CONTRIBUTIONS TO THE MINERALOGY OF NORWAY

No. 19. Red corundum of Froland at Arendal.

By

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To Professor Ivar Oftedal with kindest regards and congratulations on the occasion of his 70th birthday.

Abstract. Red corundum crystals occur in a two meter wide zone in the gneisses 11 km northwest of Arendal, Southern Norway. The ordinary features of the crystals are described, and Universal stage work indicates that the "lamellar twinning" is due to alteration on cleavages. It is suggested as an alternative hypothesis to "lamellar twinning and parting parallel to the rhombohedron" that corundum possesses true cleavage and pseudo-twinning due to alteration.

In the late spring of 1956 a deep red mineral was sent to Norges Geologiske Undersøkelse for determination by Mr. Ole Landsverk of Froland, Arendal. The mineral proved to be corundum by its x-ray powder pattern. The finding of this ruby-like corundum in quite large crystals was reported in newspapers in the hope that the mineral might be used as a gemstone, but it soon proved to be too much below gem quality. The finding was also mentioned by OFTEDAHL (1956, p. 30) in the Communications of the Gemmological Society of Norway (in Norwegian). I visited the locality in early June, 1956. It is situated in the little hill called Kleggåsen, on the grounds of the farm Froland, 11 km northwest of the city of Arendal. This paper reports the essential facts about the occurrence, based on specimens I collected on this visit when the occurrence had been but little blasted. Later the occurrence has been visited by many other geologists and has been extensively blasted. Through mineral dealers specimens of this beautiful corundum has been scattered to collections all over the world.

Corundum was first found in Norway as microscopic grains in a titaniferous magnetite ore in Rødsand, Møre (J. H. L. VOGT, 1910). Later it has been found as small grains in anorthosite gabbro in the Bergen district (N.-H. KOLDERUP, 1936). Macroscopic crystals are described from one locality in the same area (Rebnor, Fosnøy, Austreim) by C. F. KOLDERUP and N.-H. KOLDERUP (1940, p. 81). The crystals are ruby-like in colour and in being extremely rich in Ti and Fe. Good sized crystals occur in the nepheline syenite pegmatite in Seiland, Northern Norway (BARTH, 1927), and in mica gneiss in Nes, Romerike (C. BUGGE, 1951). The latter occurrence resembles mostly the new Arendal occurrence, in that the corundum occurs as flat tabular hexagonal prisms, lying in a mica gneiss. The colour of the corundum crystals both in the Nes and the Seiland occurrences goes in brownish shades.

Thus the corundum of the Arendal occurrence is unique among the Norwegian occurrences by its colour and its large crystal size. Also among the corundum occurrences of the world the described locality may be said to be outstanding for the mentioned reasons.

Macroscopic features

Habit. The crystals occur essentially as short hexagonal prisms, bounded by the base (0001) and the prism faces ($11\bar{2}0$), see Fig. 1, B and C. Development of more long prismatic crystals and a rhombohedron face ($10\bar{1}1$) is rare (Fig. 1, D).

Broken crystals display what seems to be nearly perfect cleavage parallel to the three faces of the rhombohedron, a feature described below. The cleavage produces three sets of parallel stripes on the base, intersecting at 60°. The base usually exhibits steps bounded by small faces of the rhombohedron, a growth phenomenon usual on short prismatic corundum crystals.

The size of the crystals is most usually 1—4 cm across the base. Crystals measuring 5—7 cm are not rare, and a number of crystals measuring 10 cm in diameter have been met with. The latter crystals form extremely platy prisms, their thickness may be 1 cm or less. Thus the Arendal crystals are not much below the maximum size of corundum crystals from famous occurrences throughout the world, as presented by HINTZE (1915, p. 61): Kashmir (12,5 cm), Salem at Madras (18 cm), Ceylon (10—15 cm in solid rock).

The colour of the crystals is mostly deep red with a strong violet or purple tinge. Lighter coloured zones or parts occur within a few crystals. Really precious crystals have never been observed. The best spot within some crystals may be called semi-transparent, but mostly the crystals are translucent to semi-translucent. After heating for a couple of hours at 1400° C, a crystal attained a lighter and pinker colour.

The adsorption spectrum of the crystals is the usual chromium spectrum (WEBSTER, 1947, p. 149). As usual in rubies, the Arendal crystals show a strong red fluorescence colour under ultraviolet light, due to emission in the reds in two discret lines, 6942 and 6928 Å (ANDERSON and PAYNE, 1954, p. 121).

