

MINERAL PARAGENESES OF SOME GRANITE PEGMATITES NEAR KRAGERØ, SOUTHERN NORWAY

BY

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WITH 6 FIGURES IN THE TEXT

Field investigations of pegmatites near Kragerø have been carried out for several seasons; but most of the work was done in the summer of 1935 by grants given to me by the Fritjof Nansen Fund.

Some of these pegmatites had not been mined for many years and it was often very difficult, therefore, to collect complete series of the minerals. The description of the minerals of some of the dikes has therefore partly been based on a study of representative samples in the collections of the mineralogical museum in Oslo. Since some of these minerals have been bought from mineral dealers I have been very careful only to use the material whose origin seemed to be quite sure. For the photographs I am indebted to Miss Lily Monsen.

The Pegmatite at Kalstad-Lindvikskollen.

About 2 km W of Kragerø, on the hill Lindvikskollen an unusually large body of pegmatite crops out, the main part of which forms a dike about 500 m in length and 30 m wide, striking east and probably dipping about 30 degrees to the north (fig. 1).

From the main body some smaller dikes extend to the south cutting the surrounding amphibolitic rock with sharp contacts. This is the largest known granite pegmatite body in Norway. There are several feldspar quarries in it, the two most important ones being the Kalstad feldspar mine in the eastern part and the Lindvikskollen feldspar mines in the western part of the pegmatite.

The main part of this large pegmatite body consists of graphic granite with but smaller areas of well segregated feldspar crystals. A considerable amount of black tourmaline occurs in this pegmatite

especially in the eastern parts. The crystals are very large (30–40 cm across), partly well developed, and usually imbedded in quartz. Both in size and in amount they exceed what is otherwise known from similar occurrences in Norway.

In the feldspar quarries at Kalstad and at Lindvikskollen the chief minerals are microcline, quartz, plagioclase, and biotite. Other minerals are muscovite, orthite, apatite, calcite, magnetite, tourmaline, yttritanite, ilmenite, euxenite, alvite, hellandite, and thorite. Beryl has not been found in this pegmatite. Cleavelandite with crystals of phenacite is said to occur in the Lindvikskollen feldsparmines, but when I visited these quarries no trace of cleavelandite was encountered neither in the walls of the trenches nor in the dumps. It seems likely therefore that cleavelandite only occurs in small confined parts of the pegmatite.

The mineral paragenesis of this dike has previously been described by W. C. Brøgger (7).

Microcline occurs partly as a component in graphic granite, partly in segregated crystals. Usually it is of a coarse perthitic type, reddish to yellowish in color, and according to O. Andersen (3) of the usual composition. At the Lindvikskollen well terminated crystals imbedded in quartz have been encountered.

Plagioclase is present in relatively large amounts and, like the microcline, it occurs partly in graphic granite, partly in segregated crystals. The composition corresponds to albite-oligoclase.

Biotite occurs in this pegmatite as long thin flakes, partly altered to chlorite.

Muscovite occurs very sparingly and is generally found in small leaves in plagioclase or near this mineral.

Orthite (allanite) is generally present in large ill-defined crystals in microcline. The outer shell of the mineral is regularly strongly altered and covered with a coating rich in iron oxydes. Irregular nodules without crystal outlines are also met with. It probably crystallized at approximately the same time as microcline. Orthite from this dike has previously been described by Brøgger (9). Its content of rare earth elements has been determined by Goldschmidt and Thomassen (12).

Apatite occurs characteristically in long prismatic crystals with a blue or green color, mostly imbedded in microcline. An X ray spectrogram of the mineral powder showed the presence of small amounts of rare earth elements. An apatite crystal from the collections

