

The pegmatite dyke at Rømteland.

*A description of the minerals and a discussion of the mineral paragenesis, especially within the system
(Fe, Mn)O-TiO₂-Y₂O₃-(Nb, Ta)₂O₅-SiO₂*

By

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Introduction.

The pegmatite described is located at Rømteland, about 7 km W of Vigeland, Vest-Agder county, southern Norway.

Field investigations were made in the summers of 1955 and 1956, and the laboratory work was done under the direction of Professor Dr. Tom F. W. Barth and Dr. H. Neumann.

The pegmatite is surrounded by a hornblende bearing quartz monzonite which Barth (1945) has called farsundite.

Major (1939) believes the quartz monzonite to be a magmatic rock which during its emplacement has torn loose pieces of the surrounding gneiss and partly assimilated these. Barth (1956) expresses the opinion that the quartz monzonite is a high temperature, recrystallized diapir granite. The pegmatite at Rømteland has previously been described by Barth (1928, p. 424, 1931, p. 146), Major (1939), and Barth (1956).

Barth (1928) says that the pegmatite at Rømteland is bounded on the east by a small band of amphibolite. Amphibolite occurs in the pegmatite, but I have never observed it at the east.

The pegmatite has been subjected to a mineralogic-petrographic investigation based on field observations, chemical, X-ray, and microscopic studies, from which I have tried to form an opinion concerning the formation of the pegmatite and the mineral paragenesis.

Acknowledgements.

I would like to thank the University of Oslo for financial assistance. In 1955 for Broch's Legat and in 1956 for Lektor Halvdan Bjørnum's Legat for pegmatite studies in the Lindesnes area. For the help that I have received from Professor Tom F. W. Barth and Dr. H. Neumann during these investigations I would like to express my

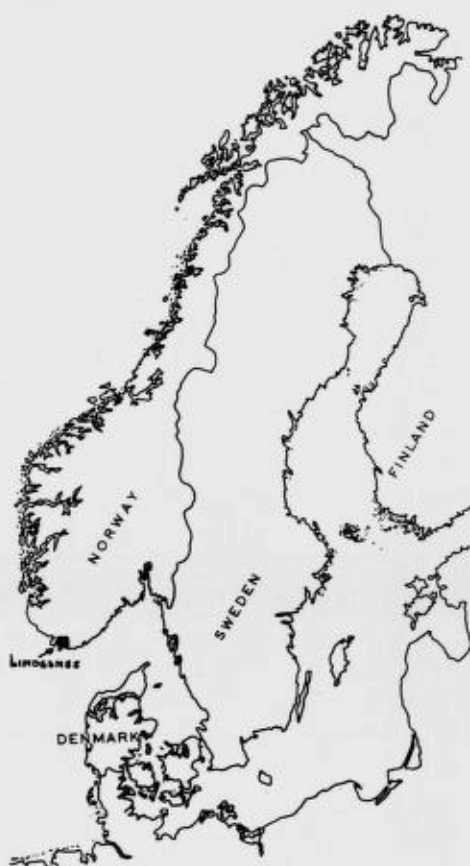


Fig. 1. Map showing the situation of the mapped Lindesnes area.

Kart som viser det kartlagte området ved Lindesnes.

most sincere thanks. I would also like to thank Director H. Bjørlykke and Dr. P. H. Reitan for many interesting discussions on various problems and Reitan for help in the translation of the original Norwegian manuscript to English. The chemical analyses were done by B. Bruun and E. Padget at the Chemical Laboratory of Norges geologiske undersøkelse. For these I would like to express my appreciation. All of the photographs were taken by B. Mauritz, and most of the drafting was done by I. Lowzow, both of the Geologisk Museum.

Description of the area.

The farsundite, according to Major (1939), and my own investigations, contains the following minerals. Essential minerals: quartz, microcline (the triclinicity of which diminishes towards the westnorthwest, the maximum triclinicity according to the X-ray patterns of (131) ($\bar{1}\bar{3}1$) being at Rømteland measured as 0.9875 while at Osestad, 2 km north of Rømteland, it was measured as only 0.4750 (Goldsmith and Laves, 1954), plagioclase (An_{29-27}), hornblende, and biotite. Accessory minerals: muscovite, myrmekite (microcline and quartz; myrmekite being of infrequent occurrence in the farsundite (Major, 1939)), sphene, zircon, apatite, magnetite, ilmenite, and pyrite.

Close to the pegmatite thin section examination has revealed the presence of epidote, much sericite in plagioclase, and albite in zones around the plagioclase and in cracks in it.

Approximately 1.5 km east of Rømteland occurs the boundary between the farsundite and the gneiss. The contact here is sharp, the farsundite being ordinarily coarse-grained and massive completely to the contact. 4 km southwest of Rømteland one can also see the contact between the gneiss and the farsundite. Here also the farsundite is massive and coarsely crystalline completely to the contact (see map, p. 128).

The planar structure of the gneiss is generally parallel to the boundary with the farsundite and also, almost always, parallel with the coast-line (see map).

Between Gjeideland and Lone, southeast of Rømteland, and at Grønsfjord, southwest of Rømteland, the gneiss has more variable strike and appears more granitic. Thin sections made from samples taken from these two granitic areas are extremely microcline rich, and accordingly poor in plagioclase (analyses of the alkali feldspars from these areas have been made for temperature determinations, see Table No. III, p. 136 and 137).

These two areas of gneiss appear to be very closely related and are assumed to be the same. They are now, however, separated by the farsundite, which itself, approximately 3 km south of Rømteland, takes on a gneissic structure. The transition between the massive farsundite and the gneissic farsundite is completely smooth. The primary difference between the gneissic farsundite and the two gneiss areas is that the farsundite has much more plagioclase. It is also more coarsely crystalline.

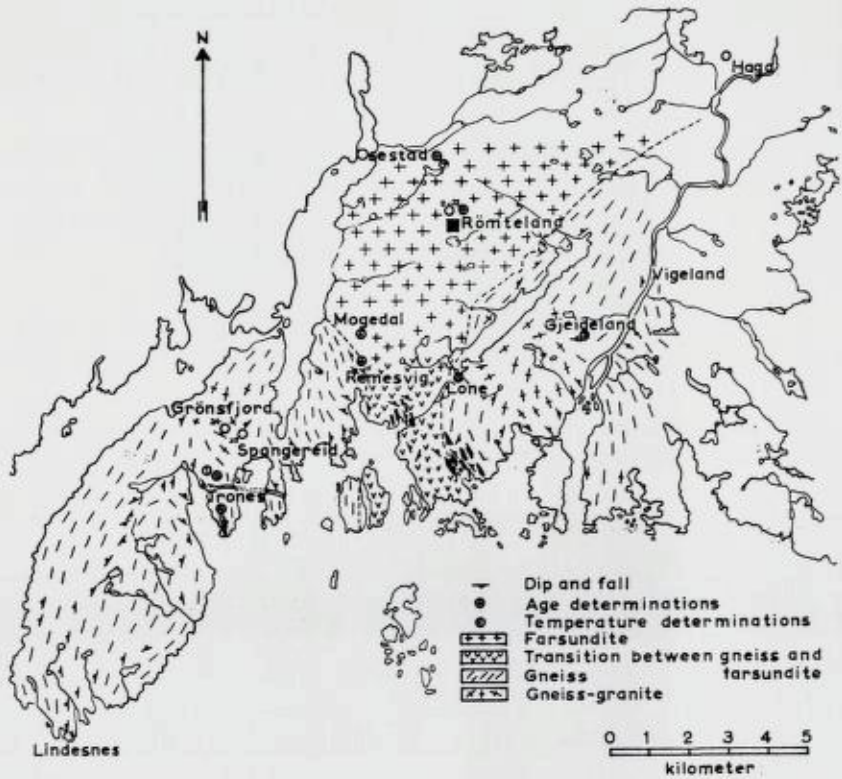


Fig. 2. Geological map of the Vigeland—Lindesnes area.
Geologisk oversiktskart over Vigeland—Lindesnes-området.

Age determinations.

Age determinations have been made of the following four rocks by the K-A method, using alkali feldspar and biotite.

Table I.

1. Gneiss, SE of Rømteland near Spangereid	587 mill. years (feldspar)
2. Gneissic farsundite, S of Rømteland, Remesvig	759 mill. years (biotite)
3. Farsundite at Osestad, N of Rømteland	560 mill. years (feldspar)
4. Pegmatite at Rømteland	483 mill. years (feldspar)

The determinations were made by director Prof. Dr. W. Gentner, Physikalisches Institut der Universität, Freiburg.

Because of argons fugitivity these figures are probably too low.

Uraninite, euxenite, and thorite from the pegmatite at Rømteland have been used by Kulp and Eckelman (1957) in order to determine the age of the pegmatite. The ages are determined on the basis of the isotope ratios Pb 206/U238, Pb 207/U235, Pb 207/Pb 206, and Pb 208/Th 232. The following ages have been determined for minerals from Rømteland:

Table II.

Uraninite	920 ± 20 mill. years
Euxenite	910 ± 20 mill. years
Thorite	830 ± 25 mill. years

Kulp and Eckelman (1957) say that the most exact age is obtained by the isotope ratio Pb 207/Pb 206. In spite of the probable lesser degree of accuracy of the K-A ages, it is possible that they give the approximate age relation between the different rocks, but if one has local differences in the movement (tectonic e. g.) after mineral formation, one must expect a variation in the degree to which argon will have escaped from the minerals at various places.

We know, further that biotite holds argon better than feldspar, (Wasserburg, Hayden, and Jensen, 1956). It is therefore difficult to say anything definite about the ages given above. It appears, however, that the farsundite and the gneissic farsundite are younger than the gneiss. This agrees with the opinion expressed by Barth (1945, 1956) and Major (1939).

History.

The present owner of the pegmatite, A. Tverstøl, Lyngdal, has given me the following data concerning the history of the pegmatite. In the period between 1916—1922 the pegmatite was operated by Gustav Lundevoll, Vennesla. He drove a horizontal drift into the pegmatite towards the east (see the perspective drawing of Rømteland). The feldspar is said to have been of a high quality, but the quantity which was shipped was not over 500 tons. He ceased operations in 1922, and thereafter the pegmatite was not operated until 1930. Then Johannes Torjesen, Sør-Audnedal, began operating. It is believed that between 1930 and 1940 he also took out about 500 tons of feldspar. Between 1940 and 1953 the pegmatite was not operated. In 1953 the property was purchased by A. Tverstøl. He began operations at once,

also building the first road to the mine. Before the end of the year he had taken out 150 tons of feldspar. During 1954 and 1955 there were approximately 800 tons of feldspar and 700 tons of quartz produced. Operations again ceased at the beginning of 1956, at this time because of sickness. The total amount of feldspar which has been produced from the pegmatite at Rømteland is about 1950 tons, and the total amount of quartz at least 700 tons. The descent to the present workings is made through an incline shaft which lies 52 m north of the southernmost exposure of the pegmatite at the surface. When operations ceased in 1956, the workings had reached a depth of approximately 13.5 m below the surface. Five m below the opening of the incline shaft, there is a little cross drift towards the east in which in the hanging wall there can be seen a zone of strong mineralization.

