Gems and Gemology

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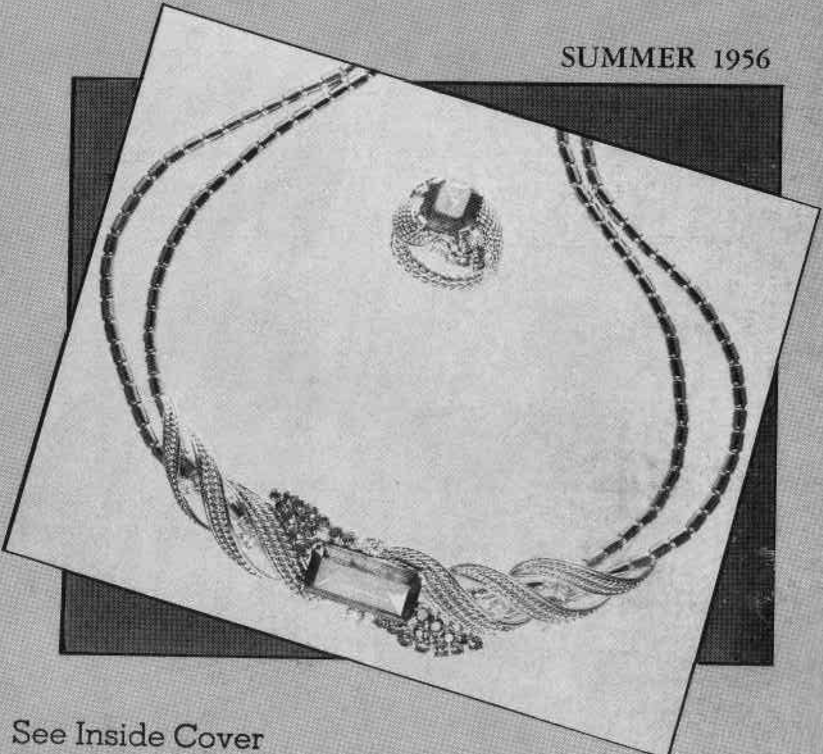

See Inside Cover

Gems & Gemology

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IN THIS ISSUE

On the Cover

A set of cocktail jewelry consisting of a necklace and ring, both made of 18-karat yellow gold and decorated with diamonds, rubies and a large emerald from Habachtal.
The Habach emerald in the ring weighs 6.06 carats and the one in the necklace 10.82 carats.
They are both of a lovely velvety emerald green and contain tremolite inclusions.

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Nigerian Topaz

by

ROBERT WEBSTER, F.G.A.

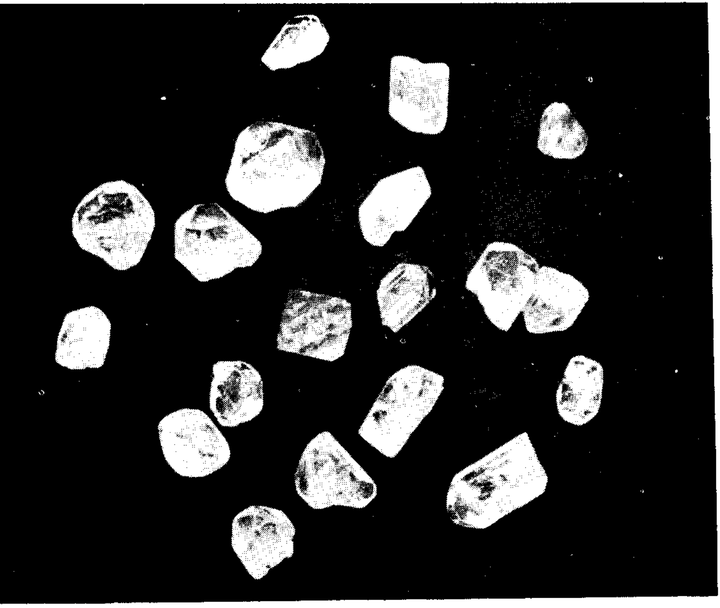
The memorable visit recently made by Her Majesty, Queen Elizabeth II, to Nigeria calls to mind the gemstone resources of this territory, and these few notes describe some of the characters of the topaz found in this locality

The topaz from Nigeria is mostly colorless or occasionally pale blue, and the material is found either as rolled pebbles in the alluvium, in river beds, or as well-formed crystals. The crystals are common in the tin mines, which form a significant economic feature of Nigeria, and which lie around the town of Jos in the Bauchi district. Topaz is such a common associate of tinstone (cassiterite) that the presence of topaz is an indication of tin ores. The minerals are found in veins and fissures in the contact metamorphosed aureoles caused by the younger of the granitic intrusions of the plateau and Bauchi districts, the mineralization being due to pneumatolytic action.

The crystals are short and prismatic in habit, with the second order prism so predominant as to produce a pseudotetragonal form. The faces of the prism zone show distinct vertical striations and the prominent dome faces, which meet to give a "chisel-shaped" aspect, may show etch markings of a triangular shieldlike shape. Some of the crystals show a small basal pinacoidal face at the apex and this face is often pitted by irregular growth or heavy etching. The base of the crystals is usually the cleavage plane but a few have been found doubly terminated. The general habit of the Nigerian crystals is similar to that of the topaz found in the Mino and Omi districts of Japan.

Cut stones generally show a faint trace of greenish or bluish color and are quite brilliant, but colorless topaz is not commercially important. In this connection it may be interesting to note that a parcel of supposedly synthetic white spinels were found, on testing, to be all colorless topaz.

The chemical composition of topaz is given as $Al_2(F,OH)_2SiO_4$; that is, the fluorine and the hydroxyl can replace each other by any amount (isomorphous replacement), so that in theory there could be a pure hydroxyl topaz ($Al_2(OH)_2SiO_4$ or a pure fluorine topaz ($Al_2F_2SiO_4$), but in fact there is always either some hydroxyl or fluorine in the chemical makeup. Fluorine has the tendency to raise the density and to lower the refractive index, whereas hydroxyl operates in the reverse way. It is found that the brown topaz and the heat-treated pink stones derived from them, which emanate from Ouro Preto, Brazil, have a density near 3.53 and refractive indices of 1.63 - 1.64 (birefringence 0.008), whereas the colorless and blue-colored topaz has a higher density (near 3.56) and refractive indices of 1.61 - 1.62 (birefringence 0.010). This indicates a richness in hydroxyl for the former and a richness in fluorine for the latter. The values 1.62-



• Topaz crystals from the Ropp Tin Mines, Ropp District Plateau Province, Nigeria. About one-third natural size.

1.63 for refractive indices of topaz, so commonly given in textbooks, is the arithmetical mean, but such values are rarely found in practice.

That Nigerian topaz conforms to the fluorine-rich type is shown by the specific gravity valuès in table 1.

The refractive indices for the two stones and for No. 5, which was subsequently fashioned into a cushion-shaped stone weighing 11.04 carts, are as follows:

No. 5	1.606	1.6132	1,6217	0.0111
No. 9	1.6106	1.6126	1.6211	0.0105
No. 10	1.6108	1.6123	1.6211	0.0103

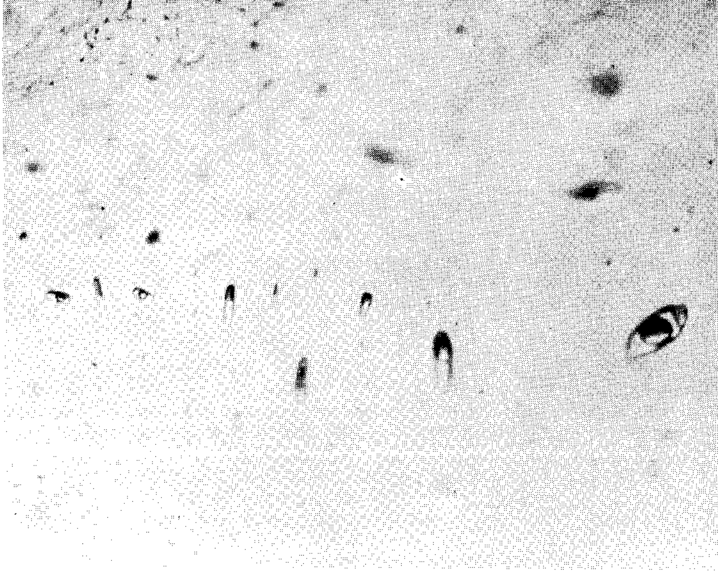
Nos. 2, 3, 4, 7, 9, and 10 were from a locality some 50 miles northeast of Kano. Nos. 1 and 6 were from the Ropp Tin Mines, Ropp District, Plateau Province, and Nos. 5 and 8 were from the Kaleri district.

The inclusions observed in Nigerian topaz are those usually encountered in this species. They are two-phase inclusions, or cavities, containing two immiscible liquids. Large irregular cavities are common, and in one specimen distinct cubic crystals, which may be fluorite, were seen.