Schiller. The cut and polished plate of Fig. 1 A shows a beautiful but faint schiller, due to internal reflection on the base. This optical effect also appears on crystals cut en Cabochon, but cannot be seen in natural crystal faces, cleavage surfaces or irregular fractures. Ordinarily the schiller is in deep red, but it may have a lighter colour in faintly reddish or yellowish, thus resembling that of an ordinary Ceylon moonstone. In the zoned crystal of Fig. 1 the lighter zone has a similar light schiller. In this crystal the schiller also shows a most beautiful hexagonal zoning of extremely thin lines, not otherwise visible.

Microscopic features

In thin sections the corundum crystals show the following features to be described separately: fracturing, zoning and inclusions, microperthite structure, cleavage and lamellar twinning.

The fracture pattern is a rather constant feature in all crystals (Fig. 2). The fractures are usually curved and dirty, and thus they are essentially responsible for the semi-translucent appearance of nearly all crystals. The clean and homogeneous crystal parts inbetween the fractures and the similarily dirty cleavage faces may be up to 0,5 mm across, and these parts may be true ruby.

Zoning and inclusions. In thin sections a more indistinct zoning is not infrequent. Here the clear, red colour of the core gives way to a more brownish or greyish colour in the margin, obviously due to a great number of minute inclusions. The latter have been studied in detail in the only sectioned crystal showing marked zoning (Fig. 1 A).

The margin is coloured by three types of inclusions.

1. The sagenite web of rutile needles, common in rubies, is well developed throughout the margin (Fig. 3).
2. Water-clear inclusions of rounded but irregular shape are frequent. They are mostly indistinct in Fig. 3. The colour is the same as the surrounding corundum and the refractive index is higher. The latter feature excludes the possibility of liquid inclusions.
3. Opaque inclusions occur as irregular, dirty spots (Fig. 3 and 4). They may well consist of iron ore. When the schiller which is macroscopically visible, is studied in a microscope with Universal stage, the schiller is seen as very strong reflections from distinct spots of irregular shape. Therefore the reflections are most likely caused by the latter type of inclusions, possibly hematite flakes. These flakes are exactly parallel and oriented on the base, as indicated by the Universal stage. The coloured reflections of these flakes are surprising. When seen under high magnification each flake has its own colour. Strong red and blue reflections are especially beautiful.

Fig. 1. Crystals of Arendal corundum. A—A zoned crystal cut nearly vertical to the c axis. B and C — Short prismatic crystals with fairly well developed prism faces. The base is rather irregular. D — A long prismatic crystal, showing a small rhombohedron face and cleavage striation on the prism faces.

Figs. 2—7. Photomicrographs of a thin section of the zoned crystal (Fig. 1 A).

Figs. 2, 5, 6 and 7 of the same lower magnification, and Figs. 3 and 4 of higher magnification. Crossed nicols in Figs. 5, 6, and 7.

Fig. 2. Irregular fracture pattern, ordinarily seen in Arendal corundum. The fine structure inbetween is the "microperthite".

Fig. 3. Rutile needles oriented parallel to the three prism faces, and small, irregular inclusions.

Fig. 4. The "microperthite" or feather pattern in Arendal corundum. Note the irregular black inclusions (hematite?) and horisontal lines of minute inclusions defining the hexagonal growth.

Fig. 5. Typical "twinning" as developed at its best in the marginal zone.

Fig. 6. More irregular twins and cleavage.

Fig. 7. "Twinning" with the one set of twins in extinction.

"The microperthite structure" is quite like that of an ordinary orthoclase microperthite, with some 5—10 percent albite blebs or strings, only that the strings in the case of the corundum are more wavy than in feldspars, see Fig. 4. The strings also seem to consist of corundum, possibly with a colour a trifle lighter and a refractive index a little smaller than the host. The strings extinguish together with the host under crossed nicols. Actually they look as if they were cracks in the crystals, healed by precipitation of new corundum. Thus they are like the "feathers" found in many rubies, and the pattern is somewhat like that of Ceylon stones.

The strings are present in all crystals investigated but may be a little varying in density from place to place within one crystal (see Figs. 2 and 6). When investigated on the Universal stage, the blebs are found to be lamellar of nature, and their orientation is roughly parallel to one of the faces of the pyramid $(11\bar{2}1)$.

Cleavage and twinning. These two features are so connected that they will be discussed together.