Description of the pegmatite.

The mineralogy of the pegmatite, which will be discussed in detail later, is very much like that of the farsundite, except that among the essential minerals hornblende and biotite exchange position in abundance. In the farsundite the hornblende is often surrounded by biotite, but in the pegmatite one finds almost only biotite.

The contact between the farsundite and the pegmatite is almost always gradational, but occasionally veins extend out from the pegmatite and these have sharp boundaries against the farsundite. These can be clearly seen as coarsely crystalline veins. The breadth of the veins diminishes with distance from the pegmatite until they finally disappear completely. At the surface the pegmatite can be seen in a cliff which strikes N 385°, and dips approximately 85° towards the west. This cliff in the farsundite and pegmatite is approximately 15 m high and several hundred meters long (see the perspective drawing p. 132). The pegmatite can be seen to outcrop for ca. 68 m in its total exposure. The exposure of the pegmatite increases towards the north (see the perspective drawing). The inclined shaft is therefore at the north end of the pegmatite.

The transition between the farsundite and the pegmatite is completely gradational. This can be seen not only microscopically but also by the study of thin sections. Specifically, the following changes can be noted. The grain-size of the various minerals increases gradually towards the pegmatite from an average of ca. 8 mm for quartz and feldspar in the farsundite. Myrmekite which is evenly distributed in

the farsundite (Major, 1939), also occurs near the pegmatite, and towards the pegmatite the myrmikite becomes coarser until one reaches the graphic granite zone in the pegmatite, where one has a macroscopic intergrowth of quartz and microcline. The amount of hornblende decreases gradually as one approaches the pegmatite. In the pegmatite I have found hornblende only once, but then in a crystal 10 cm long. Corresponding with the decreases in hornblende one has an increase in the amount of biotite which also increases in grain-size towards the pegmatite. Further, it appears that the pegmatite lies along a zone of weakness in the farsundite but whether or not this zone of weakness existed before the pegmatite was formed is impossible to say. It is certain that there has been tectonic movement in the area after the pegmatite was formed, as the minerals show considerable granulation and have undulatory extinction in thin section. The same is seen to be the case in the farsundite near the pegmatite which in addition shows bending of the biotite grains.

Major (1939) believes that the biotite has been formed later than the hornblende. This seems also to me to be the case, as biotite in thin section surrounds hornblende. The biotite, however, must have been formed as an alteration of hornblende before the tectonization occurred. The tectonization was clearly strongest along the contact between the pegmatite and the farsundite and decreased in intensity away from the contact.

Approximately 16 m north of the incline shaft pegmatite disappears under cover, and north of this point it has been impossible to find it again. It is possible that the pegmatite continues in the same direction, i. e., N 385°, or that its continuation continues towards the west in the direction N 340°, i. e. below the boggy area (see the perspective drawing). It appears to me that the latter is the more likely possibility, while the pegmatite body gradually plunges deeper. Towards the north one can see that the contact between the farsundite and the pegmatite becomes more westerly than the direction of the cliff in the farsundite. It can also be seen that the zones in the pegmatite become lower and lower the further north one comes. The measurements which have been made, revealed that the pegmatite strikes ca. N 360° and dips ca. 45° E, although the dip is variable. It therefore appears that the pegmatite occurs as an elongate body rather than as a vein.

The pegmatite has a well developed zonal structure, but the thick-



Fig. 3. Perspective drawing, Rømteland. The pegmatite is in the farsundite cliff to the right of the house. Drawn by I. Lowzow.

Perspektivtegning, Rømteland. Pegmatitten er innsirklet og ligger i farsundittveggen til høyre for huset. Tegnet av I. Lowzow.

ness of the zones varies from place to place. Nearest the farsundite there invariably occurs a zone of graphic granite. The mineralogical composition of the graphic granite zone is given in Table No. VIII, p. 174 and 175. The minerals in this zone are intensely granulated and in thin section show undulating extinction. From a zone of graphic granite one has a completely gradual transition to the strongly mineralized zone of the pegmatite, in which the graphic intergrown disappears and quartz and microcline occur separately. From the zone of mineralization can be followed veins which transect the zone of graphic granite and extend into the farsundite. The minerals in these are the same as those in the farsundite, but are much coarser. The mineralogical composition of the zone of mineralization is given in Table No. VIII, p. 174 and 175. The transition to the next zone in the pegmatite, the quartz-feldspar zone, is complete gradual. The transition is one of a gradual increase in the grain-size of quartz and feldspar with simultaneous disappearance of many of the other minerals. Quartz,

microcline, and plagioclas are the most important minerals in this zone (see further Table No. VIII, p. 174 and 175).

It is impossible to say anything about the thickness of the quartz-feldspar zone, but the smallest distance between the mineralized zone and the quartz zone inside the quartz-feldspar zone is about 8 m.

Inwards microcline and plagioclase disappear leaving only quartz — i. e., a quartz zone. As this zone has been seen only in the deepest part of the mine it is impossible to determine its thickness.

Amphibolite masses occur both inside and outside of the pegmatite. Whether these are parts of a continuous amphibolite layer only exposed at places or are isolated, unassimilated masses is impossible to say.

Around amphibolite masses in the pegmatite there always occurs a zone of mineralization and the mineralization is the same regardless of the zone(s) in which the masses occur. The amphibolite masses outside of the pegmatite are, however, not surrounded by a mineralized zone; the only contact affects are that hornblende is transformed to biotite and the plagioclase becomes more acidic as is also the case within the pegmatite. The mineralized zones around amphibolite may, according to Fersmans nomenclature (1931), be called contact pegmatite.

The contact reactions have resulted in partial assimilation of the amphibolite by the pegmatite, yielding a Ca-rich area. The Ca-minerals, other than plagioclase, are allianite, sphene, apatite, and fluorite. Other minerals in these zones can be seen from Table No. VIII, p. 174 and 175. The thickness of the mineralized zones around amphibolite can be up to 1 m; the transition to the normal pegmatite is gradual and to the amphibolite sharp. The grain size within these zones increases from the amphibolite to the normal pegmatite.

A dike crosses the pegmatite. It strikes ca. 300° and dips ca. 80° S. It is rich in microcline and quartz, for other minerals see Table No. VIII, p. 174 and 175. Across the dike there is a crack filled by palygorskite and quartz.

Druses can be seen in the pegmatite. Quartz grown together with hematite, chlorite, calcite, and a montmorillonite-like clay mineral have been identified from these.

Temperature of formation of the pegmatite.

Field observations, macroscopic and microscopic studies, and chemical and X-ray analyses have been made in order to clarify the mode of genesis of the pegmatite.

In order to determine the temperatures of formation of the rocks according to Barth's (1956) feldspar thermometer the composition of plagioclase has been determined optically and that of microcline chemically. The resulting temperature determinations are recorded in Table No. III, p. 136 and 137. Thin sections have revealed that sericitization and albitization have occurred (see fig. 4).

Studies of profiles of samples have yielded the following observations. 1. Albitization increases towards the pegmatite. 2. Sericitization of the plagioclase increases towards the pegmatite but the outer albite rims remain unaffected. 3. Alkali feldspars are always fresh and the perthite is believed to have formed from an originally homogenous, high temperature feldspar (see p. 144). 4. Biotite was formed at the expense of hornblende before tectonization (see p. 157). 5. Albitization occurred after tectonization; it is found in and along fractures.

The following changes in the feldspars have been observed in the pegmatite. 1. Tectonization decreases inwards. 2. The albite zone around plagioclase diminishes inwards. 3. Plagioclase is very little sericitized away from the boundary of the pegmatite. 4. The alkali feldspar is always fresh and the perthite is believed to have been formed from an originally homogeneous, high temperature feldspar.

These changes may affect the accuracy of the temperatures determined by the two-feldspar thermometer. Barth (1956) gives the formula

$$\frac{\text{Mol fraction of the ab in alkali feldspar}}{\text{Mol fraction of ab in plagioclase}} = k_{(TP)};$$

an increase of k means higher temperature.

At Rømteland the sericitization of the plagioclase in the farsundite increases towards the pegmatite; the same is the case for albite along fracture zones; alkali feldspar is always fresh. These observations may indicate any of the following possibilities. 1. Na introduced from outside of the system was deposited as albite around plagioclase (and in cracks) and possibly reacted with the plagioclase such that it became more acidic. 2. Because the plagioclase is sericitized the Na necessary



Fig. 4. Strongly sericitized plagioclase at the contact with the pegmatite. The plagioclase is surrounded by a rim of fresh albite. The albite occurs also in cracks. Fresh microcline.

Foto av sterkt serisittisert plagioclas fra kontakten farsunditt—pegmatitt. Frisk albitt has rundt og i sprekker i plagioklasen. Frisk mikroclin.

to form albite may have been derived from the plagioclase locally. This may be the result of introduction of K. 3. The alkali feldspar may originally have been more acidic than at present. Tectonization (at ca. 460°) stimulated reaction such that Na was driven out of the alkali feldspar (a more K-rich feldspar being stable at 460°) and was deposited as albite around plagioclase. 4. Introduction of K may have caused the sericitization; introduction of Na may have accompanied tectonization.

If the first is correct the Na-content of the plagioclase has become greater than it was originally, yielding a temperature lower than that at which the rock formed. In this case only samples 7, 10, and 20 give an approximately correct temperature (i. e. > 630°, see Table No. III p. 136 and 137). This alone does not, however, account also for the

Table III.

Survey of temperatures determined from the gneiss, farsundite, and pegmatite.