The luminescence under ultraviolet light was found to be as follows: long-wave radiation (3650A), practically inert; short-wave radiation (2537A), a faint greenish-blue glow. Under X rays a pale-blue glow could be readily seen, but the stones showed a

TABLE I

No.		Weight in Grams	Specific Gravity
1	Doubly-terminated crystal	4.059	3.549
2	Pebble	3.595	3.557
3	Pebble	1.222	3.557
4	Pebble	1.016	3.557
5	Pebble	4.666	3.557
6	Crystal	6.047	3.559
7	Pebble	1.140	3.566
8	Pebble	3.751	3.567
9	Cut Stone	0.462	3.571
10	Cut Stone	0.521	3.5[illegible]

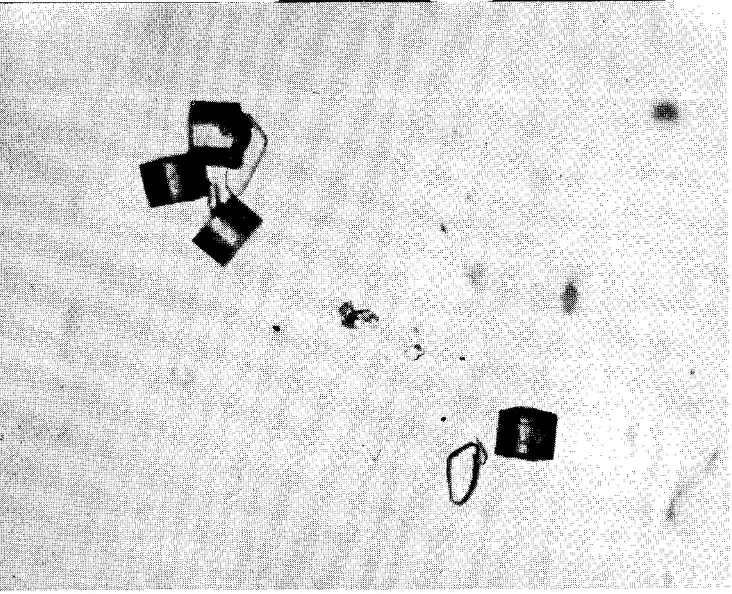


• Two-phase inclusions in a Nigerian topaz.

brown shade, an effect exhibited by many colorless and pale stones of other species. On heating the irradiated stones, a blue thermoluminescence was observed; however, the stones do not necessarily revert to their original color, the induced color remaining to some extent. This is contrary to the behaviour of stones of other species which color under X-ray bombardment.

A great number of the pebbles received by the writer from the locality northeast of Kano were blue in color, and it was hoped that some attractive blue stones could be cut from them. The resulting cut stones were disappointing, since they were completely colorless and investigation proved that the

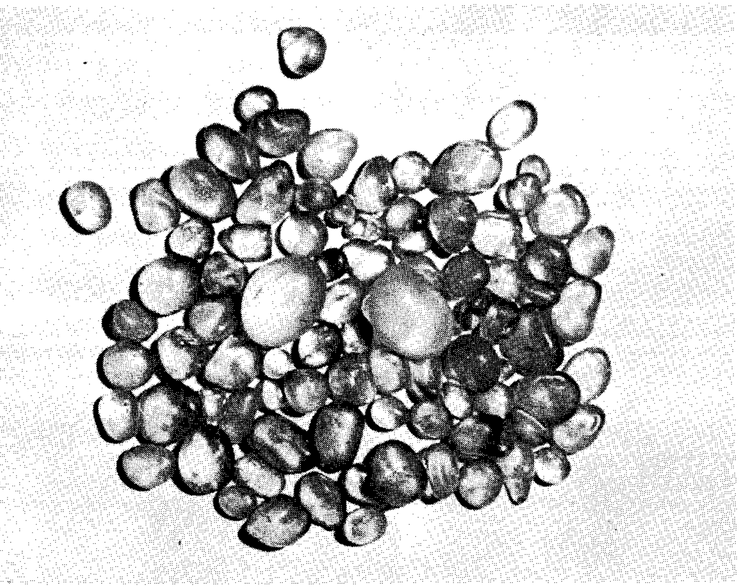
• Large cavities in a Nigerian topaz.



• Cubic inclusions (Fluorite?) in a Nigerian topaz.

pebbles had been colored on the outside with a blue dye. Subsequent inquiry elicited the information that the wily natives had immersed the white pebbles in indigo dye pits. Indigo commonly grows in Nigeria and the native Hausas call it "Babba." Since blue is a common color for native gowns, all the larger places have dye pits. Indeed, indigo dyeing is an important industry. Even along the main road of Jos, the natives do their dyeing in large earthenware pots. The dyeing of topaz pebbles for the unwary European must be an attractive sideline.

Thanks are due to my colleague, Mr. C. J. Payne, who carefully measured the refractive indices, using an Abbe-Pulfrich refractometer.



• Topaz pebbles from a locality 50 miles northeast of Kano. Many of these are surface-dyed blue with indigo.

The Emerald from Habachtal

by

DR. E. J. GUBELIN, C.G., F.G.A.

It was the initial aim of this study to discover whether the emeralds from the Habachtal differed by any local characteristics from the emeralds of other sources.

The emerald deposit of Habachtal in Austria is the only source of emeralds on the European continent and ranks among the oldest known to man. Very sporadically only has it been mentioned in the gemological literature of English-speaking countries[10, 11], and since to date practically no authoritative literature on this deposit exists in English, it may be justified to discuss this occurrence of emerald in some detail.

HISTORY

The occurrence of emeralds in the Salzburg Alps was already known to the Romans, who exploited them simultaneously with the gold mines in the Rauriser Valley. There is evidence that the Archbishop of Salzburg had the mine worked for emeralds in the Middle Ages. Old Salzburg families still retain cut specimens from this source. But the fate of the mine was subject to frequent changes throughout the centuries. Legal as well as illegal prospectors challenged their luck, but at no time did the "Mountain of Green Jewels," as it was called by the native mountaineers, yield its treasures generously. In a mining chronicle published in 1727, the emerald of Habachtal is mentioned among "ores, rocks and stones" of the Duchy of Bavaria, to which the area belonged in the 18th century. The Empress Maria Theresa owned an inkpot, the size of a big man's fist which was sculptured from a Habach emerald. It is now exhibited at the Museum of Art in Vienna. J. Frischolz described the emerald deposit thoroughly in 1821 [1]. But there was no organized exploitation until a jeweler from Vienna started regular mining in 1860, yet with no profitable success. At the beginning of this century an English company was founded which intensified the operations. In 1903-1904 seven thousand carats of emeralds were reported to have been shipped to London, but there was no mention of their quality. In 1906 the operation was suspended; the mine fell into decay and was not repaired until after World War I, when Austrian prospectors resumed mining. In 1936 a Swiss company (Schaffhauser Smaragd A.G.) bought the mine and promoted the exploitation with great energy and generosity. A fifth gallery was driven 110 yards into the mountain. All of these five drifts lay in the emerald-bearing layers. That period is said to be one of the most prosperous; one find, among others, was valued at 20,000 gold crowns. The Nazis hindered further operations of the Swiss company but continued themselves until the mine was confiscated by the Allies after World War II as German property. It was later released as property of the Salzkammergut, the Government of which leased to an old prospector, Col. Hans Zieger, who worked the deposit on a small private basis (Figure 1) with a few employees until his recent death. The cold and rainy summers of the last three years did not favor exploitation. One reason for the continued failures may be due to the fact that the source lies at an altitude of 2100 meters (about 6900 feet) in the rough and pathless area of the Gross Venediger, where for three-quarters of each year winter is in evidence. Frequent rockslides, thunderstorms, avalanches, etc., render approach and access to the mine extremely hazardous (Figure 2), and life in the simple rest camp is most primitive. At present the deposit is worked chiefly by a few solitary prospectors who hold licenses. They are adventurers who attempt to make their fortune at the price of hard labor and privation. The output is not rich. It could, of course, be larger by means of more rational operations, but who would risk investments when licenses are issued for two years only?

LOCALITY

The Habachtal — the name is a distortion of "Valley of the Hay Brook" — is the most picturesque of several valleys descending from the main ridge of the Gross Venediger in the Hohen Tauern towards the northwest. The Hay Brook (Habach) is the outlet of the Habach Glacier and one of the southern tributaries of the Salzach, which it joins near the hamlet of Habach (a local stop of the Pinzgau train). Pinzgau itself may be reached by train from Salzburg via Zell-am-See (Figure 3). The Habach Valley has the characteristic shape of a former bed of a long glacier nose. After the first ascent, which leads through a narrow V-shaped gorge, which was cut through the rocks by the melting waters of the glacier, the valley opens, revealing a U-shaped profile and presenting a beautiful view of the majestic scenery of the snow-