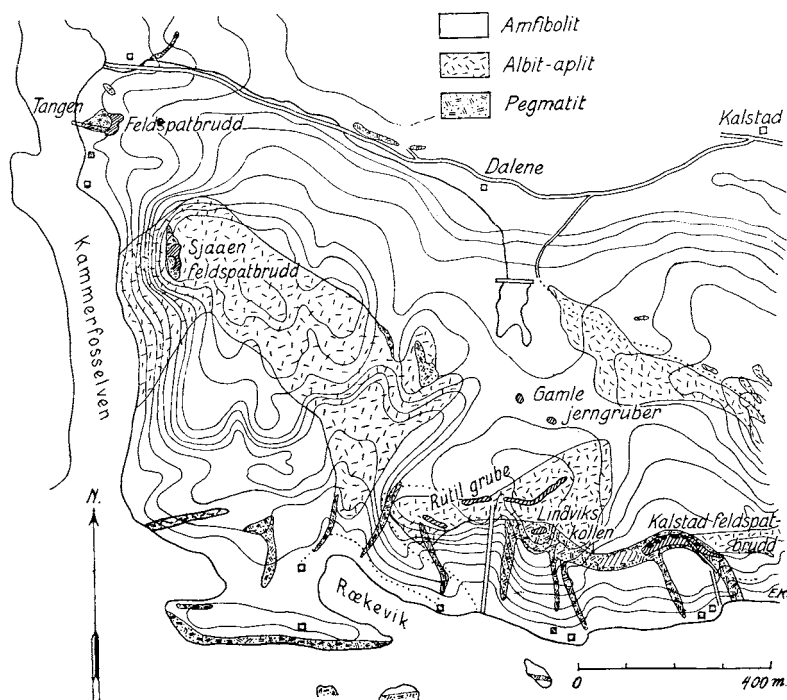


Fig. 1. Geological map of the area W of Kragerø. (Reprinted from O. Andersen: Feltspat II. Norges Geologiske Undersøkelse Publ. 128 B, p. 38, (fig. 14), with the permission of the director).

of the Mineralogical Museum in Oslo surrounded by small euxenite crystals shows that apatite has crystallized earlier than the euxenite.

Calcite, on a visit to the Lindvikskollen feldspar quarries in the summer of 1935 I found a few small fragments of pink calcite imbedded in microcline. The mode of occurrence strongly indicates a magmatic origin of this mineral.

Magnetite occurs frequently in small crystals and irregular nodules in the pegmatite.

Tourmaline occurs abundantly especially in the eastern part of the pegmatite. When imbedded in quartz it generally exhibits well developed crystal outlines, in microcline however it often occurs in irregular masses or just as a black coating on cracks.

Yttrotitanite is present in the pegmatite in large well developed crystals up to a weight of 3—4 kg. The crystal faces are often covered with small crystals of tourmaline.

Ilmenite occurs frequently in large but thin plates, especially in the eastern part of the pegmatite.

Euxenite occurs partly as large irregular masses and partly as smaller well defined crystals. In the wedge-shaped spaces between two plates of ilmenite meeting each other at a low angle euxenite is frequently encountered thus indicating a later time of crystallization for euxenite than for ilmenite.

As shown by an X ray spectrogram its composition is similar to that of the ordinary euxenites from granite pegmatites in Southern Norway.

Hellandite from this dike, which still is the only known occurrence of this mineral, was first found and described by Brøgger (7, 9). It is a rare silicate of the Y elements and, in agreement with the behavior of other silicates of rare earth elements, the crystallization of hellandite belongs to a late stage of the crystallization of the accessory minerals. Generally speaking it crystallized later than tourmaline although crystals of tourmaline inclosed in hellandite also have been observed.

Thorite occurs in small red colored nodules in microcline.

Tangen Feldspar Quarry.

The Tangen feldspar quarry lies on the east side of the river Kammerfosselven about 4 km W of Kragerø. The pegmatite crops out as an irregular body about 40 m in length and 10–15 m wide on the western slope of the Sjøen Mt. Only the upper boundary between the pegmatite and the surrounding amphibolite is visible (fig. 2). The western part of the pegmatite is chiefly composed of cleavelandite and quartz. But numerous irregular patches of microcline surrounded by cleavelandite are indicative of a hydrothermal replacement of an earlier magmatic microcline by cleavelandite. In the central parts of the pegmatite microcline occurs in large masses but is often cut by veins of cleavelandite.