Samples: rock type, location, and other comments	Max Optical data			Analyses for alkalis in alkali feldspars			Results of calculation			
	Extinction in the zone — (010)	Optic sign	An % in plagioclase	Na ₂ O	K ₂ O	Analyst	Mol % Ab in alk.f.	Mol. Ab. in alk.f.		Temp. of formation
								K	Mol. Ab. in plag.	
1. Gneiss at Spangereid (for age determination)	13°	—	30	2.28	9.56	B. Bruun	27.40	0.3916	650°*	
2. Gneiss at Gjeiteland, between Snig and Tarvannet	15°	—	33	3.71	10.77	T. Sverdrup	34.36	0.4700	725°	
3. Gneiss at Lone, near Tarvannet. Sample no. 142	7°—8°	—	26	1.28	14.56	B. Bruun	11.80	0.1594	430°	
4. Pegmatite on Trone peninsula. South of the farsundite. Sample no. 134	11°	—	28	3.00	12.00	—	28.00	0.3839	645°	
5. Pegmatite at Hags, north of Vigeland	4°	—	18	2.96	12.56	—	26.08	0.3190	585°	
6. Farsundite at Remesvig-Mogedal, south of Rømteland. Sample no. 130	11°	—	28	2.920	11.78	—	27.20	0.3778	635°	
7. Farsundite at Osestad, north of Rømteland. Sample no. 143	10°	—	27—28	3.07	11.64	T. Sverdrup	28.56	0.3939	655°	
8. Schistose farsundite at the tarn ca. 200 m north of Rømteland	10°	—	27—28	3.08	10.82	B. Bruun	29.70	0.4068	660°	
9. Farsundite in the gap, ca. 150 m north of Rømteland	10°	—	27—28	2.92	11.38	T. Sverdrup	28.60	0.3950	655°	
10. Farsundite ca. 100 m east of Rømteland. Sample no. 1—1956	8°	—	26	3.12	12.00	B. Bruun	28.02	0.3784	635°—640°	

11. Farsundite ca. 75 m east of Rømtelæand. Sample no. 2—1956	13°	-	30	2.70	12.00	—	25.60	0.3660	625°
12. Farsundite ca. 50 m east of Rømtelæand. Sample no. 3—1956	10°	-	27—28	3.82	9.26	—	38.40	0.5260	780°*
13. Farsundite ca. 10 m east of Rømtelæand. Sample no. 4—1956	11°	-	29	2.42	12.00	—	23.44	0.330	600°
14. From the contact between farsundite and pegmatite' Rømtelæand	15°	-	33	2.34	13.47	T. Sverdrup	20.02	0.2988	575°
15. Graphic granite zone, Rømtelæand	10°	-	27—28	2.42	12.83	—	21.62	0.3028	580°
16. Mineralized zone, Rømtelæand (outer part)	9°	-	26—27	2.91	12.77	—	25.79	0.3533	615°
17. Mineralized zone, Rømtelæand (inner part)	9°	-	26—27	2.85	12.83	—	25.37	0.3475	610°
18. Quartz-feldspar zone, Rømtelæand (outer part)	6°	-	25	3.13	12.77	E. Padget	27.07	0.3609	620°
19. Quartz-feldspar zone, Rømtelæand (inner part)	6°	-	25	3.00	12.85	—	26.11	0.3480	610°
20. Quartz-feldspar zone, Rømtelæand (Analyzed for A Tverstøl)	-	-	25	3.23	12.68	Statens råstofflaboratorium	27.79	0.3705	630°
21. Younger, cross-cutting dike, Rømtelæand	**)	+	<5	1.83	13.92	E. Padget	16.64	0.1752	450°—460°
22. Gneissic farsundite, ca. 30 m west of the pegmatite at Rømtelæand	9°	-	56—27	2.45	13.18	T. Sverdrup	22.02	0.3030	580°
23. Farsundite from Lista (received from Barth)	-	-	-	-	-	-	-	-	540°—550°
24. Gneiss granite between Spangereid and Grønsfjord. Sample no. 124	8°	-	26	2.30	13.28	—	20.50	0.2770	550°
25. Gneiss granite between Spangereid and Grønsfjord. Sample no. 125	12°	-	29	2.30	13.60	B. Bruun	20.40	0.2873	565°

* No. 1 and 12 in the table consisted of impure material. These analyses are not used later.
 ** An % determined by index of refraction (see albite in table 000).



Fig. 5. Photo showing hornblende replaced by epidote and biotite.
Foto som viser biotitt og epidot dannet på bekostning av hornblende.

stabilized the area at lower temperature (more acidic plagioclase — lower temperature; see Barth, 1956), tectonization of the area has occurred followed by albitization.

The temperature of the young, cross-cutting dike was found to be 450° — 460° , and its formation must be associated with the tectonization which, therefore, is assumed to have taken place at that temperature. By using the Na content of the pure albite found in zones around plagioclase in the tectonized zones in relation to the fresh microcline with which it is in contact, the temperature 475° is obtained.

However, both sericitization and albitization will result in determined temperatures much lower than the primary temperature of formation. Only temperatures $> 630^{\circ}$, i. e. those at some distance out in the farsundite and centrally in the pegmatite where secondary processes have been minimal, may be assumed to correspond with the temperatures at which the rocks formed. The temperatures determined are shown graphically in Fig. 7 while the probable original temperature curve is shown in Fig. 6.

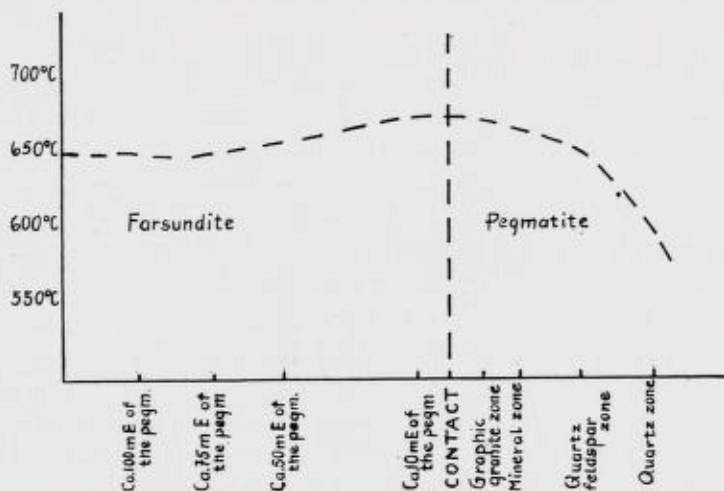


Fig. 6. Temperature curve I. Natural curve for temperatures if the pegmatite is melted.

Temperaturkurve I. Naturlig kurve for temperaturer om pegmatitten er oppsmeltet.

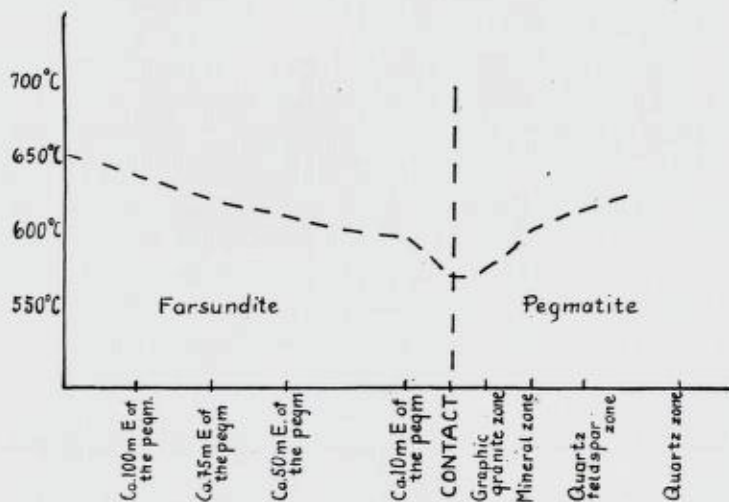


Fig. 7. Temperature curve II. Temperature variation at Rømteland based on temperature determinations (see p. 136 and 137).

Temperaturkurve II. Figuren viser temperaturene som er funnet på Rømteland. Kurvene er satt opp ut fra temperaturbestemmelsene (se side 136 og 137).

Magmatic origin; supporting observations.

I have discussed the temperature of formation of the pegmatite, based on temperatures determined by the two-feldspar thermometer and adjustments of the determined temperatures due to post-formation modifications of the feldspars. I have elsewhere discussed the origin of the pegmatite in greater detail (Sverdrup, 1957).

The conclusion drawn was that the farsundite which had a temperature near its melting point, has at some places melted.

One of these places is at Rømteland. One possible explanation for local melting here can be an enrichment of radioactive elements.

The melt has a greater volume than the original crystalline phase. The result was that the farsundite near the local melt cracked and was then filled by molten material which can now be seen as veins extending out into the farsundite from the pegmatite. The first thing which melted was a eutectic mixture of quartz and feldspar. This mixture, after again crystallizing, now appears as the zone of graphic granite between the pegmatite and the farsundite. After the area again became cooler, a K-rich solution moved out into the farsundite and into the amphibolites from the pegmatite. Plagioclase was then sericitized and hornblende altered to biotite. Both of these products can be explained as the result of the same K-rich solution. This type of alteration decreases away from the pegmatite.

Assuming a slow cooling of the area the zonal structure of the pegmatite can also be explained. Because the expansion upon melting caused some of the melt to be injected into the farsundite (the veins mentioned above), the remaining material, when again crystalline, will occupy less than the original volume, and therefore druses occur.

The final result of this crystallization will be a very acidic plagioclase, as seen now in the younger dike crossing the pegmatite. The temperature for this dike is found to be 450—460°. (Na in plagioclase and microcline, Barth 1956). This temperature and the mineral association indicates a hydrothermal mode of formation for this dike. The minerals are listed in Table VIII, p. 174 and 175. Muscovite and epidote, two of the minerals found here, are stable minerals under 400—500° (Ramberg 1952, p. 51 and 53). Further, Fersman (1931) says that the minerals epidote and albite are intermediate between the pneumatolytic and hydrotherman phases. Both of these minerals are present.

He also regards the sulfides as hydrothermal minerals. Pyrite and chalcopyrite are found in the dike. It seems therefore that the temperature determined is correct and that the dike is of hydrothermal origin.

A tectonizatic of the pegmatite took place around 450—460°, and a Na-rich hydrothermal solution has moved into and crystallized in all the cracks. Recrystallization has occurred along with the formation of the younger dike crossing the pegmatite.

Description of the minerals.

Many of the minerals have been identified by X-ray powder patterns. A 9 cm diameter Debye and Scherrer camera was used with Fe-radiation and Mn-filtration, 40 kV and 14 m. A.

The number below the X-ray patterns included here refers to the index at the X-ray laboratory in the Geological Museum, Tøyen, Oslo. Identification of metamict minerals has been made after heating the minerals to 770° C (unless otherwise stated) in order to allow the damaged structure to be repaired. However it is not absolutely certain that a new structure will not be formed in some cases.

For determination of the triclinicity of the alkali feldspars a "quadruple Guinier type focussing camera" (Nonius Co., Delft, Holland), with Fe-radiation monochromatized by a bent quartz crystal, was used with "Kodak's Kodirex" X-ray film.

The chemical formulae for the minerals were taken from Klockmann-Ramdohr's "Lehrbuch der Mineralogie" (1954).

Microcline: $\text{KAlSi}_3\text{O}_8\text{-NaAlSi}_3\text{O}_8$. Optically —, $2V > 75^\circ$, $n_\beta = 1,525$.

Both the farsundite and the pegmatite have much alkali feldspar. In thin sections taken from the pegmatite and from the farsundite near the pegmatite the microcline polysynthetic cross-hatched twinning is always well developed. At Osestad (about 2 km N of Rømteland) this twinning is much more diffusely developed. This feature is to be expected from the triclinicity determinations described earlier (see p. 127).

The grain size of the microcline increases from the farsundite to the center of the pegmatite. In the farsundite the grain size is about 0.8 mm. In the quartz-feldspar zone, however, there are crystals up to

one meter in diameter. The microcline is red to yellow in colour. Chemical analyses for alkali feldspar can be seen in Table No. III, p. 136 and 137. As can be seen, the K-content is somewhat lower in the farsundite than in the pegmatite.