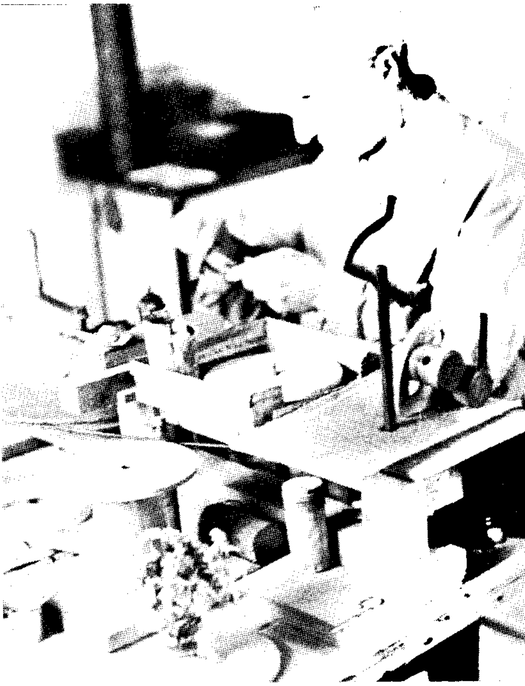


Figure 1.
- **Col. Hans Zieger at his lapidary bench.**

Photograph: H. Zieger

Figure 2.
- **Difficult approach to the mine.**

Photograph: H. Zieger

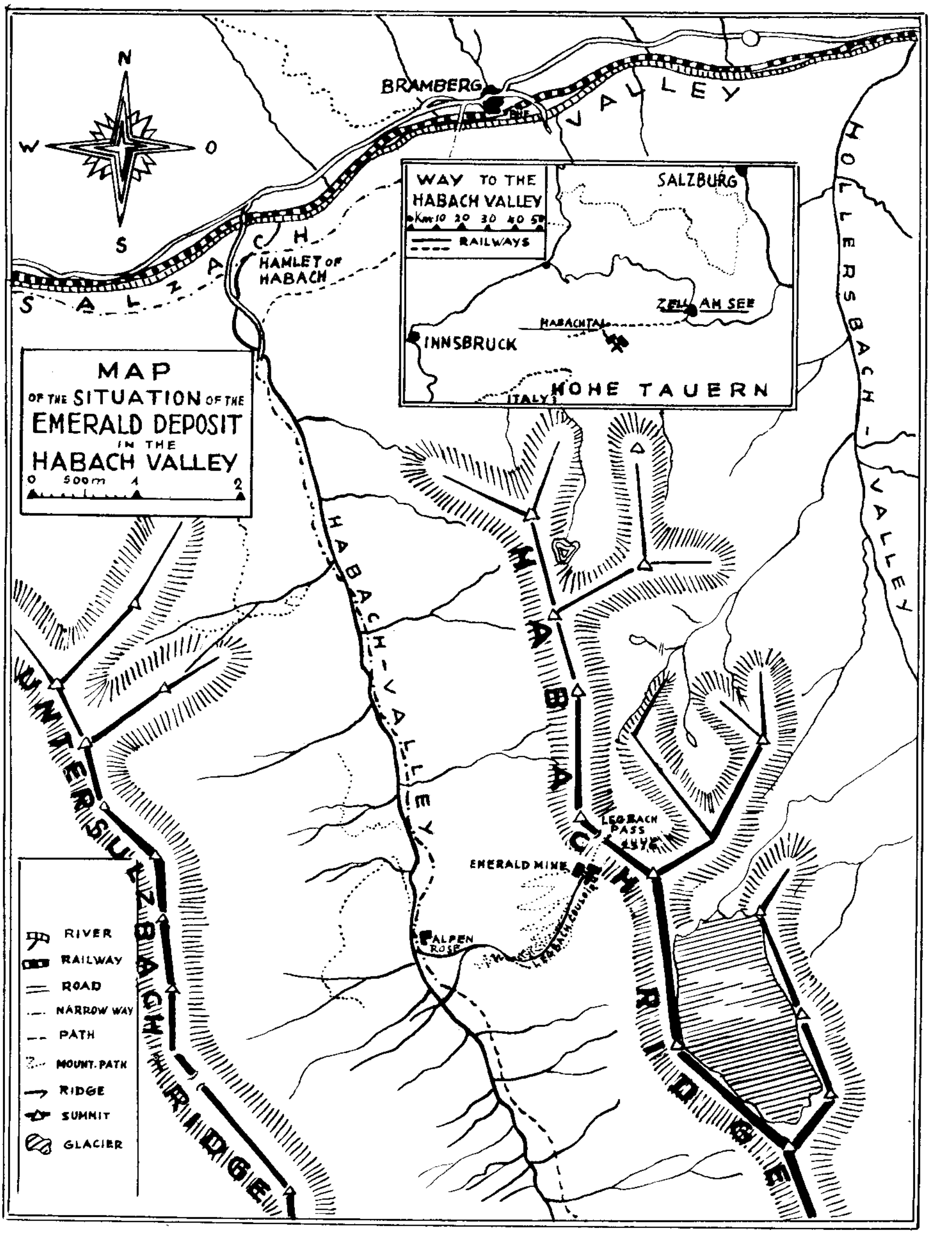


Figure 3.

• Map of the Habach Valley. *Simplified from R. Bölsche (Lit. 7)*

Figure 4.

• **Legbachrinne and Legbachscharte Pass.** *Photograph: R. Bölsche (Lit. 7)*

capped peaks of the Hohen Tauern. After seven hours of rigorous hiking one reaches the mine, which is situated on the western slope of the Habach ridge that forms the side of the Habach Valley on the east. A narrow stony pass called Legbach Scharte (2375 meters) (Figure 4) leads into the neighboring valley to the east, the Hollersbachtal. The emerald deposit is situated a little below this pass in the topmost part of the Legbachrinne (Figure 5).

GEOLOGY

This couloir, which is a geotechnical depression, is situated in the actual contact zone of the two main bodies of rock forming the Hohen Tauern, the central gneiss of the northern side and the schists on the southern side. Originally this contact was an injection contact, and the emerald deposit owes its formation to the intrusion of residual solutions from the granitic magma of the central gneiss.

The local geological conditions are such a classical example of the alteration of old, neighboring rocks by the intrusion of eruptive (igneous) rocks (so-called contact metamorphism), that it may be instructive to give a more detailed description of this deposit.

The gneiss originated from granite which solidified from molten masses in the depths of the earth. During the formation of the mountains it was mauled and assumed a schistose character and thus turned into so-called gneiss. Its color is pale grey-white and its composition of grains of quartz, feldspar and mica may be seen with the naked eye. The disintegration of this gneiss is already quite remarkable.

The amphibolite on the southern side is a dark schistose rock, which, contrary to the gneiss, consists of such tiny mineral components that even with a loupe they cannot be distinguished. Under the microscope thin sections disclose hornblende (amphibole), the main component besides feldspar, zoisite, epidote and others. The hornblende is responsible for the dark-green hue of the amphibolite-schist. This amphibolite is a so-called crystalline schist, which was reformed in the depth of the earth's crust out of some other rocks as a result of pressure and high temperature. This amphibolite happened later to get in contact with the molten masses, out of which the granite (gneiss) was formed through the process of cooling off and solidifying. The couloir of the Legbachrinne is one section of the zone where contact took place. Along this contact zone the molten mass of granite affected the amphibolite and through the reaction of these two rocks new rocks and minerals were formed. The contact rocks and contact minerals of this schist pod are of various kinds. The emerald mother rocks and the emerald itself, being the most precious product of this contact metamorphism, belong to them.

One interesting species of rock is the "migmatite" (mixed rock), which clearly shows some effect of the intrustion process. It was formed by an intermixture of the molten mass of granite with the amphibolite. The migmatites form layers, dark amphibolite layers interchanging with layers of light-colored granite The fact that these layers are often bent and folded is evidence that during the intrusion of the granite into the amphibolite the mountains went through a phase of formation. Another most conspicuous kind of rock is a bright, white talc schist which appears above the emerald mine. This rock is soft and greasy to the touch and in many places it is interspersed with glittering specks of brass-yellow cubes of pyrite. The same pyrite inclusions may also be found interstratified in a further altered rock of this intrusion zone (the aplite), which is almost white and consists of minute grains. This is a gangue which was formed by the molten mass of granite penetrating into clefts of the adjacent rock. The most beautiful rock of this contact metamorphism is a sort of tremolite rock, bearing long, slender, bright, dark-green tremolite crystals in a white groundmass. The serpentine rock belongs to the gabbro group and owes its formation to a metamorphism from peridotite.

In connection with the present study, still another altered rock of this contact zone is of eminent interest: the strongly schistose, dark brownish to brownish-green biotite schist which is the actual emerald-bearing bed of the whole complicated metamorphic schist pod and the mother rock of the Habach emerald. The biotite appears in all colors from deepest black and green through brown to almost colorless transparent plates. The

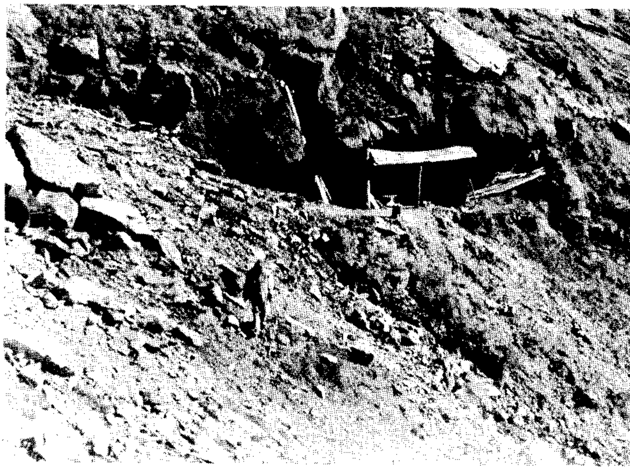


Figure 5.
- **Entrance to the mine**
Photograph: H. Zieger

biotite schists often form veins within the amphiboles, yet emerald and white translucent beryls may occur only in a few places and only within hanging aplites or where strongly dispersed with aplitic veins. The best specimens, clear and with few or no cracks, are found in the softest, talcy parts of the biotite schist, where they were able to develop undisturbed. Also in tremolite schists, talc schists, and very rarely in actinolite schists, have emeralds been found, but only in closest relationship to biotite schists.

Microscopic and chemical examination revealed that the distribution of rock, the variety of minerals, and the transportation of material during the formation of the deposit show greatest similarity to those larger and richer emerald mines in the eastern Siberian Urals. In the Habach Valley the central gneiss must have brought all the minerals. Free silica and potash must have reacted with ingredients of the melanocrate basic rock pods; MgO, FeO, and CaO forming great masses of biotite schists along with tremolite, actinolite and chlorite. It is interesting to note that here in the Habach Valley below the Legbach Pass the same arrangement and succession of mixture rocks may be observed as described by Fersmann for the emerald deposits in the region of the Tokowya in the Urals, namely:

a) Aplite (present in Ural pegmatite)
b) Biotite schists
c) Tremolite, actinolite, and chlorite schists
d) Talc

According to Fersmann, these are the rocks of the emerald series and all four of them are in close contact with each other[2,3,4].

THE EMERALD COLOR

The majority of beryls (which never occur as massive pieces, but always as well developed euhedral crystals) are green, whereas only a small part shows true emerald-green color. Most are pale sea-green, gray-green, and sometimes particolored white and green. White and yellowish varieties are rather rare. The green hue of well-colored emeralds from the Habach Valley is extremely beautiful. Some jewelers consider it the finest velvety emerald green that exists. Indeed, the highly prized green of the finest emeralds occurs more often in the Habach emeralds than in emeralds from Muzo, El Chivor, Tokowaya, Transvaal or India. As in all emeralds, the green hue is caused by an intermolecular impurity of chromium oxide, of which H. Leitmeier in his chemical analysis found .12% to be present in pale emeralds and .16% in deep-green emeralds. This again substantiates the contention that the percentage of the chromium content is responsible for the shade of the emerald-green hue. However, the greatest number of these stones are unfortunately marred by numerous inclusions; hence the appearance and value of the otherwise beautiful Habach emerald are completely impaired.