Historically, the idea that what looks like a good cleavage is really a parting, dates back to 1874 with the publication of a study of selected corundum specimens by BAUER (1874, p. 192). He compares the corundum with the hematite with its lamellae: "Durch eine ähnliche lamellenförmige Zwillingverwachsung ist auch der eigentümliche Umstand zu erklären, dass der mit Eisenglanz isomorphe Korund häufig mit zwei Rhomboederflächen R deutlich spaltbar erscheint, parallel mit der dritten nicht, ...". Thus the reason for parting and not cleavage is the fact that the three faces show quite different degree of cleavage perfection, and lamellar twinning is assumed as the reason. This behaviour of the cleavage is also observed by JUDD (1895, p. 49) and others. Therefore it is now a simple fact that the corundum possesses parting and lamellar twinning parallel to the rhombohedron $(11\bar{2}1)$, see for instance PALACHE, BERMAN and FRONDELL (1944, p. 522). However, suggestion of a true cleavage has been voiced (WEBSTER, 1962, p. 162).

The Arendal crystals usually show one or two marked cleavages in thin sections, less frequent are one or two sets of twin lamellae. These features have been studied in a section of the zoned crystal of Fig. 1 A on the Universal stage.

The section is cut about 20° off the base and shows one cleavage as widely spaced, strong and dirty lines. Two sets of twin lamellae intersect at an angle of about 30° (Figs. 5—7). Plotted in a stereogram, however, these three planes are located symmetrically around the optical axis. They intersect at an angle close to that of two $(11\bar{2}1)$ rhombohedron planes (94°) and have also the prescribed angle against the base (57½ °). The behaviour of the twinning is interesting. The one set of cleavage looks as such only because it is nearly vertical to the section. When tilted, the cleavage becomes "twinning". Oppositely, the twins disappear when looked at along the twin plane. Under highest magnification (30 × objective) the lamellae are seen to be a thin film, mostly somewhat irregular, of some alteration product. It lies near at hand to think of diaspore, as already done by BAUER (1874). This conclusion is supported by the following observations.

1. The "lamellae" have no extinction, only when the interference colour is very little different from that of the surrounding corundum, the extinction is nearly homogeneous. This may be explained by very thin dirt film, as is also observed on the Universal stage.
2. Some of the broad "lamellae" show offshoots along cracks (lower right of Fig. 5) or other irregularities (zig-zag lamellae of upper part of Fig. 7). This should also be expected if the "lamellae" are due to alteration from percolating solutions.

The other crystals of the Arendal corundum seem to have exactly the same characteristics about their "twinning", and it seems a fair conclusion to assume that the Arendal crystals do not possess lamellar twinning, but an optical phenomenon which looks as such.

Discussion of cleavage and twinning in corundum. The previous observations on corundum have led to the general conclusions that the mineral possesses lamellar twinning and parting parallel to the rhombohedron $(11\bar{2}1)$. Of course, the conclusions about the Arendal corundum is no base for assuming that the same is the case in corundum generally. However, from years of experience at the Universal stage with lamellar twinning in plagioclases (OFTEDAHL, 1949), I consider it quite likely that if alteration in corundum generally appears as it does in the Arendal corundum, then mineralogists will consider the observed pattern as twinning if they do not use the Universal stage.

So far, I have not discovered any Universal stage study of twin lamellae in corundum crystals from others localities. Accordingly, until such a study is undertaken, I suggest that the general statement "rhombohedral parting and lamellar twinning in corundum" should be considered as a hypothesis, with the following alternative hypothesis: True cleavage and pseudo-twinning due to alteration products on the cleavage faces.

The assumption that the parting is really a true cleavage requires a special explanation. This may be sought in the following features of corundum.

1. It has a mechanical hardness which is very much different from that of enclosing silicate minerals.
2. It is only formed under a relatively high degree of metamorphism, or, at a considerable depth in the Earth's crust.

Accordingly, all observed corundum crystals have risen from great depth to the surface. During some part of this ascent the silicate minerals behave more or less in a semi-plastic way, whereas the hard corundum will be brittle. At this stage the flowage of the surrounding rock will produce slips in the corundum crystals with opening up of cracks. These slips may then follow one potential cleavage direction, if it is suitably located, otherwise two directions, but it is unlikely that all three directions should be equally influenced during this period of strain. At the surface the produced fractures may appear as perfect cleavages.