The following minerals are met with in these dikes: microcline, quartz, oligoclase, cleavelandite, tourmaline, topaz, magnetite, hematite, apatite, yttritanite, orthite, alvite, thorite, betafite, columbite, and phenacite. Biotite, muscovite, and beryl have not been encountered.

Microcline of this dike is a coarse perthite rich in soda. It is translucent in parts and has a greyish color.



Fig. 2. The upper boundary between pegmatite and amphibolite.
Tangen feldspar quarry.

Quartz of the microcline pegmatite is white or transparent while the quartz which occurs together with the cleavelandite often is smoky.

Cleavelandite is a platy variety of albite and occurs in large masses and fanlike aggregates as well as in small veins in the microcline. It has been formed distinctly later than microcline which it seems to have replaced on a large scale. It is blue or colorless.

An chemical analysis of this mineral published by Andersen (2) (analyst. E. Klüver) shows a nearly pure albite composed of 96.3 % Ab, 0.9 % Or, 0.7 % An, and 2.1 % impurities.

Tourmaline occurs abundantly, partly in well developed crystals in quartz and partly in irregular masses in microcline or on cracks in this mineral. It also occurs frequently in cleavelandite.

Topaz. One specimen of topaz surrounded by cleavelandite labelled Tangen belongs to the collections of the Mineralogical Museum

in Oslo, but on my visits to the dike I have not been able to find this mineral.

Magnetite occurs in nodular masses in the microcline. An X ray spectrogram of the mineral powder shows that it contains considerable amounts of Ti and Mn.

Hematite is present in nodules in cleavelandite (fig. 5). The color is brown with a red streak. An X ray spectrogram shows that it contains Ti and Mn, but in somewhat smaller amounts than does the magnetite. The mode of occurrence and the chemical composition of this mineral indicates to me that it was formed by the action of gasses and solutions on the magmatic formed magnetite during the hydrothermal-pneumatolytic stage of the cleavelandite formation. Such secondary formed hematite has previously been described under the name of martite from Canadian pegmatites by Ellsworth (10).

Apatite of this dike is usually met with in small, green crystals.

Yttrotitanite is present in sharpened crystals in microcline and quartz.

Orthite (allanite) occurs abundantly in irregular nodules and ill-defined crystals. X ray spectrograms of this orthite show it to contain considerable amounts of Ti.

Alvite is a very common mineral in the dike. It occurs in relatively large crystals and irregular masses, brown of color with a greyish outer zone. It crystallized partly later than the betafite. X ray spectrograms show it to contain considerable amounts of Y, Th, and U, and as first pointed out by Goldschmidt and Thomassen (13) it is also very rich in Hf.

Thorite is met with in small red colored nodules, some of them occur in betafite while others are distinctly younger than this mineral. As shown by an X ray spectrogram it is exceptionally poor in U, contains, however, small amounts of the Y-elements.

Betafite from this dike has previously been analyzed and described by me (4). It occurs both in microcline and cleavelandite. It differs from the previously described betafites by being richer in TiO_2 , the amount of which ranges from 32% to 35%. Minerals of the betafite group have also been found in pegmatite dikes in Iveland (4) where they with considerable certainty have been referred to the magmatic stage of formation. At Tangen the betafite which occurs encompassed by cleavelandite should therefore in my opinion be regarded as a magmatic mineral that on account of a greater power of resistance



Fig. 3. Microcline (M) surrounded by metasomatic cleavelandite (Cl).
Tangen feldspar quarry.



Fig. 4. Crystals of columbite in cleavelandite.
Tangen feldspar quarry.

to hydrothermal solutions was able to escape alteration, while most of the other magmatic minerals were replaced by cleavelandite and quartz. Around the nodules of betafite cleavelandite has been stained red.

Columbite is present in beautiful crystals imbedded in cleavelandite and often cut by blades of this mineral. It has not been

found in microcline. X ray spectrograms show the content of Mn to be greater than that of Fe and the mineral should therefore be characterized as *manganocolumbite*. This is insofar in accordance with what I previously have found in other Norwegian pegmatites as hydrothermal-pneumatolytic minerals generally are enriched in Mn as compared with minerals of magmatic origin.