CRYSTALLIZATION

All varieties of beryl in this Habach deposit developed the same habit. The emerald from the Habach Valley has poorer crystal faces than the emeralds from other sources. Without exception only the prism face (1010) and the base (0001) are developed, though the latter is usually absent. In the biotite schist the emeralds lie partly parallel and partly oblique to the schist plane (Figure 6). In the latter case they are often developed as tablets, in that two opposite prism faces dominate, although they may sometimes recede so that the crystals assume a rhombic habit.

CHEMICAL COMPOSITION

H. Leitmeier carried out numerous analyses with abundant material, the purest of which gave the following values:

BeO	12.28%
MgO	1.82
CaO	.71
Al_2O_3 Fe_2O_3 Cr_2O_3	18.20
SiO_2	63.24
H_2O	3.03
	99.28%

Figure 6.
• **Habach Emeralds in situ**
Photograph: R. Bölsche

If when considering theories of crystal structures the calculation was based upon RO only for the value of Be0, and R_2O_3 only for Al_2O_3 and Cr_2O_3, the chemical analysis would concur well with the formula, which would allow one to assume that by far the majority of the other elements do not act as atomic replacements. One would obtain:

$$1\ R_2O_3 : 3.1\ RO : 6.2\ SiO_2\ \ (:1\ H_2O)$$
$$= Al_2O_3.BeO.6SiO_2$$
$$= Be_3Al_2Si_6O_{18}$$

The chemical composition, just the same as the particular geological circumstances of the deposit, offers instructive information on the formation of the emerald. Beryllium, which occurs in the composition as BeO, is a chemical element which originates from the granite; the anphibolites do not carry any beryllium. The color pigment chromium, present as Cr_2O_3, was offered by the serpentine rock, which, as a member of the gabbro group, brought that valuable element into the process of contact metamorphism.

PHYSICAL PROPERTIES

The determination of the specific gravity was carried out by the hydrostatic method with a semiautomatic Mettler balance, immersing the stones in ethylenedibromide. It proved rather difficult to obtain constant density values for all the material tested, the reason for this being partly the enormous quantity of impurities which are so densely enclosed by almost all Habach emeralds. However, this variation in values should be attributed to the variation in chemical composition rather than to mere inclusions, and mainly due to the impurity of ferric iron (Fe_2O_3), which forms a structural impurity by isomorphous replacement. The density

TABLE NO. 1

Emerald from Habachtal		Refractive Indices			Specific Gravity	Dichroism
		ω	ε	Δ		
15.35ct	No. 1	1.59505	1.5880	—.00705	2.7470	ω yellowish green ε blue green
11.79ct	No. 2	1.5925	1.5856	—.0069	2.7395	ω yellowish green ε bluish green
10.82ct	No. 3	1.5901	1.5831	—.0070	2.7536	ω greenish yellow ε bluish green
6.06ct	No. 4	1.5922	1.5853	—.0069	2.7522	ω yellow-green ε bluish green
4.77ct	No. 5	1.5970	1.5901	—.0069	2.7460	ω yellow-green ε bluish green
—.69ct	No. 6	1.5919	1.58466	—.00724	2.7670	ω yellowish green ε bluish blue-green
—.26ct	No. 7	1.5901	1.5831	—.0070	2.7401	ω yellowish green ε bluish blue-green
—.60ct	No. 8	1.5880	1.58094	—.00706	2.7309	ω yellowish green ε bluish blue-green
—.44ct	No. 9	1.58514	1.57815	—.00699	2.7203	ω yellowish green ε bluish blue-green
—.54ct	No. 10	1.5871	1.58002	—.00708	2.7266	ω yellowish green ε bluish blue-green
—.62ct	No. 11	1.5892	1.5821	—.0071	2.7337	ω yellowish green ε bluish blue-green

was found to vary from 2.72 to 2.76, with an average value of 2.74.

All the author's data pubished hereafter were measured with an Abbé-Pulfrich refractometer and, despite small facets on the smaller stones, reliable values could be read in all directions. It was interesting to observe that dark specimens showed higher indices and the birefringence remained quite constant for all stones tested. Chromium content seems to have a greater influence on this variation than the amount of iron. The following average values may be established:

$\omega = 1.591$ $\varepsilon = 1.584$ $\Delta = 0.007$

No optical anomalies were observed.

Keen gemologists may be interested in receiving more detailed information of the findings with individual specimens (wide special Table No. 1).

TABLE NO. 1

The average data from Table No. 1 may

TABLE NO. 2

Authors		ω	ε	Δ	Spec. Gravity	
H. Leitmeier	No. 5	1.5819	1.5769	—.005	2.703	Lit. 2
H. Leitmeier	No. 7	1.5790	1.5740	—.005	2.704	
Böse	No. 30	1.5907	1.5839	—.00681	2.740	Lit. 9
W. F. Eppler		1.5907	1.5839	—.00681	2.740	Lit. 8
R. Webster		1.591	1.584	—.0068	2.740	Lit. 10
E. Gübelin		1.591	1.584	—.007	2.740	

Absorption	Chelsea filter	Fluorescence			Inclusions
		Stokes'	U-V long 3650A	U-V short 2537A	
normal: 6830, 6800, 6620, 6460, 6370, 6300-5800	red	distinct, pale red	inert	inert	tremolites
normal	red	distinct, red	inert	inert	biotite, microlites & sec. liquid inclusions
normal	red	distinct, red	inert	inert	tremolites
normal	red	distinct, red	inert	inert	Numerous inclusions, parallel fine fissures
normal	red	distinct, pale red	inert	inert	numerous inclusions, polysynthetic layers parallel to basis
very strong, all lines are broad bands	red	weak, red	inert	weak, red along girdle	tremolites
normal	pink	strong, red	inert	inert	All of them contain many inclusions, especially biotite, fissures, tremolites, apatites, other microlites and secondary inclusions
normal	pink	strong, red	inert	inert	
normal	pink	strong, red	strong, red	inert	
normal	pink	strong, red	strong, red	inert	
normal	pink	strong, red	inert	inert	

now be compared with indications published by other authors.

TABLE NO. 2

In order to reveal how individual and of what local importance these values of the Habach emerald are, especially with a view to clearly recognizing them and distinguishing them from emeralds of other localities, the data become particularly instructive when compared with the average constants of emeralds from other sources.

TABLE NO. 3

The dichroic colors vary slightly according to the specimen's body color, but may generally be described as yellow-green for ω and bluish green for ε in dark stones. The dichroism is never strong.

The absorption spectrum appears to be

TABLE NO. 3

Locality	ω	ε	Δ		Spec. Gravity
Transvaal	1.593	1.586	—0.007	(Lit. 10)	2.78 - 2.72
Indian	1.593	1.585	—0.007	(Lit. 10)	2.73 - 2.74
Habachtal	1.591	1.584	—0.007		2.72 - 2.76
Eidsvold	1.5908	1.5838	—0.007		2.759
Siberian	1.588	1.581	—0.007	(Lit. 10)	2.72 - 2.74
Columbian (Muzo)	1.584	1.578	—0.006	(Lit. 10)	2.71
Columbian (El Chivor)	1.577	1.571	—0.006		2.69
Brazilian	1.571	1.566	—0.004/—0.005	(Lit. 10)	2.67 - 2.70
Synthetic	1.564	1.561	—0.003/—0.004	(Lit. 10)	2.645 - 2.665

normal with slight changes in the strength and width of the absorption lines and bands, and all of the following were observed: 6830, 6800, 6620, 6460 and 6370.

Through the Chelsea filter the Habach emeralds appear pink, a very pale pink in transmitted light but pronounced pink in reflected light.

The high iron content in the majority of the Habach emeralds acts as a strong inhibitor of fluorescence in ultraviolet light (both long and short waves). Only along the girdles of some thin slabs or stones of low specific gravity can reddish fluorescence be observed. On the other hand, the fluorescence is quite distinct between the crossed filters of Stokes' fluoroscope and varies from red for dark stones to pink for paler ones.

INHOMOGENEITIES AND INCLUSIONS

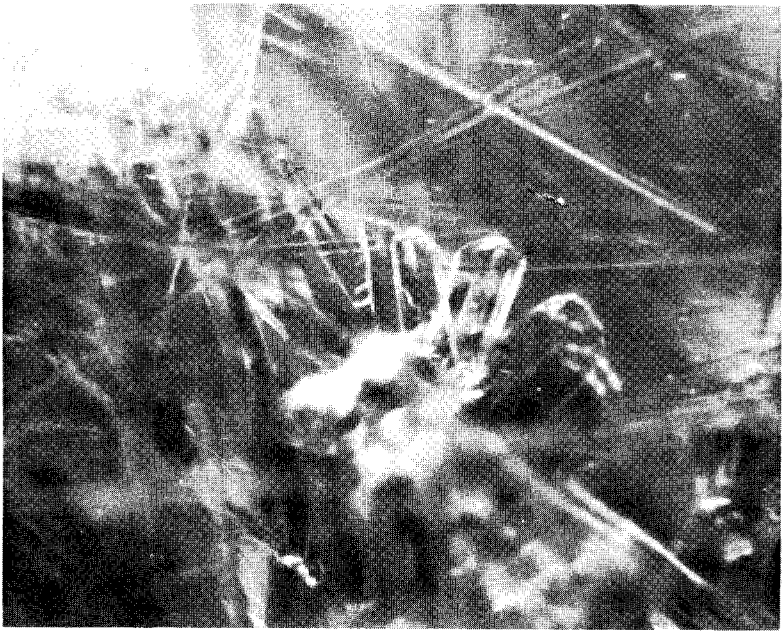
The dense cloudiness of the interior, which makes most Habach emeralds so turbid to the naked eye, reveals itself to be a multitude of fascinating inclusions, which are very characteristic of this locality. Cleavage parallel to the base is quite remarkable. Specimens without any cleavage cracks or indications thereof, are quite rare. As a matter of fact, this easy cleavage is perhaps the most serious drawback of Habach emeralds, in that the crystals very often do not only break readily under the slightest pressure (even when carefully removed from their mother rocks), but also frequently contain a succession of numerous cleavage cracks. Open cleavage cracks into which biotite has intruded appear quite often. In addition, numerous fissures and fracture cracks may occur which usually traverse the crystals with striking regularity and at angles deviating from 10° to 20° from the basal plane. Together with the cleavage cracks, they often form a lozenge-shaped grill pattern. As long as the crystal still lies in its mother rock it may be observed that many of these cracks run parallel to the exfoliation of the surrounding schists.