Mineral paragenesis

Geologic setting. The corundum occurs in a two meter wide zone in steeply dipping gneisses. The best exposed cliff is littered with small and large corundum crystals, and the percentage may be estimated to between 5 and 10. A few bad outcrops show the zone to have a length of at least 30 m. Due to the highly varying size of a number of its mineral, the zone gives a pegmatite impression. This zone forms a concordant layer in a complex of highly varied gneisses. The typical members of the series are: two-mica gneiss, garnet-biotite gneiss, amphibolitic gneiss and garnet-bearing amphibolite. The surrounding region is described by JENS A. W. BUGGE (1940, 1943).

Minerals of the corundum zone. Apart from corundum (say 10 %) the zone has the following constituents: Oligoclase (main constituent), biotite (possibly as much as 5 %), beryl, kyanite, sillimanite, tourmaline, rutile, and fuchsite in abundance judged to be around one percent each.

The oligoclase (ca. 12 An) makes up the base for all the other mineral . It is nearly pure white and forms crystals up to five centimeters across.

The biotite occurs in evenly scattered flakes of one millimeter size and is abundant in all hand specimens. In pegmatitic parts "books" may attain a size of one centimeter. In thin sections the biotite proves to be a light brown magnesia-rich variety.

The beryl occurs in the form of irregular green and dull aggregates, mostly a few millimeters across. It is either much altered or loaded with minute inclusions, as shown by powder in immersion liquids. Only rarely the beryl is transparent.

Kyanite makes up inconspiceous platy aggregates of faint, greenish blue colour. The size is around one centimeter.

Sillimanite occurs very unevenly distributed, and most specimens from the occurrence are completely devoid of this mineral. But one corundum-bearing specimen contains thick balls of pure sillimanite, and in the corundum zone Dr. O. A. Broch, State geologist, has collected a sillimanite schist, with typical lenses of sillimanite and a little of oligoclase, biotite, and rutile.

Tourmaline forms orbicular aggregates with radially arranged needle crystals, with size up to 10 cm. In addition there are smaller and more irregular black aggregates of centimeter size.

Rutile is fairly evenly scattered in small grains around one millimeter in size, rarely in aggregates up to one centimeter across.

The fuchsite occurs mostly on cross-cutting fissures and may be the last mineral to crystallize. It is faintly to strongly green.

The mineral paragenesis is thus characterized by the following minerals:

Corundum, kyanite, sillimanite, biotite, oligoclase.

First of all the co-existence of kyanite and sillimanite indicates unequilibrium. Since the kyanite plates are developed preferably along the basal faces of corundum crystals, the kyanite is probably formed later than the sillimanite and on fissures formed at the boundary of corundum crystals. Next the association corundum, sillimanite (kyanite), biotite and oligoclase is a most unusual association, barely reported before. It is deficient in K and silica, but otherwise in equilibrium. The relationship of this association to the paragenesis of the adjacent rock zones will be interesting to study.

The origin of the corundum is most uncertain after this preliminary study, but it is tempting to assume that the mineral is formed by simple regional metamorphism of an unusual sedimentary bed rather than by metasomatism of a more ordinary rock. The unusual bed could for instance be a laterite-bearing sediment.

Trace elements. Semi-quantitative determinations by optical spectroscopy revealed the following contents.

In p.p.m	Cr	V	
Corundum	10 000	1 000	
Sillimanite	1 000	100	
Kyanite	3 000	200	
Fuchsite	500	1 000	Sr—30, Ba—30 000.

The contents of Mg, Fe, etc. show that the minerals were not completely free from small inclusions of other minerals.