In some places the microcline is in near contact with radioactive minerals. The microcline is then characteristically coloured. The colours are from yellow to red to black. On the microcline cleavages (001) and (010) there can often be seen small patches of sericite. Andersen (1931, (II) p. 23) mentions the same from other pegmatites.

In thin-sections two different types of perthites can be seen, film and vein perthites (Andersen, 1928). The film perthites are fine, small, regular and parallel, while the vein perthites are coarser and uneven in their forms. The film and vein perthites generally have the same orientation. Andersen (1928) has the following opinion about the film and vein perthites, p. 150: "The writer is inclined to regard also the film perthites as formed by a process of exsolution, . . ., and possibly in connection with contraction cracks". And p. 150: "This vein type of perthite the writer regards as formed in connection with the opening of contraction cracks, giving access to circulating solutions derived from the same pegmatite magma from which the initial crystallization of the feldspar took place."

I believe that the film perthites are formed by exsolution from a nonhomogeneous feldspar. They are ca. 0.004 mm wide and 0.13 mm in length. They are of uniform size, the distance between them is almost constant, and they are evenly distributed except in the near vicinity of the vein perthites, where they are absent (see photograph, Fig 8).

Assuming that the film perthites are exsolution perthites I have made the following examination. Under the microscope I have measured the thicknesses of the film perthites and the average distance between them. As can be seen from the photograph (Fig. 8), there is a "dead" area with respect to the film perthites near the vein perthites. I have measured the distance of this "dead" area on each side of the vein perthites. I have then calculated the number of film perthites which could have been expected to occur in this area if there had been no "dead" area and no vein perthite. Knowing then the thickness of the film perthites and how many could be accommodated in this area it is easy to calculate the area which these film perthites would occupy were they combined to form one perthite vein. A-A, B-B, C-C, and D-D are cuts taken in a thin section across a vein perthite, represented



Fig. 8. Film and vein perthites. Note that distance x-x is devoid of film perthites.
 × ca. 100, + nicols.

Film- og veinperthitter. Avstanden x-x er et dødt område for filmperthittene.
 × ca. 100, + nicols.

in the photograph, Fig. 8, by X-X. (All of the values given below (Table IV) must be divided by 20 in order to obtain the true size of the pegmatites.)

Table IV.

Cut	Width of film perthite	Width of vein perthite	Film perthites pr. cm. where they occur most frequently.	Dead area w. r. t. film perthites.	Number of film perthites which can occur in the different cuts.	The film perthites will be equivalent to one vein perthite of width
A—A	≈ 0.3 mm	17.0 mm	4.5	90 mm	40.5	12.5 mm
B—B	≈ 0.3 "	20.0 "	4.5	90 "	40.5	12.5 "
C—C	≈ 0.3 "	16.0 "	4.5	100 "	45	13.5 "
D—D	≈ 0.3 "	9.0 "	4.0	60 "	27	7.2 "

Based on these measurements and calculations it would appear that the vein perthites have been formed by the combination of small film perthites (themselves formed by exolution from an originally

homogeneous feldspar) into the larger vein perthites, possibly without the addition of Na from some external source. That the measurements do not fully account for the vein perthites, seems not to be surprising, as further cooling would result in further exsolution with increased perthite formation. That the later exsolved Na would primarily crystallize out in continuity with the larger vein perthites seems likely on the basis of surface energy and surface tension considerations.

Andersen (1928, p 166) says: "The veins have never been observed cutting the films, and there is no reason therefore to believe that they may be younger." It seems to be right that the vein perthites do not cut the film perthites, but it is equally right that the film perthites do not cut the vein perthites. However, by studying the perthites in thin-sections it can be seen that the film perthites have a direction, which in some places is not parallel to that of the vein perthites. It seems to me that the film perthites are formed first, and that the vein perthites are formed at the expense of these. The following mode of formation of the perthites seems to me to be indicated. By cooling of the homogeneous feldspar the formation of film perthites took place by exsolution. During this uniform cooling there have been disturbances in the system which have caused the formation of the vein perthites. There has been tectonization of the Rømteland area after the minerals had crystallized. The younger dike crossing the pegmatite, according to the temperature determinations made (see Table III, p. 137), formed at ca. 460° C. I believe that this dike was formed during the tectonization.

A. Tverstøl has had a chemical analysis made of an alkali feldspar from Rømteland:

SiO ₂	64.46 %
Al ₂ O ₃	18.96 »
All Fe as Fe ₂ O ₃	0.08 »
CaO	0.78 »
MgO	0.05 »
Na ₂ O	3.23 »
K ₂ O	12.68 »
H ₂ O	0.06 »
Lost under heating	0.26 »
	<hr/>
	100.56 %

Analyzed by Statens Råstofflaboratorium.

The melting point for this feldspar is 1450° C.

According to the optical determinations the composition of the microcline is 25 % Ab and 75 % Or (Winchell 1951). This is in good agreement with the chemical analysis (Table III, p. 136 and 137).

Variations in triclinicity measurement can be seen p. 127.

Allanite: $(Ca, Ce, La, Na)_2 (Al, Fe, Mg, Mn)_3 (OH) (SiO_4)_3$.

Allanite occurs in most zones at Rømteland. See Table VIII, p. 174 and 175. In the mineralized zone in the pegmatite and in the quartz-feldspar zone the mineral is black and metamict, but by heating the mineral to 600° for 72 hours under water pressure, an X-ray pattern good enough for identification was obtained. In these zones allanite can be 1 meter in length and 30—40 cm across. $n \approx 1.690$. The content in the mineral = 2 %, U content in the mineral = trace.

An optical spectrogram was taken by the Sentralinstitutt for Industriell Forskning, and the following elements were found: Si, Ca, Al, Mn, Fe, Mg, Pb, Th, Ce, Y, La, and Yb.

The sample has most of Si, Ca, Al, Mn, Fe and Mg (the amount decreases from Si to Mg). The sample has little Pb. Of Th and the rare earths there seems to be most of Th and Ce. The sample has very little Yb.

Another variety of allanite has been found where the mineralized zone in the pegmatite is in contact with the mineralized zone around amphibolite. The colour of this allanite is gray to green on the surface, but darker in the center. This allanite is metamict and it has been impossible to identify the mineral by X-ray (also after heating the mineral).

The Sentralinstitutt for Industriell Forskning has also taken an optical spectrogram of this type of allanite. The following elements were found: Si, Al, Ca, Fe, Mg, Th, Ce, La, Mn, Y, Yb, Ti, Ga, and Sc.

The sample has most Si, Ca, Al; much Th, Ce; some Fe, Mg, Mn, Yb, La, Y; and little Ti, Ga, Sc.

The amount of Sc is very interesting in that the allanite here occurs in the most basic area of the pegmatite. Goldschmidt (1954) has mentioned that Sc occurs most frequently in basic ferromagnesium rich rocks. Specific gravity is 3.16, $n \approx 1.749$.

Allanite also occurs in the mineralized zones around amphibolite and is here a characteristic mineral. The crystal form, however, is here

different from that of the two earlier described allanites. The mineral is always black and platy formed. It is metamict, and even after heating to more than 1000° C it was impossible to identify the mineral by X-ray. Much, however, indicates that it must be a platy formed allanite, which has been described earlier (O. Andersen (1926) and Klockmann-Ramdohr (1954)). The platy formed allanite often has a silky luster on the surface.

Specific gravity is = 3.14, hardness 5½.

An optical spectrogram was taken and following elements were found: Si, Al, Ca, Fe, Th, Ce, Zr, La, Mg, Mn, Ti, Pb, Yb, and Y, possibly also U. (Analyzed by the Sentralinstitutt for Industriell Forskning). With hand goniometer all the angles were measured, and, as can be seen below, all the angles are in good agreement with earlier described allanites ("A system of Mineralogy", Dana (1898), allanite from Moriah, N.Y., Fig. 1, p. 522, Bucklandite, Laacker See, Rath. Dana (1898), and Klockmann-Ramdohr (1954)).

*These publications give
the following angles:*

al — 154°
lr — 154.39°
rc — 116.60°
ca. — 115.02°
au — 143.47°

*Angles measured on platy
formed allanite,
Rømteland:*

152°—155°
about 155°
118°—120°
115°
140°—143°

$n \approx 1.749$. The planes best developed are a (001) and u (210). The platy formed allanite from Rømteland splits best along u (210).

The platy formed allanite occurs in small crystals close to amphibolite, but inwards into the pegmatite the crystals increase quickly in size. Within a distance of 30 cm the mineral increases in size from a few mm to more than 10 cm across. The thickness of the plates is usually not more than 1 cm. Three chemical analyses of three different allanites have been made. As can be seen, there is not great difference between them, and all of them are in good agreement with earlier analyses of allanite (Dana 1898).

Analyses of three different allanites.

	Type I Ordinary allanite	Type II Allanite with the grey to green surface	Type III Platy form allanite.
SiO ₂	29.9 %	29.5 %	30.6 %
ZrO ₂	—	—	0.4 *
TiO ₂	0.5 *	0.4 *	0.9 *
CeO ₂	9.4 *	10.0 *	8.4 *
ThO ₂	1.9 *	1.4 *	2.8 *
Al ₂ O ₃	16.9 *	16.7 *	14.8 *
Fe ₂ O ₃	8.8 *	6.1 *	11.9 *
FeO	6.0 *	7.5 *	3.5 *
La ₂ O ₃	6.4 *	9.9 *	7.7 *
Y ₂ O ₃	0.7 *	1.1 *	0.5 *
PbO	0.1 *	0.6 *	0.2 *
MnO	1.9 *	2.5 *	0.8 *
MgO	1.3 *	1.1 *	0.7 *
CaO	7.6 *	8.9 *	10.9 *
Na ₂ O	—	—	— *
K ₂ O	—	—	— *
H ₂ O	0.4 *	0.4 *	0.8 *
H ₂ O ⁺	8.4 *	4.0 *	4.7 *
P ₂ O ₅	0.1 *	0.1 *	0.2 *
Sum	100.3 %	100.2 %	99.8 %

Analyzed by E. Padget, NGU.

The calculation of the formula from the analyses is based on the formula for epidote, Ca₂Al₃(OH)Si₃O₁₂, in which the (OH) group is expressed as 1/2H₂O + 1/2O. The calculation is then based on the number of oxygen ions present in the formula X₂Y₃O_{12 1/2} (H₂O)₁. In order to determine the molecular proportions I have used "Molecular Proportions" by von Echer mann (1925). The analyses are directly recalculated to atomic proportions and multiplied by 1000.

Calculations of the formula from analysis I, p. 149.