Phenacite is present in nicely developed crystals in cleavelandite and quartz and is the only beryllium mineral in the dike. In harmony with Goldschmidt's (11) classification of phenacite as a plumasitic mineral it occurs in this pegmatite together with topaz. Muscovite has not been found in this pegmatite and thus the formation of phenacite instead of beryl may be due to a deficiency of alumina. Phenacite from this dike has been analyzed by Andersen-Aars (1).

Obviously the granite pegmatite dike at Tangen has been formed in two epochs, one magmatic and one hydrothermal-pneumatolytic. It belongs therefore to the type of pegmatites that Landes (15) calls complex pegmatites.

The magmatic pegmatite is microcline pegmatite containing the following primary minerals: quartz, oligoclase, tourmaline, magnetite, apatite, yttrotitanite, orthite, alvite and betafite.

By the action of thermal solutions and gasses many of the previously formed magmatic minerals were replaced by hydrothermal-pneumatolytic material chiefly cleavelandite and quartz. Black tourmaline with the same appearance as the magmatic one was also formed during this phase. Other minerals formed by hydrothermal-pneumatolytic activity are: topaz, hematite (by alteration of magmatic magnetite?), columbite and phenacite.

Replacement origin of certain minerals in magmatic pegmatites has been contended by me in the case of several occurrences in Iveland. However, here the cleavelandite-quartz deposits form rather regular dikes and bodies with sharp boundaries against the microcline pegmatite while the occurrence at Tangen exhibits a more interdigitating association with veins and apophysae of cleavelandite cutting through crystals of microcline. It looks as if the magmatic pegmatite at Tangen once became subjected to intense shearing and cracking with consequent facilitating the injection and interpenetration of the secondary gases and solutions.



Fig. 5. Nodules of hematite in cleavelandite.
Tangen feldspar quarry.

Sjåen Feldspar Quarry.

At the top of the mountain Sjåen at Tangen a granite pegmatite crops out on the face of a cliff in the shape of a rather irregular body surrounded by albite aplite (Kragerite). It is about 100 m in length and 20—30 m broad.

The main part of the pegmatite consists of well segregated large crystals of feldspar and quartz, but it is also rich in graphic granite. The microcline is penetrated by a large number of dikes, veins, and irregular bodies of cleavelandite and quartz of metasomatic origin. The pegmatite is strikingly similar to that at Tangen and is obviously formed in the same way.

The minerals of this pegmatite are: microcline, quartz, plagioclase, cleavelandite, tourmaline, magnetite, yttrotitanite, orthite, and

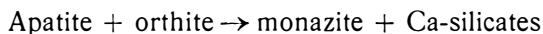
betafite. Other than these minerals large crystals of green pyroxen frequently occur.

On many of the islands south of Kragerø granite pegmatites have been opened for feldspar production. These feldspar quarries have been previously described by Andersen (2, 3).

It is worthy of notice that some of these pegmatites contain plagioclase as the chief feldspar with but lesser amounts of microcline. Some dikes also contain calcite of magmatic origin. This is for instance the case with a plagioclase pegmatite dike rather rich in red colored calcite on the island Risø. The microcline of these dikes is red and seems to be of the ordinary type. However, the pegmatites on the islands south of Kragerø are very poor in rare minerals, thus no niobate or tantalate minerals have been found in them. Nor has any cleavelandite-quartz phase been observed. Common accessories are tourmaline and titanite.

The pegmatite dikes in the neighbourhood of Kragerø, in spite of marked difference between them, yet seem to exhibit many similar features that distinguish them from the granite pegmatites in other parts of Norway.

A most striking feature is for instance the plenitude of Ca as indicated by the presence of calcite and of the Ca-bearing, rare minerals, hellandite, titanite, and betafite. As previously pointed out by me (6) the presence of apatite in granite pegmatites containing silicates of the rare earths also indicates sufficiency in Ca. In dikes deficient in Ca phosphorous and the rare earth elements will react with formation of monazite and xenotime. Under magmatic conditions the combination of orthite and apatite obviously becomes unstable if the Ca-content drops under a certain value. With decreasing amounts of Ca the following reaction thus will take place:



Another characteristic feature of the pegmatites of this area is the abundance of tourmaline.