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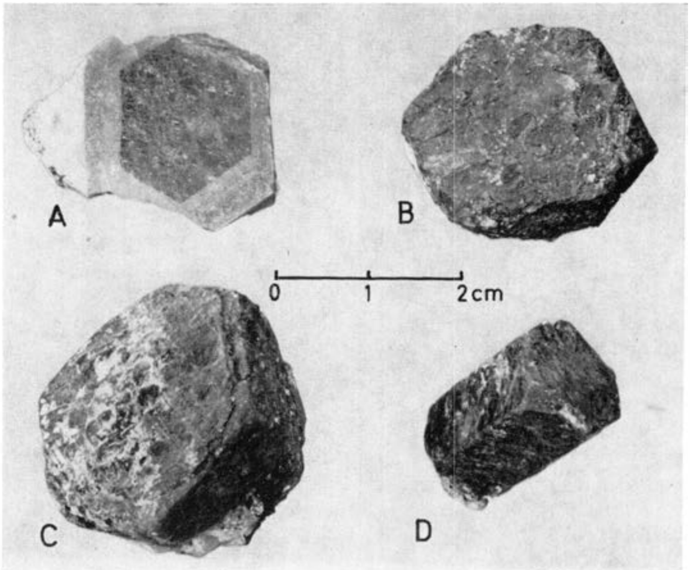
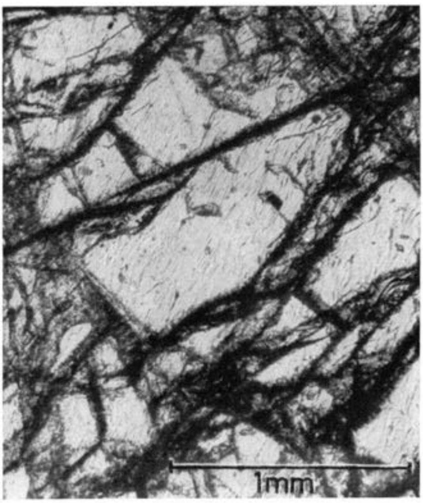


Fig. 1.



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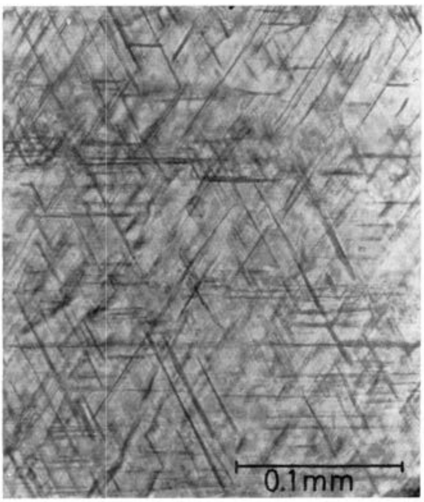

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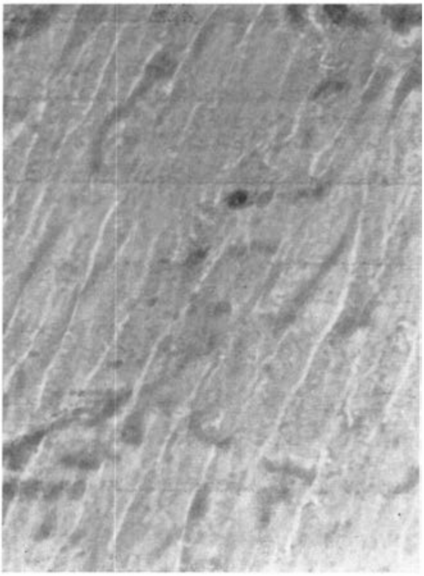

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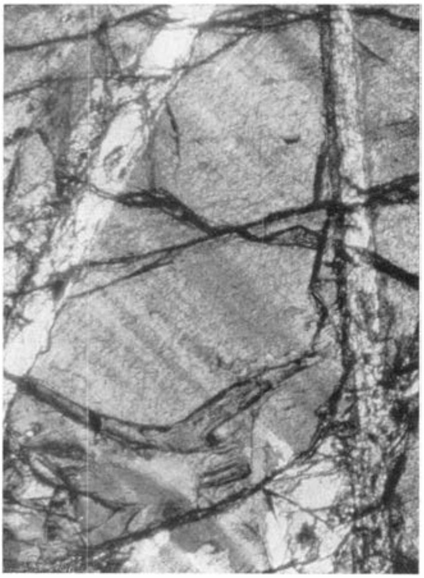

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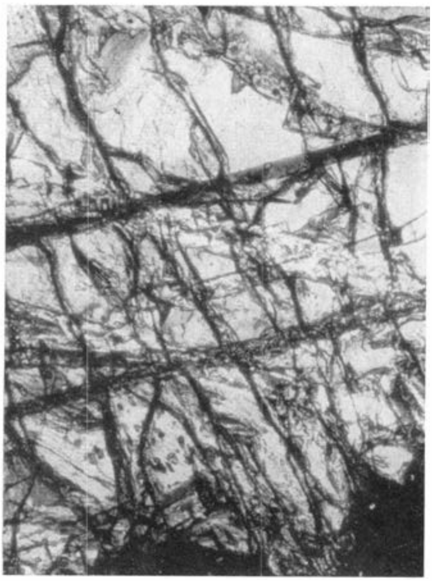

Fig. 7.