Atom proportions	O-atoms	The calculated amount of O-atoms in relation to total O ₁₂	Cation proportion in relation to O ₁₂
SiO ₂ 497	994	5.800	Si ^{iv} 2.900
TiO ₂ 6	12	0.069	Ti ^{iv} 0.035
CeO ₂ 55	110	0.640	Ce ^{iv} 0.320
ThO ₂ 7	14	0.080	Th ^{iv} 0.040
AlO _{1½} 331	497	2.900	Al ⁱⁱⁱ 1.933
FeO _{1½} 110	165	0.961	Fe ⁱⁱⁱ 0.642
FeO 84	84	0.498	Fe ⁱⁱ 0.498
LaO _{1½} 40	60	0.350	La ⁱⁱⁱ 0.233
YO _{1½} 6	9	0.052	Y ⁱⁱⁱ 0.035
MnO 27	27	0.157	Mn ⁱⁱ 0.157
MgO 32	32	0.183	Mg ⁱⁱ 0.183
CaO 136	136	0.791	Ca ⁱⁱ 0.791
PO _{2½} 2	5	0.029	P ^v 0.012
	2.149	12.500	

Ideal formule: Ca₂Al₃ (OH) Si₃O₁₂

Ca ⁱⁱ 0.791	Al ⁱⁱⁱ 1.933	Si ^{iv} 2.900
Ce ^{iv} 0.320	Fe ⁱⁱⁱ 0.642	P ^v 0.012
Th ^{iv} 0.040	Ti ^{iv} 0.035	
Fe ⁱⁱ 0.379	Mg ⁱⁱ 0.183	Sum 2.912
La ⁱⁱⁱ 0.233	Fe ⁱⁱ 0.119	
Y ⁱⁱⁱ 0.035		
Mn ⁱⁱ 0.157	Sum 2.912	
Sum 1.955		

The formula for ordinary allanite, Rømteland:
 (Ca, Ce, Th, Feⁱⁱ, La, Y, Mn)₂ (Al, Feⁱⁱⁱ, Ti, Mg)₃ (OH)
 (Si, P)₃O₁₂.

Calculations of the formula from analysis II, p. 149.

Atom proportions		O-atoms	The calculated amount of O-atoms in relation to total O ₁₂	Cation proportion in relation to O ₁₂	
SiO ₂	497	994	5.710	Si ^{IV}	2.855
CeO ₂	58	116	0.669	Ce ^{IV}	0.335
TiO ₂	5	10	0.058	Ti ^{IV}	0.029
ThO ₂	5	10	0.058	Th ^{IV}	0.029
AlO _{1½}	327	491	0.830	Al ^{III}	1.887
FeO _{1½}	76	114	2.658	Fe ^{III}	0.439
FeO	104	104	0.600	Fe ^{II}	0.600
LaO _{1½}	61	92	0.530	La ^{III}	0.353
YO _{1½}	10	15	0.086	Y ^{III}	0.057
PbO	3	3	0.017	Pb ^{II}	0.017
MnO	35	35	0.203	Mn ^{II}	0.203
MgO	27	27	0.153	Mg ^{II}	0.153
CaO	159	159	0.916	Ca ^{II}	0.916
PO _{2½}	2	2	0.012	P ^V	0.005
		2.172	12.500		

Ideal formula: Ca₂Al₃ (OH) Si₃O₁₂

Ca ^{II}	0.916	Al ^{III}	1.797	Si ^{IV}	2.855
Ce ^{IV}	0.335	Fe ^{III}	0.439	P ^V	0.005
Th ^{IV}	0.029	Ti ^{IV}	0.029	Al ^{III}	0.090
La ^{III}	0.353	Mg ^{II}	0.153		
Y ^{III}	0.057	Fe ^{II}	0.532	Sum	2.950
Pb ^{II}	0.017				
Mn ^{II}	0.203	Sum	2.950		
Fe ^{II}	0.068				
Sum	1.978				

The formula for allanite with grey to green surface
(Type II):
(Ca, Ce, Th, La, Y, Pb, Mn, Fe^{II})₂ (Al, Fe^{III}, Ti, Mg,
Fe^{II})₃ (OH) (Si, Al P)₃ O₁₂.

Calculations of the formula from analysis III, p. 149.

Atom proportions	O-atoms	The calculated amount of O-atoms in relation to total O ₁₂	Cation proportion in relation to O ₁₂
SiO ₂ 499	998	5.780	Si ^{iv} 2.890
ZrO ₂ 3	6	0.035	Zr ^{iv} 0.018
TiO ₂ 11	22	0.128	Ti ^{iv} 0.064
CeO ₂ 49	98	0.569	Ce ^{iv} 0.285
ThO ₂ 11	22	0.128	Th ^{iv} 0.064
AlO _{1½} 290	435	2.527	Al ⁱⁱⁱ 1.683
FeO _{1½} 149	224	1.297	Fe ⁱⁱⁱ 0.865
FeO 49	49	0.284	Fe ⁱⁱ 0.284
LaO _{1½} 47	70	0.406	La ⁱⁱⁱ 0.271
YO _{1½} 4	6	0.035	Y ⁱⁱⁱ 0.023
PbO 1	1	0.006	Pb ⁱⁱ 0.006
MnO 11	11	0.064	Mn ⁱⁱ 0.064
MgO 17	17	0.100	Mg ⁱⁱ 0.100
CaO 194	194	1.112	Ca ⁱⁱ 1.112
PO _{2½} 2	5	0.029	P ^v 0.012

2.158 12.500

Ideal formula: Ca₂Al₃ (OH) Si₅O₁₂

Ca ⁱⁱ 1.112	Al ⁱⁱⁱ 1.683	Si ^{iv} 2.890
Ce ^{iv} 0.285	Fe ⁱⁱⁱ 0.865	P ^v 0.012
Zr ^{iv} 0.018	Ti ^{iv} 0.064	
Th ^{iv} 0.064	Mg ⁱⁱ 0.100	Sum 2.902
La ⁱⁱⁱ 0.271	Fe ⁱⁱ 0.190	
Y ⁱⁱⁱ 0.023		
Pb ⁱⁱ 0.006	Sum 2.902	
Mn ⁱⁱ 0.064		
Fe ⁱⁱ 0.094		
Sum 1.937		

The formula for the platy formed allanite (Type III).
 (Ca, Ce, Zr, Th, La, Y, Pb, Mn, Fe)₂ Al, Feⁱⁱⁱ, Ti,
 Mg, Feⁱⁱ)₃ (OH) (Si P)₃ O₁₂

Because it has been necessary in the calculation of the allanite formula to put Fe⁺⁺ in the Al group I have, as a control, calculated the formula of an allanite from Kragerø, the analysis of which is found in Dana "A system of mineralogy" (1898), p. 524.

Calculations of the formula:

Chemical analysis	Atom proportions	O-atoms	The calculated amount of O-atoms in relation to total O ₁₂	Cation proportion in relation to O ₁₂
SiO ₂ 31.72	526	1.052	6.020	3.010
ThO ₂ —	—	—	—	—
Al ₂ O ₃ 17.80	348	522	3.010	2.007
Fe ₂ O ₃ 2.52	32	48	0.276	0.184
Ce ₂ O ₃ 19.43	112	168	0.966	0.644
FeO 9.37	130	130	0.748	0.748
CaO 13.17	235	235	1.352	1.352
MgO 0.74	18	18	0.103	0.103
K ₂ O 0.25	5	3	0.019	0.038
Na ₂ O 0.04	2	1	0.006	0.012
H ₂ O 3.30	—	—	—	—
		2.177	12.500	

Ideal formula: Ca₂Al₃ (OH) Si₃O₁₂

Ca ⁺⁺ 1.352	Al ⁺⁺⁺ 1.991	Si ⁺⁺⁺⁺ 3.010
Ce ⁺⁺⁺ 0.644	Fe ⁺⁺⁺ 0.184	Al ⁺⁺⁺ 0.016
Na ⁺ 0.012	Mg ⁺⁺ 0.103	
K ⁺ 0.038	Fe ⁺⁺ 0.748	Sum 3.026
Sum 2.046	Sum 3.026	

The formula of this allanite:
(Ca, Ce, Na, K)₂ (Al, Fe⁺⁺⁺, Mg, Fe⁺⁺)₃ (OH) (Si, Al)₃ O₁₂

As can be seen it is also necessary here to put Fe⁺⁺ into the Al group. On the basis of the chemical analysis, angle measurements and specific gravity determinations, all of the above must be allanites, even though only the ordinary allanite could be identified by X-ray.

Alvite: ZrSiO₄ (Th and Hf bearing).
See also Ceytolith.

The mineral called alvite is metamict. $n \approx 1.733$. It is found in the mineralized zone. It is reddish to black in colour. Hardness = 7⁺. Specific gravity is 3.90. After heating the mineral to 1045° C the X-ray pattern was that of zircon, with some other lines which can be identified as corundum lines.

The mineral is found with feldspar, and the feldspar is always granulated and destroyed close to the alvite.

An optical spectrogram of the mineral was made at the Sentral-institutt for Industriell Forskning, Oslo. The following elements were found. Most abundant: Si, Zr, Yb, Y and perhaps U, less abundant: Ca, Fe, Al, Mn, Mg, Pb, Hf and perhaps Th.

A chemical analysis of the mineral was also made.

SiO ₂	32. 7 %
ZrO ₂	34. 7 »
TiO ₂	0. 3 »
CeO ₂	0.05 »
ThO ₂	»
Al ₂ O ₃	18. 1 »
Fe ₂ O ₃	2. 7 »
Y ₂ O ₃	1. 6 »
PbO	0. 5 »
MnO	0. 5 »
CaO	0. 9 »
Na ₂ O	1. 1 »
H ₂ O ⁻	0. 9 »
H ₂ O ⁺	6. 5 »
P ₂ O ₅	0. 2 »
	<hr/>
	100.75 %

Analyzed by E. Padget, N.G.U.

As can be seen there is good agreement between them, except for the great content of Al₂O₃ in the analysis. In the spectrogram, however, there occurs uranium, which in the chemical analysis will have been determined as Al₂O₃.

The uranium content was therefore determined at Institutt for Atomenergi. Two different samples were used. See Table V.

Table V.

Sample 1:	
Radiometric analysis	5.40 % U_3O_8
Polarographic analysis	5.07 % * *
Average for sample 1	5.23 % U_3O_8
Sample 2:	
Radiometric analysis	4.86 % U_3O_8
Polarographic analysis	4.45 % * *
Spectrographic analysis	4.28 % * *
Chemical analysis	4.56 % * *
Average for sample 2	4.54 % U_3O_8

Because the material of sample 1 is identical to that used in the analysis these results are used.

Plagioclase and possibly corundum are the only possible containments, and therefore in one case all the Na and Ca with the appropriate amounts of Al and Si are used for the formation of plagioclase, and in the other case all the Na, Ca and Al with the appropriate amount of Si are used for formation of the two minerals plagioclase and corundum. All these results can be seen in the calculated analyses given below.