As explained in a previous paper (6) by me, the granite pegmatites of Iveland may be divided into two main groups: *I. Pegmatites poor in Ca, and II. Pegmatites rich in Ca.*

In Iveland more than 100 of the pegmatites studied could be referred to the first group, and only 5 to the second group. The pegmatites belonging to group II were characterized by:

1. The occurrence of Ca-rich niobates, tantalates, and titanates of the pyrochlore group such as beta-fite, or the titanosilicate titanite.
2. Apatite occurring frequently.
3. The dikes usually being rich in plagioclase feldspar.

The mineral assemblage of the Ca-rich pegmatites of Iveland thus is analogous to that of the magmatic pegmatites near Kragerø.

The magmatic and the hydrothermal-pneumatolytic deposits at Tangen represent two different mineral parageneses which do not seem to be in equilibrium with each another, the same was the case in the complex pegmatite dikes in Iveland. The columbite of the cleavelandite pegmatite for example is probably unstable together with the Yttrium-bearing silicates, hellandite, and yttriotitanite of the magmatic pegmatites. In Iveland the cleavelandite-quartz pegmatites are enriched in Ta as compared with the magmatic pegmatites and contain microlite and tantalite very poor in Nb. At Tangen the characteristic niobate-tantalate mineral of the cleavelandite-quartz pegmatite is columbite which does not seem to differ from the magmatic columbites of the Norwegian pegmatites in its proportion Nb:Ta. However, as distinct from the magmatic columbites it does show a high ratio Mn:Fe and may properly be called a mangano-columbite.

In columbite from Katterås, Iveland about the same high ratio Mn:Fe is encountered. This columbite occurs in cleavelandite and seems to have been formed therefore during the hydrothermal-pneumatolytic phase. In tantalites from cleavelandite pegmatites at Landås and at Skripeland in Iveland the ratio Mn:Fe is also greater than in magmatic columbites.

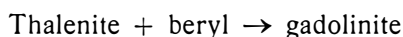
From X ray spectrograms of a great number of columbites and tantalites from Norwegian granite pegmatites it can be deduced that the ratio Mn:Fe ranges from 1:6 to 1:2 in the magmatic minerals, while columbites and tantalites of the cleavelandite pegmatites, have a ratio Mn:Fe about 2:1 for the columbites, and near 1:1 for the tantalites.

Beryllium in the magmatic phase is conspicuous by its absence in the dikes near Kragerø. Such Ca-rich granite pegmatites containing rare minerals but without beryllium have not been described from any other parts of Norway.

In the pegmatite at Kalstad-Lindvikskollen the relative amount of the Y-elements is large as compared with the amounts of Nb and

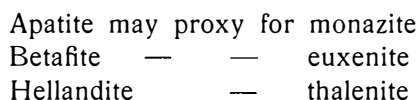
Ta; the excess yttrium has here formed the silicate hellandite. In my paper on the Iveland pegmatites I pointed to the fact that the formation of yttriumsilicates is possible only if the pegmatite contain a surplus of the yttrium elements over the combined amounts of Nb and Ta.

In pegmatites poor in Ca the yttrium silicate thalenite results if no or insufficient beryllium is present in the magma as first pointed out by Schetelig (16). But in beryl-bearing dikes the yttrium-beryllium-silicate, gadolinite, is the stable mineral. Thus beryl and thalenite can not occur together in the same pegmatite but react according to following scheme:



The mineral paragenesis of the Ca-rich granite pegmatites of Iveland (table 1) indicates that gadolinite is the stable Y-silicate in presence of Be. The paragenesis of the Ca-rich pegmatite at Kalstad-Lindvikskollen shows that thalenite is not stable in this pegmatite in spite of the absence of Be, but that the Ca-Y-silicate, hellandite, has formed instead.