Apart from these cleavage and fracture cracks which still persist, the stones show proof of successful healing activity during their growth, since they are often densely interspersed with healed fissures. This proves that in the course of crystal formation we may conclude that some mechanical forces must have caused fractures, and while the beryl formation continued the cracks filled with healing substance out of the mother liquor. Very often this healing liquid lacks pigment, resulting in a thin colorless layer within the otherwise green emerald. This observation may allow the assumption that the Cr_2O_3 was exhausted during the early phase of beryl formation which resulted in emerald, whereas in a later phase only colorless beryls were able to grow. These healing fissures are the cause of the numerous liquid feathers which form irregular, wavy conchoidal planes traversing the crystals in all directions.

Since most of the minerals of the rocks in the "emerald series" were formed almost simultaneously, we may expect to encounter most of the externally paragenetic minerals again in the internal endogenesis of the Habach emeralds. Thus we find biotite, tremolite, tourmaline, apatite, epidote, sphene and rutile in evidence (Figures 7 and 8). Biotite is by far the most frequent mineral inclusion, often intruding the emerald through its surface: i.e., from the mother rock extending through the host, partly irregular and partly along cracks. Sometimes these cracks, accompanied by biotites, run parallel to the exfoliation of the former matrix through the emerald which would be oblique according to the relative position of the crystal in the schistose rock (Figure 9). In many emeralds there are clusters of biotite "books," which are nothing but tiny enclosures of the mica component of the mother rock. Then again, biotite laminae are strewn singly throughout the crystal (Figure 10) or filed into parallel or irregular rows. This biotite is either brown (in all shades) or completely colorless in thin leaves; again, it may be light to dark green in ac-

Figure 7.
- Liquid and solid inclusions. 120x.

Figure 8.
- Enclosed apatite crystals. 80x.



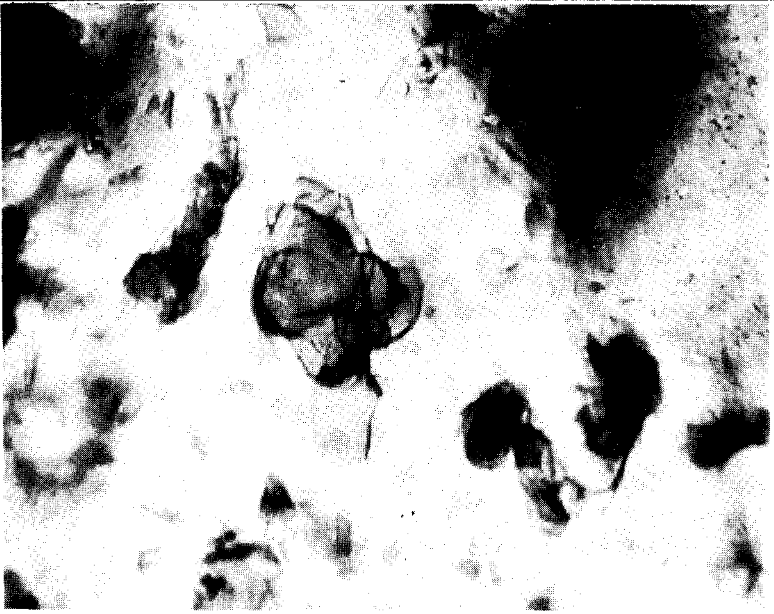
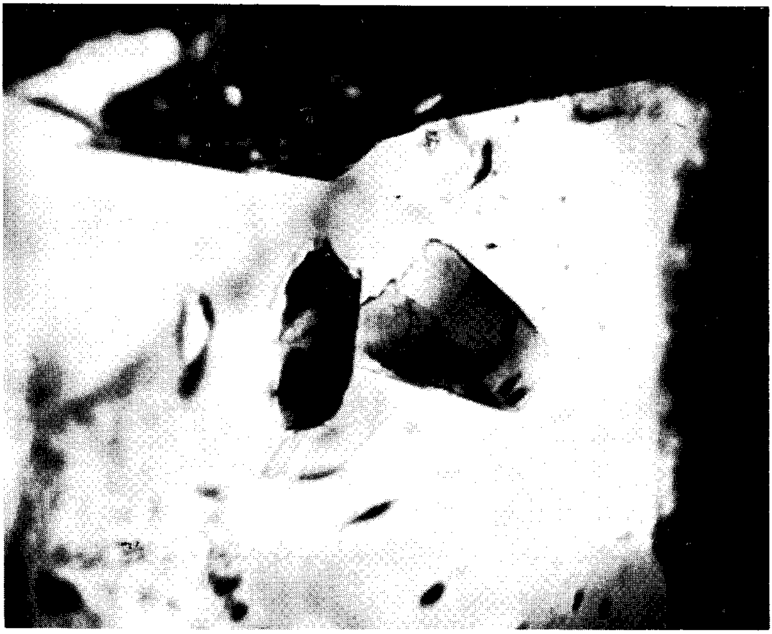


Figure 9.
- Strongly resorbed biotite flakes. 120x.

Figure 10.
- Individual biotite plates. 80x



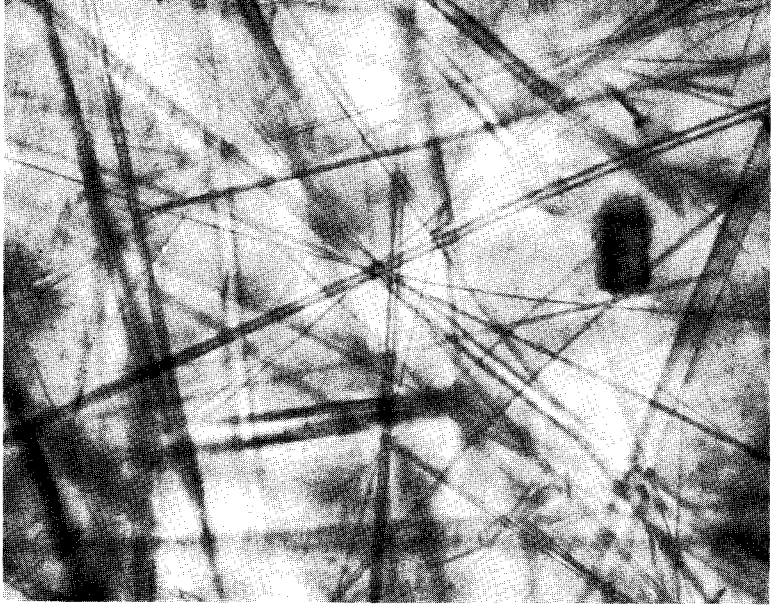


Figure 11.

- Fine tremolite rods traversing the entire emerald crystal. 75x.

Figure 12.

- Tremolite needles densely packed in emerald. 75x.

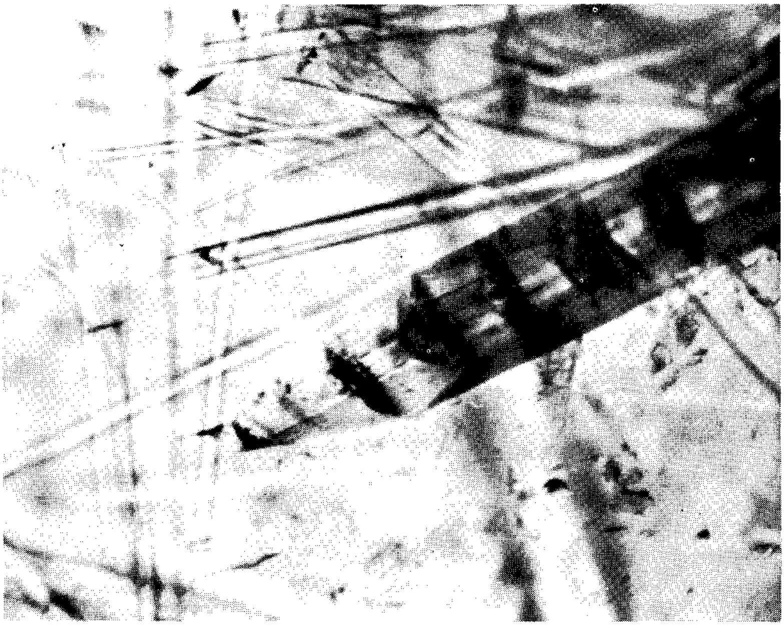
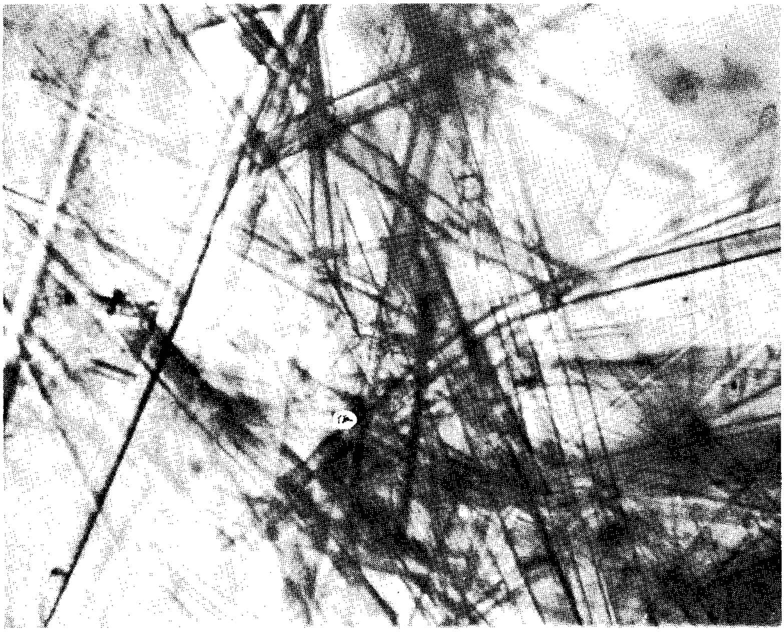


Figure 13.