Analysis		Analysis after formation of plagioclase and recalculated to 100%		Analysis after formation of plagioclase and corundum and recalculated to 100%	
SiO ₂	32.7 %	SiO ₂	28.00%	SiO ₂	31.42%
ZrO ₂	34.7 %	ZrO ₂	39.64%	ZrO ₂	44.42%
TiO ₂	0.3 %	TiO ₂	0.35%	TiO ₂	0.39%
CeO ₂	0.05%	CeO ₂	0.06%	CeO ₂	0.07%
ThO ₂	—	ThO ₂	—	ThO ₂	—
U ₃ O ₈	5.23%	U ₃ O ₈	6.09%	U ₃ O ₈	6.84%
Al ₂ O ₃	12.87%	Al ₂ O ₃	10.90%	Al ₂ O ₃	—
Fe ₂ O ₃	2.7 %	Fe ₂ O ₃	3.13%	Fe ₂ O ₃	3.52%
Y ₂ O ₃	1.6 %	Y ₂ O ₃	1.85%	Y ₂ O ₃	2.09%
PbO	0.5 %	PbO	0.58%	PbO	0.66%
MnO	0.5 %	MnO	0.58%	MnO	0.66%
CaO	0.9 %	CaO	—	CaO	—
Na ₂ O	1.1 %	Na ₂ O	—	Na ₂ O	—
H ₂ O ⁻	0.9 %	H ₂ O ⁻	1.04%	H ₂ O ⁻	1.18%
H ₂ O ⁺	6.5 %	H ₂ O ⁺	7.55%	H ₂ O ⁺	8.49%
P ₂ O ₅	0.5 %	P ₂ O ₅	0.23%	P ₂ O ₅	0.26%
	100.55%		100.—%		100.—%

Alvite (cyrtolith) is a poorly defined mineral (D. Forbes and T. Dahll (1885) and Dana (1898)), and in more recent literature (Klockmann—Ramdohr (1954) and Dana (1932)) the mineral name does not appear. If the mineral is a zircon the formula must be written $ZrSiO_4$, and then Al must occupy positions equivalent to both those of Si and Zr. It is doubtful that this is correct because of the great difference in the ionic radii ($Al^{+++} = 0.57 \text{ \AA}$ and $Zr^{++++} = 0.87 \text{ \AA}$).

Furthermore, there is no way in which the remaining available elements can be used to attain electrostatic neutrality when Al substitutes for Zr.

However, after subtracting the amounts necessary for the formation of plagioclase and corundum (note: by heating the mineral 1045° C for identification by X-ray, the pattern of zircon with some lines which could be attributed to corundum, was found), and recalculating the primary analysis to 100 %, I get a result close to earlier analyzed cyrtoliths. See C. Doelter, Band III, p. 138 no. 43 and 44 (1918).

Much seems therefore to indicate that this recalculation is correct in this case. The problem alvite—cyrtolith will be discussed in more detail in a later paper.

Apatite: $Ca_5(PO_4)_3(Cl, F, OH)$.

Apatite occurs in the amphibolite, in the mineralized zone around the amphibolite, and as an accessory mineral in the farsundite. Apatite is optically —, $n_o = 1.644$ and $n_e < 1.644$.

There are two generations of apatite: 1, as small grains in the amphibolite associated with biotite, and 2, as independent needles. When going from the amphibolite to the mineralized zone around the amphibolite, type 2 becomes more and more abundant; type 1, however, being seen in thin-sections the whole time. The grain size for fluor apatite associated with biotite is ca. $1/100 \text{ mm}$ in diameter. The independent needles are up to two centimeters in length and ca. two mm in width. The crystals are colourless and the hexagonal forms are usually well developed.

Bastnäsit: $(Ce, La, Dy) FCO_3$.

Bastnäsit was found at Rømteland, which is the first locality for this mineral in Norway. It is found as an alteration product after allanite. (See Sverdrup, Bryn and Sæbø, 1959).

Beryl: $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$.

Beryl is found at only one place at Rømteland. The crystals grow through alkali feldspar, and the hexagonal form of the green crystals is well developed. I believe that the mineral was formed at an early stage of crystallization, because it is found in the transition between the graphic-granite and mineralized zones. The crystals show no orientation. I have never found minerals containing rare earths in the neighbourhood of beryl. Because of the great concentration of Y and Ce in the pegmatite one should expect that gadolinite would be formed in the pegmatite if the concentration of Be also was great. It is therefore reasonable to believe that the concentration of Be is small and very local. Gadolinite was not found at Rømteland. Beryl is uniaxial optically —, $n_o = 1.580$ and $n_e = 1.575$.

Biotite: $\text{K}(\text{Mg}, \text{Fe})_3(\text{OH})_2(\text{Al}, \text{Fe}) \text{Si}_3\text{O}_{10}$.

Biotite occurs throughout the whole area (see Table VIII, p. 174 and 175). It usually occurs in small flakes, but inside the pegmatite can it be seen in very large crystals, e. g., in the quartz-feldspar zone and partly in the mineralized zone.

The mineral occurs often in wedges and in the internal angles of these, rare minerals can be found e. g., yttrotitanite and uraninite. Andersen (1926) says the same for other pegmatites. From the amphibolite to the pegmatite the crystal size grows gradually. In a distance of from one to two meters the size of the biotite flakes grows from ca. one mm to more than 10 cm in diameter. The quantity of biotite also increases on going from the amphibolite to the contact with the pegmatite. The mineral is black to brown in colour.

Biotite is also found in the younger dike crossing the pegmatite, but at the contact with the pegmatite is it chloritic. In thin-sections from the graphic granite zone and from a little way inwards into the farsundite it can be seen that there has been tectonization of the area after the formation of biotite. The biotite flakes are bent. At the same time the biotite is secondary and formed by alteration of hornblende (as well in the farsundite as in the amphibolite).

Optical data for different types of biotite.

Biotite from amphibolite Rømteland: optically —, $2v = 0-15^\circ$, $r < v$, $n^\beta = 1.620$. Pleochroic: $\alpha =$ yellow, $\beta =$ dark brown, $\gamma =$ green brown. After Winchell (1951) this indicates more Mg than Fe in the biotite from the amphibolite.

Biotite from the pegmatite Rømteland: optically —, $2v = 0-15^\circ$, $r < v$, $n_\beta = 1.661$. Pleochroic: $\alpha =$ yellow, $\beta =$ deep green, $\gamma =$ greyish-green. After Winchel (1951) this type of biotite has more Fe than Mg.

Biotite from the farsundite (Osestad, ca. 2 km N of Rømteland): Optically —, $2v = 0-15^\circ$, $r < v$, $n_\beta \approx 1.655$. After Wincheli (1951) this indicates more Fe than Mg in the mineral.

Calcite: CaCO_3 .

Calcite is one of the latest formed minerals at Rømteland. In the younger dike crossing the pegmatite great quantities of the mineral are found. The colour is white, yellow-brown, and brown-violet. Hematite inclusions (determined by X-ray) give calcite its colour. Calcite also occurs in druses in white and yellow coloured crystals. The mineral is optically —, $n_o \approx 1.659$, $n_e \approx 1.485$.

Chalcopyrite: CuFeS_2 .

The quantity of this mineral, which is found only in the younger dike crossing the pegmatite at Rømteland, is small. However, chalcopyrite is easy to find because it is always surrounded by a green mineral, which was identified as malachite by X-ray.

Malachite: $\text{Cu}_2((\text{OH})_2\text{CO}_3)$

is an alteration product of chalcopyrite.

Chlorite:

The mineral is found in the younger dike crossing the pegmatite. It is fine-grained and the colour is black. In powder the colour is green. It occurs together with fine-grained muscovite and calcite, and it appears that these minerals were formed at the same time. According to the optical and X-ray data the chlorite must be iron rich, i. e. daphnite: $\text{Fe}_4\text{Al}_2(\text{OH})_8\text{Al}_2\text{Si}_2\text{O}_{10}$, $n_\beta \approx 1.659$. The mineral is too fine-grained to allow the determination of the optical sign.

Columbite: $(\text{Fe}, \text{Mn})(\text{Nb})_2\text{O}_6$.

The mineral, which is blue-grey and metallic in appearance, can almost always be seen in long, thin flakes. By eye it is difficult to distinguish it from ilmenite, which also sometimes occurs as flakes.

The columbite is found in the inner part of the mineralized zones and in the quartz-feldspar zone. It occurs more frequently in the quartz-feldspar zone than in the mineralized zone. I believe that the mineral is formed at a late stage of crystallization. By X-ray it is impossible to say more than that the mineral is either columbite or tantalite (these two minerals have identical X-ray powder patterns). Sentralinstitutt for Industriell Forskning has determined the amount of Nb-Ta in the mineral. The mineral contains 76 % Nb_2O_5 and only 2.0 % Ta_2O_5 . Titanium has also been determined: $\text{TiO}_2 = 3.2$ % (analyst Erna Padget, NGU). As can be seen, it is very clean columbite. The specific gravity of the mineral is 5.31. This also indicates a very Nb-rich columbite (Dana, 1932, p. 696).

Epidote: $\text{Ca}_2(\text{Al}, \text{Fe})_3\text{OH}(\text{SiO}_4)_3$.

Epidote is found in the farsundite close to the pegmatite and in the contact with the pegmatite. It appears together with biotite. In thin sections it can be seen that the mineral has well developed crystal forms (see photograph Fig. 9). The mineral is optically —. Extinction $x/c = 4^\circ$. Non pleochroic. Epidote has very strong interference colours.

Euxenite: PQ_2O_6 , P = Y, the rare earths, U, Th and Ca.
Q = Nb, Ta, Ti and Fe.

Euxenite is found in the mineralized zone and in the quartz-feldspar zone. The colour is black.

Sphene and alvite have been found within a large euxenite crystal. Samarskite occurs around euxenite. Further, euxenite disappears when samarskite appears. My opinion is therefore that the crystallization sequence has been sphene and alvite, followed by euxenite and then samarskite.

Euxenite is found in large crystals. The mineral is metamict, but it can be identified by X-ray when heating it to 1000° .

An analysis for Th and U in the mineral yields Th = 3.3 %, i. e. 3.45 % ThO_2 ; U = 8.5 %, i. e. 10 % UO_2 . Analyzed by Institutt for Atomenergi, Kjeller.

$\text{TiO}_2 = 23.5$. Analyzed by B. Bruun, NGU.

Sp. gravity = 4.352, $n > 1.888$.