Thus hellandite seems to substitute for thalenite much in the same way as the Ca-bearing niobate, betafite, partially substitutes for euxenite in some places. Thus certain minerals of the granite pegmatites may become unstable if much Ca is present, and be replaced by Ca-bearing minerals of similar composition:



The mineral parageneses of the Iveland and Kragerø pegmatites further indicate that hellandite like thalenite is unstable together with beryl. Thus following reaction holds:



Thus gadolinite will be the stable Y-silicate of the Ca-rich dikes if sufficient beryllium is present and hellandite if beryllium is deficient. Therefore I have called the Y-silicate bearing Ca-rich granite pegmatites the *hellandite-gadolinite type*. It constitutes an analogue to the thalenite-gadolinite type of the pegmatites poor in Ca. Other characteristic minerals of the pegmatites belonging to the hellandite-gadolinite type are betafite, yttrotitanite, and apatite.

Table 1.

The mineral parageneses of the Ca-rich granite pegmatites of the Iveland and Kragerø area.

	Iveland and Evje					Kragerø		
	Rosås 4	Birketveit 1	Ljosland 10	Ljosland 11	Landsverk	Tangen	Kalstad	Høgsjåen
Microcline.....	x	x	x	x	x	x	x	x
Quartz.....	x	x	x	x	x	x	x	x
Plagioclase.....	x	x	x	x	x	x	x	x
Biotite.....	x	x	x	x	x	x	x	x
Muscovite.....	x	x	x	x	x	x	x	x
Garnet.....	x	x	x	x	x	x	x	x
Tourmaline.....	x	x	x	x	x	x	x	x
Beryl.....	x	x	x	x	x	x	x	x
Gadolinite.....	x	x	x	x	x	x	x	x
Hellandite.....	x	x	x	x	x	x	x	x
Orthite.....	x	x	x	x	x	x	x	x
Alvite.....	x	x	x	x	x	x	x	x
Yttrantalite.....	x	x	x	x	x	x	x	x
Fergusonite.....	x	x	x	x	x	x	x	x
Yttritanite.....	x	x	x	x	x	x	x	x
Euxenite group.....	x	x	x	x	x	x	x	x
Betafite.....	x	x	x	x	x	x	x	x
Ilmenite.....	x	x	x	x	x	x	x	x
Magnetite.....	x	x	x	x	x	x	x	x
Thorite.....	x	x	x	x	x	x	x	x
Monazite.....	x	x	x	x	x	x	x	x
Xenotime.....	x	x	x	x	x	x	x	x
Apatite.....	x	x	x	x	x	x	x	x
Chalcopyrite.....	x	x	x	x	x	x	x	x
Chalcocite.....	x	x	x	x	x	x	x	x
Calcite.....	x	x	x	x	x	x	x	x

The granite pegmatite at Landsverk, Evje, contains calcite, apatite, and betafite and is therefore relatively rich in Ca. It also contains fergusonite but no Y-silicate minerals have been encountered. Thus this dike represents a third type of Ca-rich pegmatites which I have called the *fergusonite-betafite type*. The fergusonite is obviously a stable mineral also when the pegmatite is relatively rich in Ca. Parallel to the euxenite type is the *betafite type* in which neither Y-silicates nor Y-orthoniobates are present, the characteristic mineral being the metaniobate, betafite.

My earlier classification of the Ca-poor pegmatites of Iveland has therefore now received its counterpart in an analogous classification of the pegmatites rich in calcium:

- | | |
|----------------------------------|-----------------------------------|
| I. <i>Pegmatites poor in Ca.</i> | II. <i>Pegmatites rich in Ca.</i> |
| 1. Thalenite-gadolinite type. | 1. Hellandite-gadolinite type. |
| 2. Fergusonite type. | 2. Fergusonite-betafite type. |
| 3. Euxenite (samarskite) type. | 3. Betafite type. |
| 4. Columbite type. | |

In the Gjerstad district North of Kragerø additional granite pegmatites have been mined for feldspar and beryl. The mineral parageneses of these dikes exhibit some differences from those of the granite pegmatites of the area around Kragerø. However, the abundant occurrence of black tourmaline in the pegmatites of both areas makes a genetic relation probable. Most of the dikes in this area contain heryl.

