that a mineral must be exceedingly stable to last for many millions of years. He went on to explain the fundamental principles underlying the structure of minerals. In these the bonds between the atoms were mainly ionic—a result of the tendency of some metallic atoms to part with a loosely-held electron, becoming thereby an electropositive ion, while other elements tended to pick up an extra electron, becoming an electronegative ion. The erratic orbits of these loosely-held electrons were shown to the audience in the form of models based on atomic structures as first conceived by the genius of the Danish physicist Niels Bohr.

The overriding importance of the relatively large electronegative ions in minerals was explained to the audience : in particular oxygen—the tiny metallic ions often fitting into interstices in an almost close-packed oxygen lattice. When one reviewed the relative abundance of elements in the earth's crust it was remarkable to find that 98% of the total could be accounted for by eight elements only, in the order oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium. Oxygen and silicon (the essential elements in the formation of the silicates) between them accounted for nearly three-quarters of the whole. Even such " common " elements as copper and sulphur dwindled into insignificance by comparison.

The main bulk of minerals were silicates, the structure and stability of which depended essentially upon the intensely strong silicon-oxygen tetrahedron, in which silicon at the centre was equally surrounded by four oxygen ions. This can be linked with other such units in four different ways, making four great groups of minerals. In a group containing olivine (peridot) chrysoberyl, topaz, and the garnets, the SiO_4 tetrahedra were not directly linked to one another. In another group, which included beryl, the tetrahedra were linked by sharing one of the four oxygens, forming rings. In the great amphibole and pyroxene families (which include the jade minerals) there were chains of SiO_4 tetrahedra in which two of the oxygens were shared. Yet another group comprised the micas, chlorites and serpentines, in which there were endless sheets of linked tetrahedra, giving rise to the flaky structure of mica and similar minerals. To another group belonged the feldspars and the crystalline forms of silica itself.

By the aid of slides and models Sir Lawrence made these structures plain. Of the beryl structure, he related how, after he had just worked it out, he showed it to his wife, who was so charmed with the beauty of the pattern that she embroidred it on the front of her nightdress. Later, it was used as a decorative theme in the Festival of Britain, and was adapted by a Nottingham lace manufacturer.

The lecturer made the interesting point that the commonest minerals were those of lowest density (quartz and the feldspars), as though they had floated to the surface of the magma sea. Of the main groups, the olivine group was the densest.

In addition to the tetrahedra of silica Sir Lawrence showed the role in pattern making of the octahedral unit of alumina. He spoke of these two units as being analogous to the plain and purl of the knitter, from which basic stitches such an amazing variety of pattern could be formed.

Towards the close of his lecture Sir Lawrence had something to say on colour. He showed an amusing slide in which the elements in ascending atomic order were competing for seats (=electron shells) in a theatre. After one row of good seats had been completed (representing the rare gas structure) the next element had the " choice " of inferior side seats in an inner shell of electrons or central seats in the next row, further from the " stage " (=nucleus). It was transition elements of this kind (chromium, iron, etc.) which usually gave rise to colour ; electrons being moved by the light from one place to another.

Some words on hardness followed, in which the importance of highly charged ions with small cations was mentioned. The idea of hardness inevitably makes one think of diamond, and Sir Lawrence's last slide showed the structure of that extraordinary mineral (which was one of the first to be elucidated by him and his father). So exceptional was the nature of the diamond, said the lecturer, that it could hardly be classed as a mineral at all !

In accordance with the lecturer's wish and the traditions of the Royal Institution there was no formal introduction to the lecture, and no vote of thanks at the close. The gratitude and enthusiasm of the audience was, however, well expressed by the prolonged applause which greeted Sir Lawrence at the end of his masterly address.

WEST OF SCOTLAND BRANCH

At the fourth annual general meeting of the West of Scotland Branch of the Association the following Officers were elected—Chairman : Mr. Douglas Wade, Secretary : Mr. C. Wade. Mrs. McGregor and Messrs. E. Macdonald and R. Dickson were elected to serve on the Standing Committee.

MIDLANDS BRANCH

The May meeting of the Midlands Branch was held on the 10th of the month, when Mr. Ivan Shortt, J.P., a Guardian of the Assay Office in Birmingham, gave a talk on " Antique and modern silver and plate."

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, London, E.C.2, on Wednesday, 12th June, 1957. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :

FELLOWSHIP

Argent, George, Vancouver, Canada

PROBATIONARY

Drapkin, Clive M. Birmingham
Kothari, Ramesh R., Madras, India
Milito, John T., London
Phillips, Alan L., Leeds
Weatherill, John, Cardiff

ORDINARY

Brown, Thomas C., Tarkwa, Ghana
Dholakia, Anilkumar B., Bombay, India
Fuhrbach, John R., Amarillo, Texas, U.S.A.
Jones, James R., Mortdale, Australia
Jones, Wilfred R., Auckland, New Zealand
Marais, Hoffman, Johannesburg, S. Africa
Moloo Brothers & Co. Ltd., Zanzibar
Monath, Henry, Newcastle-on-Tyne
Nei-Chong, Li, London
Olkowski, Leonard J., London
Parekh, Pravin H., Bombay, India
Patrick, John T., Christchurch, New Zealand
Phillips, Dennis, Leeds
Phillips, Frank C., Bristol
Ryan, Pat, Albrook, Canal Zone

CURATOR :

Mr. Robert Webster was elected as Curator in place of Mr. G. M. Sprague, who wished to resign for personal reasons. The Council recorded their appreciation of Mr. Sprague's services to the Association.

RESEARCH DIPLOMA

The Council, upon the recommendation of the examiners, decided to award a research diploma to Edward Gübelin, Ph.D., F.G.A., C.G., for his work in connexion with the inclusions that occur in gemstones.


JEANNE HEAL
Famous Radio and
T.V. Personality
Famous hands—
Famous watches
SMITHS
DE LUXE
Among the famous owners of Smiths de Luxe watches are leaders in every field of achievement. For their matchless timekeeping . . . for their supreme elegance . . . Smiths de Luxe watches are a joy to possess. Sold by Jewellers everywhere from £8.19.6 to £75.
B.318
Lady's 15 jewel, gold plated model with black dial. Fitted with Golden Fleece bracelet. 12 gns.
A.358
17 jewel, gold plated watch with raised gilt batons on black dial. Golden Fleece bracelet. £13.10.0.
A 'SMITHS OF ENGLAND' PRODUCT
SMITHS CLOCKS & WATCHES LTD., SECTRIC HOUSE, LONDON, N.W.2
A Division of S. Smith & Sons (England) Ltd.

Vol. VI
No. 3
July, 1957

CONTENTS