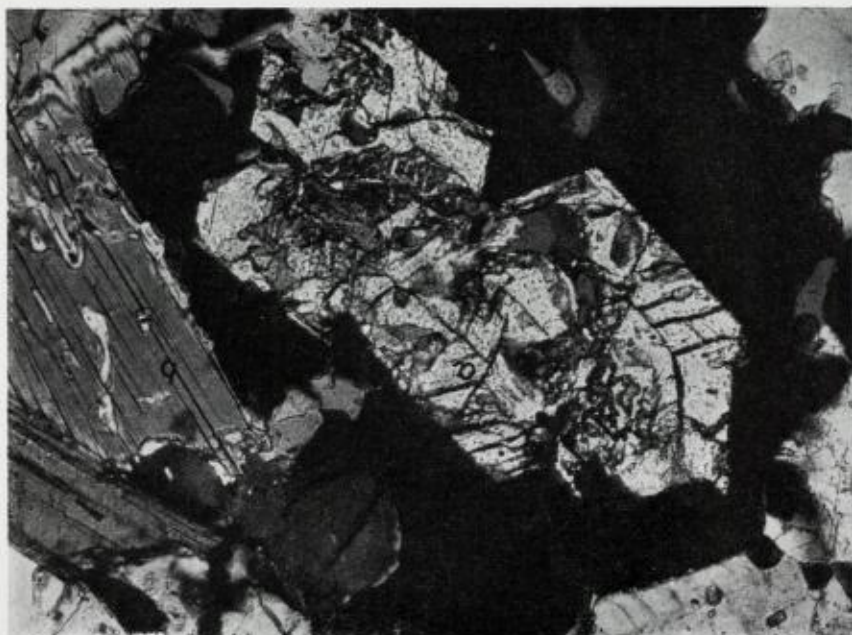


Fig. 9. a) epidote and b) biotite. Note the excellent crystal faces of epidote.
× ca. 100, + nicols.

a) epidot og b) biotitt. Man ser hvor godt epidoten har krystallisert ut.
× ca. 100, + nicols.

Fluorite: CaF₂.

The mineral is red to violet in colour and is isometric. It occurs frequently in the zones round the amphibolites, but usually in small crystals, ca. 5 mm across. In the amphibolite it occurs in contact with apatite and biotite. It surrounds biotite, but the boundary between them, as seen in thin sections, is sharp. The fluorite must have been formed later than the biotite in the amphibolite. In the mineralized zones around the amphibolites it often occurs together with magnetite and apatite. $n = 1.426$.

Hematite: Fe₂O₃.

This mineral is not found in crystals, except at one place in the mineralized zone around the amphibolite where it occurred in octa-

hedral crystals, probably pseudomorphic after magnetite (Martite). Usually the mineral occurs as a red-brown coating on other minerals. Hematite is a secondary mineral the primary minerals being magnetite and pyrite.

Hornblende: $X_2Y_5(OH,F)_2Z_8O_{22}$.

Hornblende occurs both in the farsundite, in the amphibolite and in the graphic granite zone in the pegmatite; in the latter in crystals up to 10 cm length. Hornblende disappears from the farsundite and the center of the amphibolite on moving towards the boundary of the pegmatite, being supplanted by biotite. The colour is grey to green. Robert Major (1939) concludes that in the farsundite the amphibole has $2V \approx 60^\circ$. Optically —, $n_\alpha = 1.667$ and $n_\gamma = 1.683$.

The amphibole in the graphic granite zone is actinolite. The interference colour is bright green. The optical data for this is: Optically —, extinction $x/c \approx 18-20^\circ$. Pleochroism: $\alpha =$ yellow, $\beta =$ deep green, $\gamma =$ blue green, $n_\alpha = 1.630$, $n_\beta = 1.635$ and $n_\gamma = 1.650$.

Determination of the mineral in the amphibolite indicates an ordinary hornblende. Optically —, extinction $z/c = 21^\circ-23^\circ$. Pleochroism: $\alpha =$ bright yellow, $\beta =$ deep green, $\gamma =$ green, $n_\alpha \approx 1.664$ $n_\gamma = 1.680$.

The size of the hornblende crystals is 1 mm in length, both in the farsundite and in the amphibolite.

Ilmenite: $FeTiO_3$.

This mineral occurs as an accessory mineral in the farsundite and in the amphibolite, and is often seen to be surrounded by titanite in thin-sections. It occurs at several places in the pegmatite. See Table VIII, p. 174 and 175.

The largest crystal (more than 2 kg) is found in the mineralized zone. The colour is steel grey. It can be found both in lumps and in thin plates.

Magnetite: $Fe_3O_4(FeO \cdot Fe_2O_3)$.

Magnetite occurs in several zones at Rømteland, often together with ilmenite. In the farsundite it occurs as an accessory mineral.

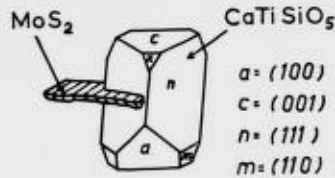


Fig. 10. Intergrown titanite and molybdenite.
Sammenvoksning av titanitt og molybdenglans.

The largest crystals are found in the mineralized zone, where lumps larger than 1 kg are found. In the amphibolites and the mineralized zones around the amphibolites it often occurs together with fluorite and apatite.

Malacon: ZrSiO_4 with Th, U, and perhaps V. Uniaxial (+), $n_o \approx 1.888$, $n_e \approx 1.888$.

Malacon is found in the mineralized zones around the amphibolites and occurs together with zircon. Often it is difficult to differentiate between zircon and malacon. Usually the surface of the malacon is duller. However, in fractures there are great differences, the zircon being fresh brown while the malacon has brown, white, grey and blue colours. Partly the malacon is metamict, yielding therefore a diffuse zircon X-ray powder pattern if the mineral is not heated. See Fig. 15 p. 172. The play of colours and the metamict character are due to the radioactive content in the mineral (Klockmann-Ramdohr). It would appear that malacon and zircon grade into another.

Both of the minerals have perfect tetrahedral crystal morphology. The length of the crystal is not much more than 1 cm.

Molybdenite: MoS_2 .

This mineral is also found in the mineralized zones around the amphibolites, mostly in the same zone as the platy formed allanite. It occurs in thin flakes in small quantities. Molybdenite and titanite are completely intergrown in this zone. See Fig. 10. However, the molybdenite seems to be formed later than the allanite, because it is always to be found on the surface of allanite. Re-content is 0.0015 %.

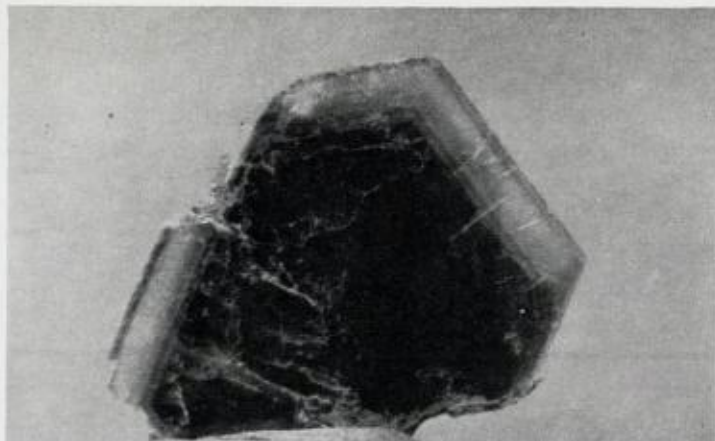


Fig. 11. Zonal structure around the c-axis of muscovite. Natural size.

*Muskovitt. Den sonare oppbygging rundt c-aksen sees tydelig.
Naturlig størrelse.*

Muscovite: $KAl_2(OH, F)_2AlSi_3O_{10}$.

Usually the colour of the muscovite at Rømteland is green, but sometimes it is colourless. The green colour of the mineral must be due to Fe^{++} . Analyses for Cr in the muscovite have been made, but the Cr content was too small to account for green colour (analyst: B. Bruun, NGU). Flakes of muscovite often appear on the (001) plane of alkali feldspar. The flakes are ca. 0.5 cm in width. The green muscovite is found in larger flakes in the mineralized zone. In this zone the mineral always occurs with beautiful zonal structure around the C-axis. See picture, Fig. 11. I have studied the zonal structure both optically and by X-ray. It is not due to a chlorization of the mineral. The muscovite is biaxial, optically —, $2V = 30^\circ-45^\circ$, $n_\beta = 1.585$.

In the younger dike crossing the pegmatite I have found much green, fine-grained muscovite. This is optically —, $2V = 30^\circ-45^\circ$, $n_\alpha \approx 1.575$, $n_\beta = 1.580$.

The optical data indicate almost ideally pure muscovite (Winchell 1951).

Orangite: $ThSiO_4$.

The honey yellow to brown mineral is found only in the mineralized zone around the amphibolites. The mineral is translucent in thin

flakes. The mineral is easy to find. Orangite is believed to be identical with the black coloured thorite, but chemical analyses for Th and U are different for the two minerals. (Thorite also occurs at Rømteland.) The analyzed material was not pure (much feldspar contamination, but the difference in Th and U can be seen). For orangite Th = 6.0 %, U = traces; for thorite = 4.6 %, U = .7 %.

Analyst: Institutt for Atomenergi, Kjeller.

Different theories have been proposed to account for the colour difference. There can be differences in age, and in the metamict grade of the two minerals. Goldschmidt (1954) believes that the yellow colour of orangite is due to a content of cerium. Because orangite occurs in a cerium zone (thorite does not) the theory of Goldschmidt seems to me to be reasonable.

Orangite is metamict. The mineral was identified by X-ray after heating. Specific gravity is 4.425, $n \approx 1.685$.

Palygorskite: $\text{MgAlSi}_4\text{O}_{10}(\text{OH})_4 \cdot 4\text{H}_2\text{O}$. (Antum 1956).

Cracks occur in the younger dike crossing the pegmatite, and in these cracks the mineral palygorskite is found. The mineral is, together with quartz, the latest formed mineral at Rømteland. It was identified by X-ray.

Plagioclase: $\text{NaAlSi}_3\text{O}_8$ — $\text{CaAl}_2\text{Si}_2\text{O}_8$.

Except for the quartz zone, plagioclase is found in all the zones at Rømteland. The composition varies around 27 % An. The plagioclase from the pegmatite is optically —, $2V > 75^\circ$, n_α somewhat > 1.535 , n_β somewhat > 1.545 , max. extinction in zones normal to (010) about 10° . Other determinations, see Table III, p. 136 and 137. As for the alkali feldspars the grain size of the plagioclase coarsens from the farsundite (about 0.5 mm) inwards into the pegmatite, where it can be found in very large crystals. The colour is usually white, but near radioactive minerals it is often dark red-brown. A labradoritic play of colours can be seen in the plagioclase from the quartz-feldspar zone. In the farsundite, myrmekite occurs at some places (quartz/plagioclase). In the mineralized zone around the amphibolites in the pegmatite, plagioclase graphic-granite occurs.

The plagioclase in the farsundite has also been determined by R. Major (1939) to be between 22 % and 28 % An. In the contact

area between the pegmatite and the farsundite the plagioclase has undulating extinction and the twinning lamellae are often bent. The undulating extinction disappears both inwards into the pegmatite and outwards into the farsundite. This indicates a tectonization in the area after the minerals were formed. The plagioclase is also sericitized in the same area, the sericitization also disappearing to both sides. The plagioclase has also a zonal structure. Around a central An ca. 27 % zone and along cracks a clean albite zone often occurs. This albite zone occurs most frequently in the graphic granite zone, and disappears both inwards into the pegmatite and outwards into the farsundite. It seems as if the albitization followed the tectonization.