- Strongly enlarged euhedral head of a tremolite rod. 120x.

Figure 14.

- Broad tremolite blades, some of them bent. 75x.



cordance with the rock in which the host emerald was formed. Also, the biotite is not always fresh and well preserved but quite often surrounded by a brown coating of hydrate of iron oxide or strongly resorbed. Sometimes biotite seems to have disappeared so that only the residual ferrite substance may be seen. The biotite inclusions are almost always accompanied by liquid inclusions, either irregular cavities or negative crystals, very often forming two-phase inclusions and frequently so tiny and so numerous as to form feathers. They are the type which are most common in beryls and they are mainly responsible for the turbid appearance and hence the inferior quality of the Habach emeralds of the biotite schists.

The emeralds from the tremolite rocks are considerably clearer and more beautiful, although their color may not be as fine but rather a cold bluish green. They are, on the other hand, less frequently and less densely marred with cracks and yet they are normally filled with a great quantity of tremolite needles (Figure 11) or broad blades. They may either traverse the entire host crystal (Figure 12) or end within its body with broken stumps (Figure 13) or with euhedral heads. They are usually evenly distributed through the emerald or congregate in clusters and bundles and are not always straight but often bent (though rarely crushed) (Figure 14). Their color is always green but varies from pale to dark shades. The phenomenological picture of these tremolite inclusions is absolutely unique and most characteristic for Habach emeralds, particularly to the jeweler, since most cut specimens originate from the tremolite rocks which produce the clearer emeralds. This type of inclusion cannot be easily confused with those in emeralds from other sources, not even with Ural emeralds, although these are characterized by actinolite inclusions which admittedly show some resemblance to tremolite. Rutile inclusions are quite rare, but sometimes occur in dense masses within a single crystal. The clearest of all are the bluish emeralds from the barite-mica rocks. They contain none of the above-described mineral inclusions and usually have very few cracks.

SUMMARY

Detailed investigation of the deposit demonstrated it to be a classical example of emerald for formation in biotite schist and revealed close relationship to the deposits in Siberia, India and the Transvaal. As regards physical properties, the emerald from Habachtal ranks well with emeralds of similar occurrence and even excels by its phenomenological physiognomy of internal paragenesis.

I hope that with this study further light has been thrown on a relatively unknown but nevertheless very interesting emerald deposit, which as a source of one of the rarest and most beautiful precious stones is worth bringing to the attention of jewelers and gemologists.

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Simplified Manufacture of Diamond Tools

by

R. G. WEAVIND, M.Sc. (Eng.)

Note: The following article is a verbatim reprint of an article appearing in the March 1956 issue of OPTIMA, a quarterly review published by the Anglo American Corporation of South Africa.

Diamond tools are so important in modern engineering that any means of increasing their supply or bringing the exacting task of making them within the scope of other tool manufacturers must greatly assist the engineering industry and all who depend upon it. Developments with these objects in view were recently completed successfully by the Diamond Research Laboratory in Johannesburg, which is now making the results of its work freely available throughout the world. Brief reference was made to these developments in December, 1955, issue of "Optima." In the following article Mr. R. G. Weavind explains in greater detail the methods and equipment that may be used to make more economical use of available industrial diamonds and to produce tools to exacting tolerances without the highly specialized knowledge normally associated with such work. Mr. Weavind is the Joint Director of Research at the Diamond Research Laboratory.

The development of precision engineering in recent years has created a great demand for precision tools. And in the manufacture of such tools the diamond has no rival.

In the production of jet aircraft and guided missiles, for example, diamond tools have a vital function. Certain parts can best be made by grinding rough castings accurately to shape. The grinding is done with abrasive wheels having the form necessary to produce the final shape of the part. These wheels, however, wear rapidly in use, and unless they were continually dressed to shape, the critical dimensions of the parts they make would vary considerably. To maintain the uniformity of these parts, the wheels are re-shaped by means of diamond tools. The rising demand for jet aircraft and guided missiles is only one reason for the growing demand for diamond dressing tools.

In tools of this kind, the diamond forms the hard working face. A tool for dressing grinding wheels, for instance, usually consists of a steel shank, one end of which is chisel-shaped. In this end a diamond, or a piece of a diamond, is set and ground or polished so that the tip conforms to a definite curve with a radius that may range from two to twenty-five thousandths of an inch. Whatever radius is desired, however, is made to very close tolerances.

Some dressers are set with whole stones, which are not shaped for use. These tools are used only to clean or to square up the face of a plain grinding wheel; but, as there is no difficulty in manufacturing such tools, they will not be referred to in this article.

Other types of diamond-tipped tools requiring shaped stones are lathe tools and indenters, both of which are used in modern industry, though not to the same extent as the chisel-edged wheel dresser.

The diamond is used as the working face of these tools because it is extremely hard and has high resistance to abrasion. These characteristics raise the diamond far above competition from other materials, but, in the past, diamond tools have been relatively expensive, and a continued high cost would possibly be a deterent to their use on a large scale. Cost, in any case, becomes a major factor if the user cannot make and service his own tools and therefore has to carry a large stock to ensure uninterrupted production.

The manufacture and servicing of diamond tools has long been regarded as difficult and highly-specialized work. The Diamond Research Laboratory, in Johannesburg, has for some time been investigating the possibility of simplifying manufacturing procedures by the development of semi-automatic machinery by means of which diamond tools can be made without the services of highly-skilled cutters. The problem of making diamond tools from whole stones, which have to be sawn and cleaved into the rough shape of the final tool, has also been studied. A course of training has been prepared so that men with little or no knowledge of the diamond can be taught very quickly to be able to make and service diamond tools. The first course, completed recently, showed that persons of normal intelligence can be shown, in as little as six weeks, how to select diamonds, divide them into the small pieces for tool tips and polish them accurately to the shape required. The Diamond Research Laboratory is prepared to give further courses for manufacturers who would like to take advantage of this training.

When tools with shaped stones are made, manufacturers generally choose diamonds that have approximately the same form as that of the finished tool. This practice has the advantage that the tool can be made easily and quickly, but there are also disadvantages. For instance, when only "shape" diamonds are used, the production of tools is limited to the number of stones available. Furthermore, when the object is to retain the basic natural shape of the stone, it is not always possible to orientate the diamond in the tool shank to bring the cleavage planes perpendicular to the direction of stress. This is important, because diamonds split relatively easily along the cleavage planes, and any excessive stress in the direction of these planes will cause the stone to break. It is also difficult to arrange that the diamond will be presented to the work so that wear will take place in the direction of maximum hardness.

These difficulties can be overcome if, instead of being limited to stones of a particular shape, tool manufacturers can use stones of any shape or form. Since industrial diamonds are bought in "parcels" that contain stones of various shapes and forms, it is obviously an advantage to be able to choose any stone from the parcel and to make a tool or tools from it. Flawed diamonds can also be used if the manufacturer knows how to saw, cleave or polish the flaw out of the stone.

For these reasons, the courses instituted by the Diamond Research Laboratory include

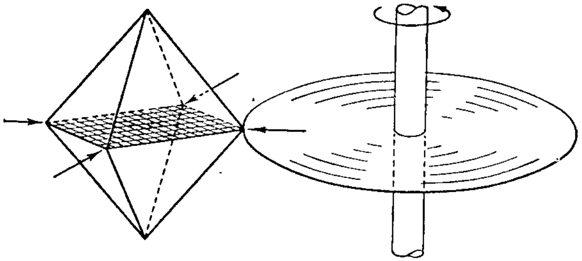


Figure 1.

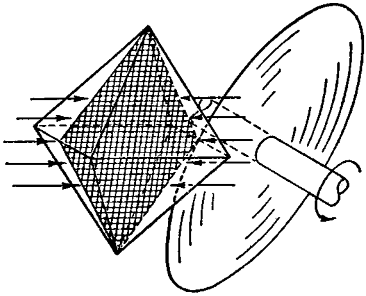
brief training in crystallography and the methods by which diamonds may be divided into smaller pieces. The students are taught to recognize the crystal form in any diamond, and when they can do this the direction in which diamonds can be cleaved, sawn or polished can be found readily.

One of the fundamental characteristics of a diamond is that it can be cleaved only along certain planes and it can be sawn only in certain directions; the cleavage planes and the directions in which it can be sawn do not coincide. If the diamond is to be shaped by polishing it on a conventional scaife (a revolving polishing wheel), then this can be done only in directions determined by the "grain" of the stone. If a diamond-impregnated grinding wheel is used, however, the stone can be shaped more quickly, and the grain is of little importance.

Diamonds are usually found in nature as octahedrons or dodecahedrons or distortions of these shapes. Occasionally they occur as cubes.

To divide a diamond into smaller pieces suitable for making tools, it may be either cleaved or sawn. It is not difficult to find out in which directions a stone may be cleaved or sawn once the crystal form is recognized. For example, an octahedron can be split along planes that are parallel to the faces of the stone. It can be sawn in planes perpendicular to a line joining the apices of the two pyramids or at right angles to these planes.

Figure 2.



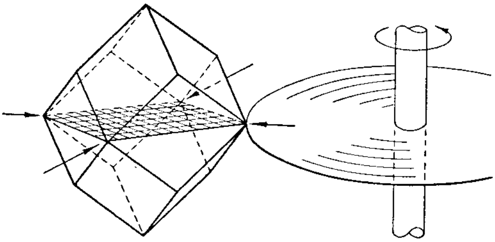


Figure 3.

Figs. 1 and 2 indicate this more clearly.