On the top of the hill Mørkhøgda in the northern parts of Gjerstad a few shots have been put in a pegmatite dike in search for beryl. The exposed part of the pegmatite consists of cleavelandite and quartz with large crystals of black tourmaline. A yellow or green beryl, without crystal outlines was present in masses up to 20 cm in diameter (fig. 6). Small crystals of fergusonite were imbedded in the beryl, thus indicating that the beryl is of magmatic origin and has partly resisted the later hydrothermal-pneumatolytic alteration. Cleavelandite also contains minute ill-defined crystals and lense-shaped nodules of microlite about 1 mm in diameter. X ray spectrograms of the microlite showed it to be a nearly pure tantalate with a composition almost identical to that of the microlite previously described from Iveland (5).

Other minerals in this pegmatite were euxenite, alvite in small needle-shaped crystals, red, translucent spessartite in plates and ill-defined crystals, and white and lilac muscovite. Undecomposed microcline pegmatite was not seen in the exposed parts of the dike. With the exception of tourmaline the mineral assemblage of this dike is very similar to that of the microlite and tantalite-bearing dikes previously described from Landås and skripeland in Iveland (6).

On the property of the farm Brokeland S. Gjerstad about 300 m N of the main road a small pegmatite dike has been mined

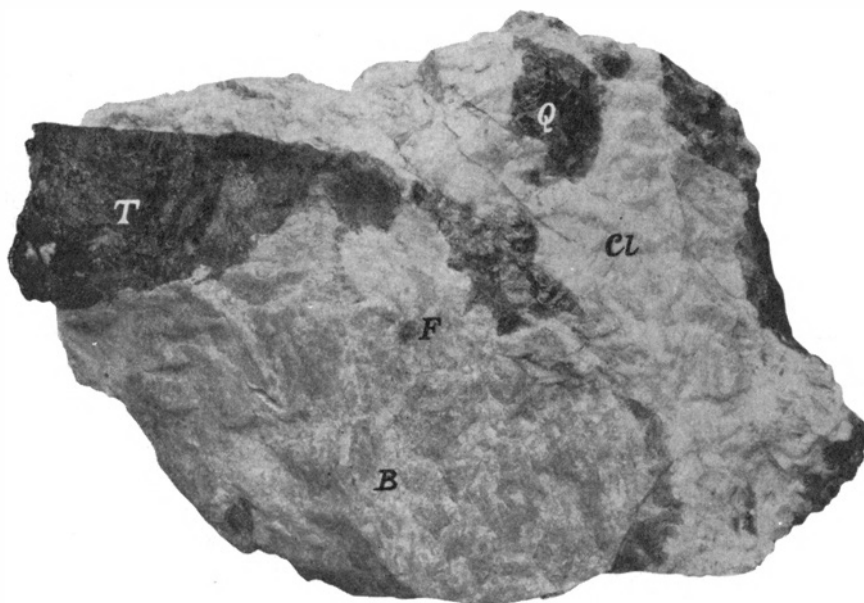


Fig. 6. Tourmaline (T), beryl (B) with inclosed crystal of fergusonite (F), quartz (Q), and Cleavelandite (C). The pegmatite at Mørkhøiden, Gjerstad.

for feldspar. The pegmatite was of the ordinary microcline type and contained the following minerals: microcline, quartz, plagioclase, biotite, muscovite, garnet, black tourmaline, beryl, and columbite. The magmatic origin of the columbite is verified by a low ratio Mn:Fe, as shown by an X ray spetrogram.

At Hulleknatten on the property of the fram Brenndalsmo in Gjerstad, a small pegmatite dike has been opened by a few shots in search for beryl. The chief minerals of the dike are white microcline, plagioclase, biotite, muscovite, and beryl. Other minerals were spessartite and columbite. Only about 250 kgms beryl has been produced. The microcline contained small blades of sericite and had therefore no commercial value. An X ray spectrogram showed that considerable amounts of tungsten were present in the columbite.

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