Dodecahedrons, on the other hand, may be cleaved in planes perpendicular to the line joining opposite corners where three edges unite. Sawing can be done in planes perpendicular to the line joining opposite corners where four edges unite or at right angles to these planes. This can be seen in Figs. 3 and 4.

When conventional methods are used, the diamond can be polished only in certain directions, which are determined by the particular plane in which polishing is attempted. Reference to Fig. 5, which indicates the basic faces of the diamond, will illustrate this detail. When the stone is to be polished on an impregnated wheel, it is possible to do so without paying strict attention to the crystallographic structure. The diamond-impregnated wheel is thus a very important article in the toolmaker's equipment. Not only can diamonds be ground in any direction but abrasion also proceeds very much more rapidly, and the presence of knots in the stone does not slow the speed of grinding to the same extent as with conventional methods. Knots, or "naats," are the result of abnormal growth in the diamond.

It will be seen that, with the necessary knowledge and little practice, it is relatively easy to divide diamonds into smaller pieces for use in tool tips. Fig. 6 shows how a

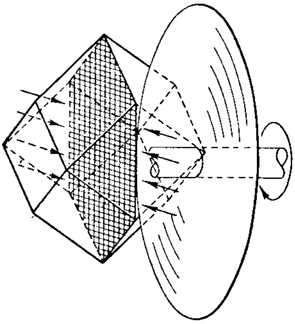


Figure 4.

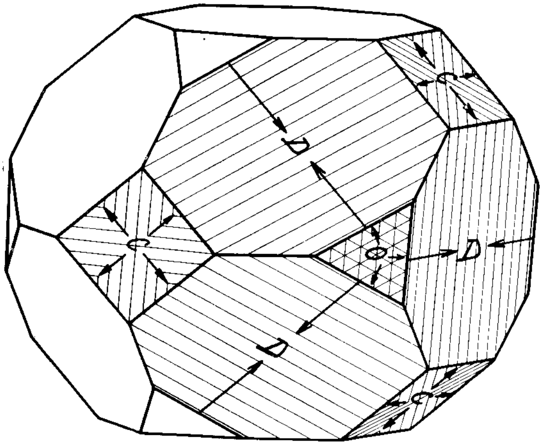
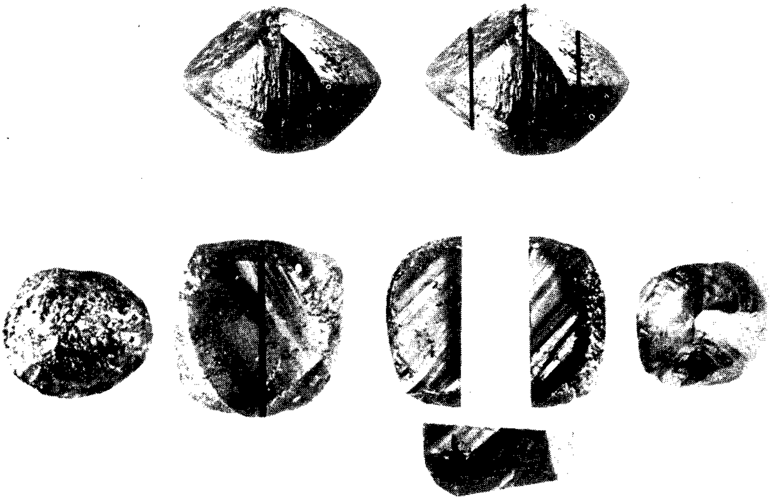


Figure 5.

• This diagram shows the basic faces of a diamond. Those marked "C" represent the faces of a cube; "D" indicates a dodecahedron, and "C" an octahedron. The arrows indicate the correct directions for grinding each face.

Figure 6.

• The dodecahedron diamond in the first row is marked for sawing into the four pieces shown in the next row. The second piece has been marked for sub-division, and the third piece has been divided along a similar plane. At the bottom of the photograph is shown one of the pieces after being polished to a chisel shape.



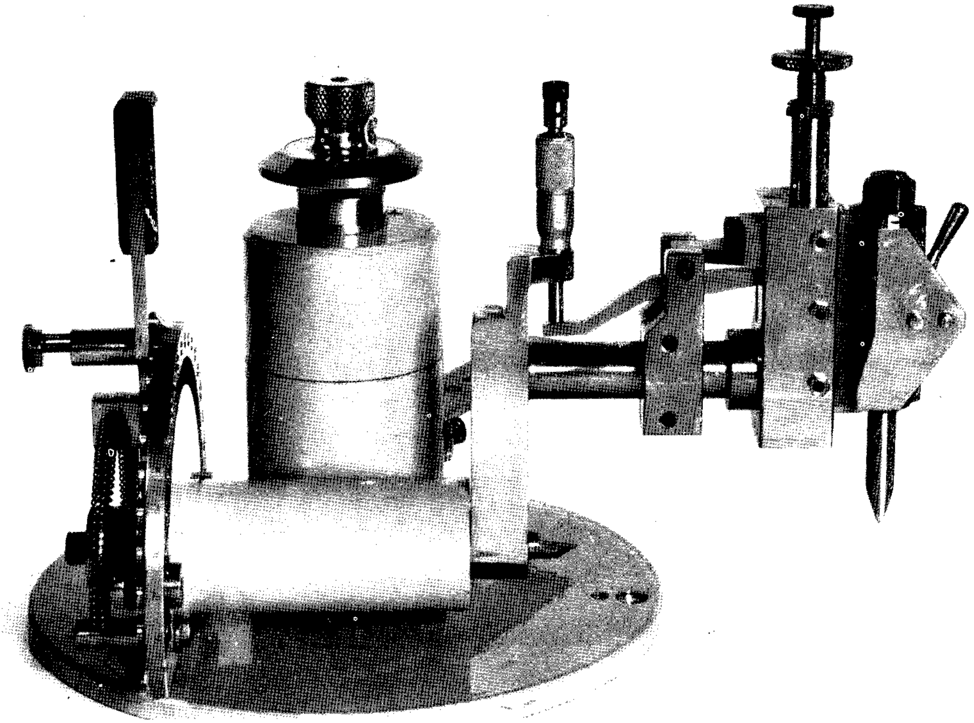


Figure 7.

- **The semi-mechanical tang developed by the Diamond Research Laboratory.**

dodecahedron can be sawn into pieces. The two outer pieces are suitable for lathe tools; the two inner pieces can be further subdivided to give four points suitable for chisel-edged tools. Thus, from one stone six tools can be made. One of the pieces obtained by sub-division is shown after grinding to shape. The polished end on the right of the piece indicates a side facet of the tool; this and similar facet on the opposite side give the tool a chisel shape. The tip of the diamond has been rounded off to a radius of two-thousandths of an inch. For the photograph the diamond was removed from the metal shank of the tool.

In use, the tool is presented to the work so that the rounded tip will form a groove of the corresponding radius in the grinding wheel. When the diamond tip is cut out of the original stone and ground to shape, as indicated in the photograph, the tip of the stone will present the most "wear-resistant" face to the work. If the piece were cut from the original stone so that the rounded tip was made at right angles to the above orientation, wear would take place in the direction of least resistance, and the tool would fail much earlier in use.

Naturally, the number of pieces to be cut from a stone depends on the size of the original stone, the type of tool required and the size of the tool tip. It should also be remembered that industrial diamonds are sometimes flawed, and flawed pieces cannot be used in tools.

For shaping the pieces required for tool tips the semi-mechanical "tang," illustrated in Fig. 7, has been developed by the Diamond Research Laboratory. This machine is intended to be used primarily for making tools with a radiused tip. By using appropriate jigs, however, faceted tools can be made with this machine. Jigs for grinding faceted or radiused lathe tools and Vickers hardness indenters are shown in Fig. 8.

The tang is designed for use in conjunction with the modern type of diamond polishing mill, shown in Fig. 9. These mills are normally supplied with a cast-iron scaife, but, for the reasons already mentioned, a diamond-impregnated wheel can also be fitted.

The design of the tang permits the height of the tool tip to be adjusted accurately above the level of the plate so that any desired radius of curvature can be produced. The tool can be removed from the machine during the grinding process for examination, and the tool-holder can be turned through 180 degrees in the longitudinal axis and replaced in the machine so that the grinding direction of the tip may be altered for "grain-finding" purposes if necessary. In each case, when the holder is replaced in the machine, the tool tip will locate itself within two-thousandths of an inch of its original position. It will be appreciated that such accuracy is essential when the radius of curvature of the tool tip is only two-thousandths of an inch. A variation of five ten-thousandths of an inch would mean 25 per cent error.

When certain types of tools are made, such as Rockwell indenters and others having a conical or spherical shape, it is necessary to alter the grinding direction continuously. If this is not done, flats and ridges will appear, corresponding to the hard and soft planes in the diamond.

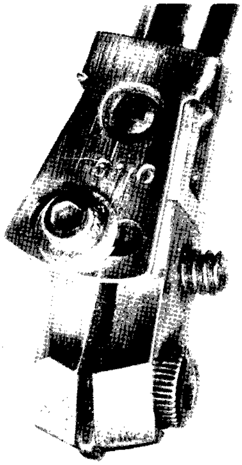
To simplify the process of finding the correct grinding direction for the diamond, the tang allows the tool tip to be moved through a horizontal arc over the face of the grinding plate. In cases where it is necessary to change the direction of grinding continually, this movement can be applied mechanically if required.

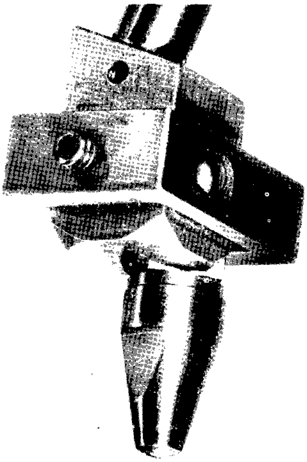
Figure 8.

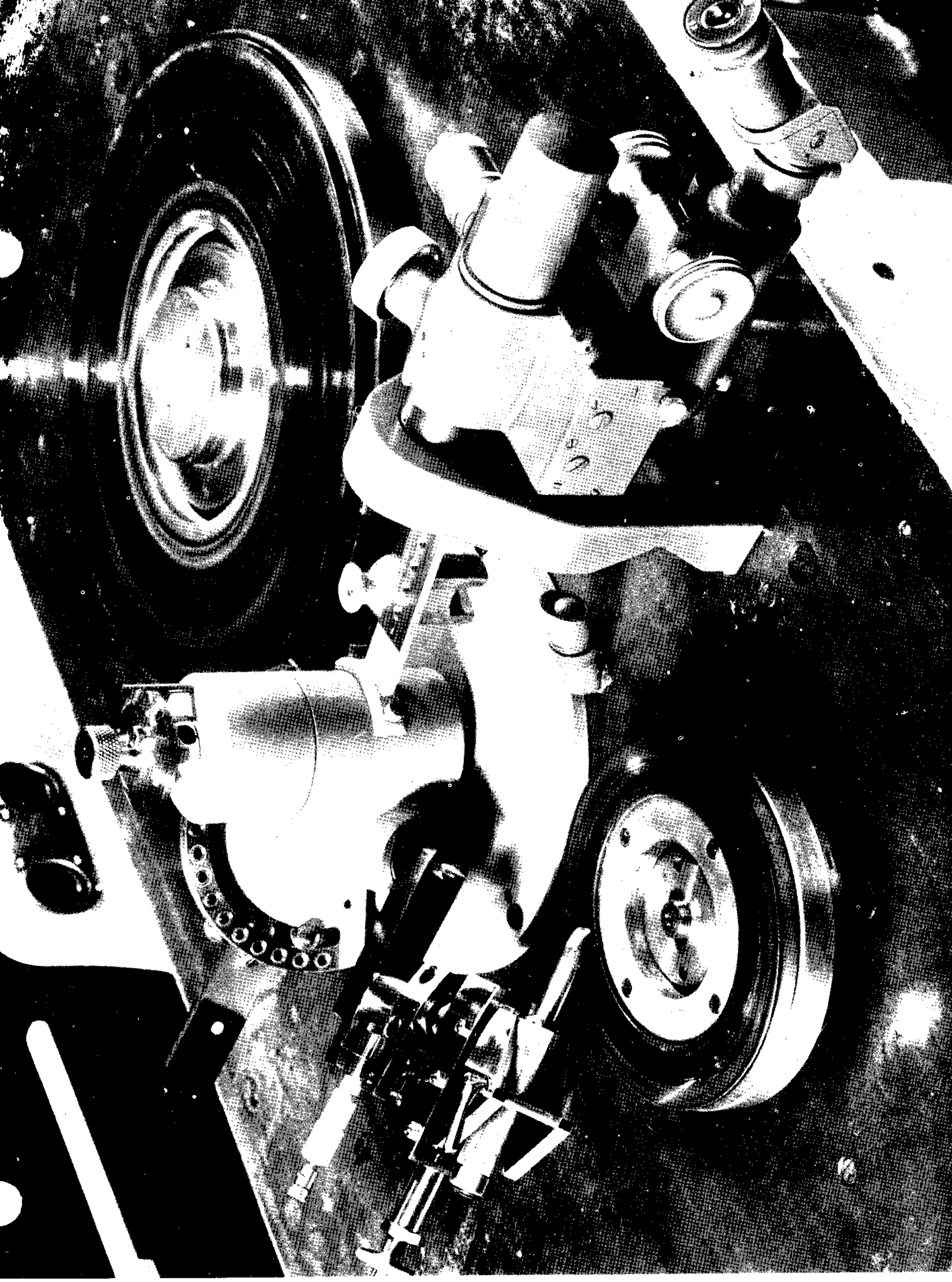
• On the left is a jig used for grinding tips for lathe tools. The jig on the right is used for making hardness indenters.

Figure 9 **(opposite page).**

• The photograph shows the tang holding a diamond tool, which is about to be polished on the mill. A microscope for checking the progress of grinding is seen in the right foreground.







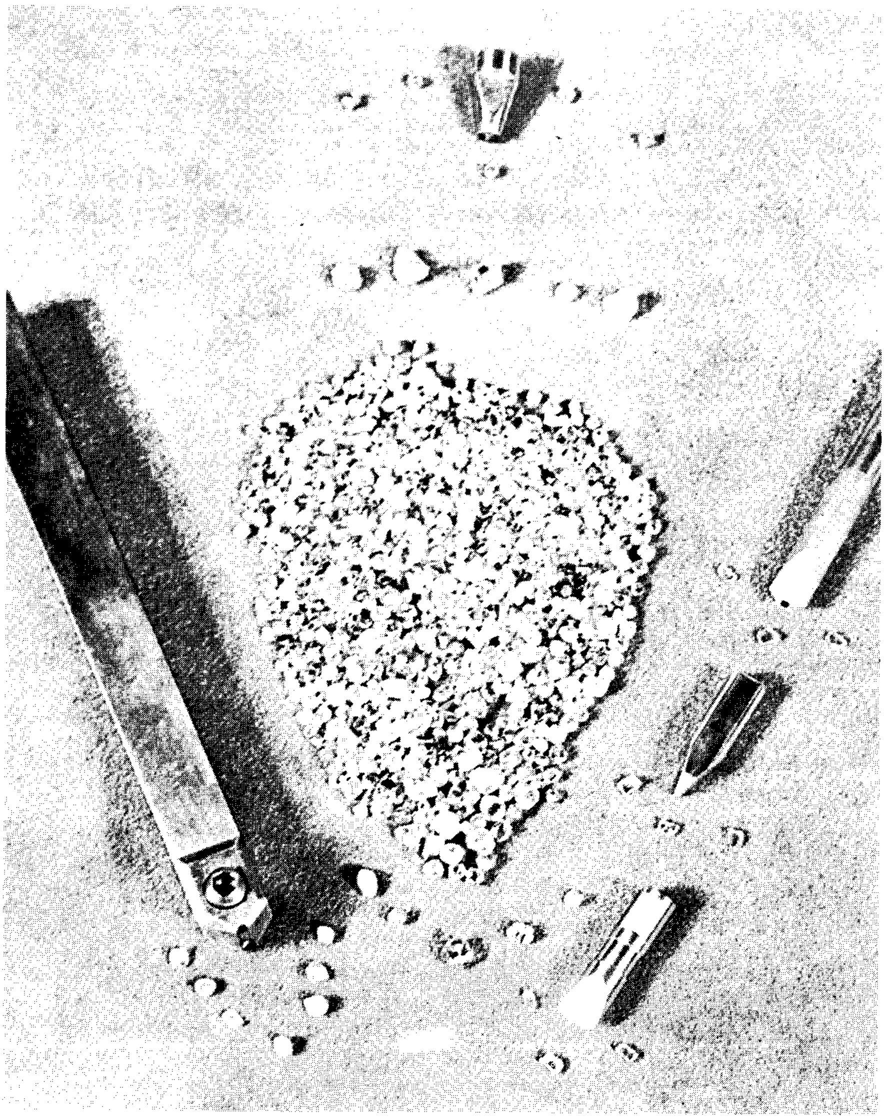


Figure 10.

• A typical parcel of industrial diamonds. Around the pile of diamonds are stones that have been divided into pieces suitable for making the tools shown adjacent to them. The tool at the top of the page is a Vickers indenter. The three on the left are chisel-edged wheel dressers. That on the right is a lathe tool.

For checking the linear measurements and the radius of curvature of the tool tip during grinding, a toolmaker's microscope can be fitted to the table of the mill. This arrangement is shown in Fig. 9. A fixed light source illuminates the tool tip when it is in position for examination. The microscope is fitted with linear scale or radius graticules, which are interchangeable. By using one or the other, as required, it is possible to examine the profile of the tool at intervals during the grinding process. By this means the progress of the work can be rapidly and accurately checked without disturbing the assembly. For more accurate observation, the tool tip can be removed, together with the holder, and examined with a comparator at a higher magnification.

The Armour Research Foundation, in conjunction with the American Society of Tool Engineers, held a symposium on diamond tools, which ran concurrently with the Industrial Exposition and Convention in Chicago in March of this year. Many toolmaking firms and users of diamond tools were invited to attend and to read papers on various subjects dealing with the manufacture and use of diamond tools.

The Diamond Research Laboratory was also invited to demonstrate the equipment and methods referred to in this article at the symposium. Members of the laboratory staff contributed two papers; one dealt with the crystallographic structure of the diamond in relation to its hardness, and the other described the selection, division and shaping of diamonds for tool manufacture.

The papers were illustrated by two short sound films. A film dealing with the mining and recovery of diamonds was also shown.

BOOK REVIEW

ROCKS & MINERALS *by Richard M. Pearl. Published by Barnes & Noble, New York City. 275 pages, 35 illustrations. 12-page glossary. Book #260 of the Everyday Handbook Series. The books in these series are inexpensively paper bound and priced in the range from $.75 to $1.95. "Rocks & Minerals" is offered at the latter figure.*

The review copy suffers from an uneven coverage in the printing from mistakes both in printing and binding (for example, page 242 being printed on the back of page 145), plus numerous other similar mistakes, and from an inconsistent registry in the color plates. As a result, although some of the color plates are excellent, others are very fuzzy. The text itself emphasizes what Pearl calls "atomic" minerals plus meteorites and minerals which fluoresce.

Some statements are questionable in the light of present geophysical beliefs; i.e., "since the earth is believed — from the evidence given by the movement of earthquake waves — to be solid throughout . . . "

Strontium titanate, the new synthetic material, is incorrectly referred to in the book as strontium oxide.

For the most part, however, Pearl has covered the various phases of geology and mineralogy in a simple and understandable fashion. Considering the fact that the book is aimed at the collector and those who have an interest in the mineral kingdom as a hobby, the book seems a workmanlike exposition of the subject.