In druses and in the younger dike crossing the pegmatite, sugar-grained albite is also found. Cameron, Jahns, McNair and Page (1949) mention that sugar-grained albite is found in many American pegmatites. Their opinion is that the mineral is a later formation than the pegmatite. I am of the same opinion for the albite from Rømteland.

Zonal albite around the plagioclase and in cracks and sugar-grained albite in druses and in the younger dike crossing the pegmatite means that the albitization processes have been active at a relatively late stage in the pegmatite's history. Sericitization, tectonization, and albitization processes have been discussed earlier. See p. 134—141. *The sugargrained albite* is white coloured. The mineral is optically (+), $2V > 75^\circ$, $n_\alpha = 1.525$, $n_\beta = 1.530$, $n_\gamma = 1.535$. This indicates albite with 5 % An. The albite around and in cracks in the plagioclase has max. extinction = 18° . The Becke-line moves slightly from microcline inwards into albite upon elevating the tube. This also indicates almost pure albite.

In the plagioclase from the quartz-feldspar zone a black mineral occurs. It has been impossible to identify this mineral. A very dark magnetic concentrate was obtained by using the Franz Magnetic Separator, but the X-ray powder pattern of this showed no lines except those attributable to plagioclase. In thin-section there can be seen an apparently opaque, disseminated, fine "dust" in the plagioclase. In hand specimens a characteristic brown border zone between the pigmented and non-pigmented plagioclase can be seen, and albite twin lamellae can be followed undisturbed through all three zones (see Fig. 12). Occasionally there can be seen a pink surficial mineral (apparently secondary) which also gives an X-ray powder pattern identical to that of plagioclase.



Fig. 12. Plagioclase pigmented by a black mineral with a brown border zone. Note that albite twinning continues through the pigmented area. Ca. $\frac{1}{2}$ natural size.

Plagioklas pigmentert med et sort mineral med brun randzone. Albittstripene kan man se fortsetter gjennom det pigmenterte område. Ca. $\frac{1}{2}$ størrelse.

Pyrite: FeS_2 .

Pyrite is found only two places; as an accessory mineral in the farsundite, and in relatively large crystals in the younger dike crossing the pegmatite. The cubic crystal planes are often well developed.

Quartz: SiO_2 .

Quartz is one of the minerals which is found all over Rømteland. From the farsundite through the graphic granite zone to the center of the pegmatite, the quartz grains increase in size from individual grains ca. 7 mm in size to a quartz mass of several tons. The colour is usually white (milky quartz). Hematite often gives quartz a red colour, especially near cracks. In the farsundite quartz occurs intergrown with feldspar as myrmekite. However, myrmekite is not frequent in the farsundite (R. Major, 1939).

In thin sections of the farsundite one sees that myrmekite becomes more abundant the nearer one approaches the pegmatite. It also becomes gradually coarser, eventually becoming visible macroscopically, and finally becoming so coarse that it is better called graphic granite.

If one of the radioactive minerals is in contact with the quartz the quartz takes on colours from black to grey to a weak reddish colour. Close to the radioactive mineral the colour is black. In thin-sections the quartz has undulating extinction, strongest in the graphic granite zone and weaker to both sides. Quartz is also to be found in beautiful crystals in druses, in which hematite can be seen covering the quartz. Elektrokjemisk A/S, Fiskå Verk, Kristiansand, has performed 3 analyses for A. Tverstøl, Lyngdal; sample 1: crystal quartz from druses, sample 2: ordinary white pegmatite quartz, and sample 3: black quartz (near radioactive minerals) (Table VI).

Table VI.

	Sample 1.	Sample 2.	Sample 2.
SiO ₂	99.90 %	99.85 %	99.68 %
Fe ₂ O ₃	0.05 *	0.08 *	0.18 *
Al ₂ O ₃	0.01 *	0.02 *	0.06 *
MnO	—	—	0.02
TiO ₂	0.005 *	0.005 *	0.005 *
CaO	0.005 *	0.005 *	0.005 *
MgO	0.005 *	0.005 *	0.005 *
Na ₂ O	0.03 *	0.05 *	0.06 *
K ₂ O			
	<hr/> 100.005 % <hr/>	<hr/> 100.015 % <hr/>	<hr/> 100.015 % <hr/>

Samarskite:

The minerals is not found in great quantity, but it occurs relatively frequently in the area. The colour is black to brown and the mineral is always surrounded by columbite.

Samarskite from Rømteland is metamict, but after heating it to more than 770° the samarskite structure returned. After heating the mineral to 800° C I got a diffuse X-ray pattern, but after heating to 1045° C the X-ray pattern was well defined. (See the films below.) The mineral was determined only by X-ray, and it must be mentioned that the pattern of fergusonite is very like the X-ray pattern of samarskite from Rømteland. (See the films below.)

I believe, however, that it is a samarskite. The surrounding envelope of columbite seems to indicate this.

The Rømteland samarskite occurs in the same zones as euxenite, but it is found more frequently in the quartz feldspar zone than in the

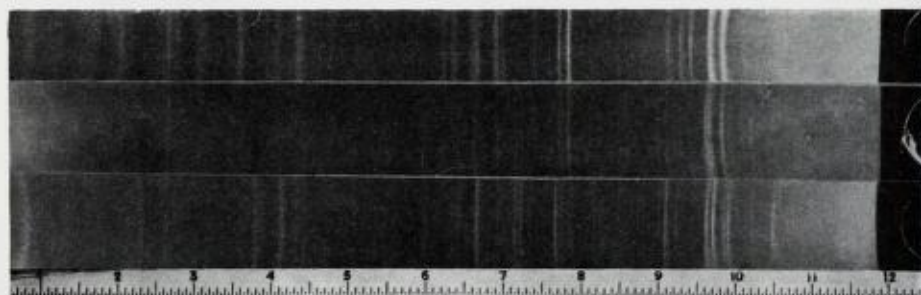


Fig. 13. X-ray powder patterns of samarskite and fergusonite.

- I. Fergusonite, Ljoslandsheia, Iveland, Setesdal, S. Norway, (1733). Heated to 1000° C.
- II. Samarskite, Rømteland (8132). Heated to 1025° C, 24 h.
- III. Samarskite, Dillingøy, S. Norway (1938). Heated to 1045° C.

Röntgenfilmer av samarskite og fergusonite.

mineralized zone. It is not found in crystals. The mineral is radioactive and other minerals (quartz and feldspar) are often dark when in contact with samarskite. The Ti content in the mineral was determined to be 2.5 % TiO_2 . Analyzed by E. Padget, NGU.

$n < 1.888$. Specific gravity = 5.240.

Spessartite:

The colour of this garnet is red-brown, $n = 1.800. \pm 0.002$. This garnet was also determined by X-ray. The cell size was calculated to be $a = 11.575 \text{ \AA}$. The cell size for pure spessartite is $a = 11.59 \text{ \AA}$ (Strunz, 1949). Maybe some Fe^{++} has replaced Mn^{++} , but the Rømteland spessartite may also have a little smaller cell size than a pure spessartite if the rare earths replace Mn^{++} . However, the Rømteland spessartite is close to pure spessartite.

The mineral is found in the mineralized zone, the quartz-feldspar zone, and also a little in the quartz one. The mineral occurs in contact with the later formed minerals samarskite and columbite, and it seems to me that the garnet also was formed at a late stage in the pegmatite history. It is always found in feldspar.

The largest garnet crystals are 4—5 cm across. Garnet is always found close to the younger dike crossing the pegmatite and is always crushed. It is reasonable to think that it was formed before the form-

ation of the dike, and was crushed during the formation of the dike. However, as mentioned earlier, it is found in contact with the radioactive samarskite, and it may have been crushed by the radioactivity of this mineral.

Specific gravity = 4.126.

Sphene (Titanite): CaTiSiO_5 with a secondary mineral.

Sphene occurs as an accessory mineral in the farsundite and the amphibolite, usually around ilmenite. It occurs in large crystals in the mineralized zone, and in the mineralized zones around amphibolites the mineral is found in great quantities. Because the mineralized zone inside the pegmatite seems to be more Y-rich than mineralized zones around the amphibolites, which seems to be Ce-rich, I have had quantitative spectrographic analyses made of the titanite from these two zones. See Table VII. Analyzed by Sentralinstitutt for Industriell Forskning.

Table VII.

<i>Sphene from the mineralized zones around the amphibolites</i>		<i>Sphene from the mineralized zones in the pegmatite</i>	
TiO ₂	29. %	TiO ₂	29.5 %
Y ₂ O ₃	0.52 *	Y ₂ O ₃	0.9 *
Yb ₂ O ₃	0.037 *	Yb ₂ O ₃	0.13 *

Maximum error is $\pm 5\%$ of the value given.

As can be seen there is a little bit more Y and Yb in the sphene from the mineralized zone in the pegmatite than in the sphene from the other zones.

In the mineralized zone sphene occurs in crystals larger than 10 cm and almost always together with biotite. I have also found sphene surrounded by euxenite, and it seems to me as though the sphene has been formed earlier than euxenite. The mineral has a brown luster, but often the surface is decomposed. Also along cracks in the mineral decomposition takes place, the desintegrated material being yellow to white powder. This powder is determined by X-ray to be *anatase*. Anatase is often pseudomorphic after sphene and ilmenite. According to Klockmann-Ramdohr (1954) the mineral is only found in crystals, but even with great enlargement it has been impossible for me to see crystal forms.

Sphene in small crystals is found in the mineralized zone around amphibolite. The size is usually 2—3 cm in length. The mineral is found here completely intergrown with molybdenite (see Fig. 10), and anatase is also found here as a secondary mineral.

Specific gravity of sphene from the mineralized zone in the pegmatite = 3.215.

Specific gravity of the sphene from the mineralized zone around the amphibolite = 3.453.

The mineral is optically (+), $2V = 30^\circ\text{—}45^\circ$, $r > v$. Pleochroism $\alpha = \beta = \gamma =$ colourless. $n_\alpha = 1.852$, $n_\gamma \approx 1.888$ (from amphibolite); $n_\beta = 1.888$ (from the mineralized zone).

Tengerite:

Tengerite is found as a secondary mineral on allanite at Rømteland. It occurs as a white luster on the surface of the allanite from the mineralized zone inside the pegmatite.

Thorite: ThSiO_4 .

Thorite occurs in the mineralized zone and in the quartz-feldspar zone. It is dark in colour and occurs in small quadrangular posts, mostly in feldspar, and close to euxenite. Quartz and feldspar are often dark coloured in contact with thorite. It is metamict, but after heating it to 770°C it can be identified by X-ray.

Specific gravity = 4.73. Optic index $n \approx 1.685$.

For thorite see also orangite, p. 163.

Uraninite: UO_2 with secondary minerals.

Uraninite is mostly found in the mineralized zone, but it occurs also in the graphic granite zone and in the quartz-feldspar zone. The colour is black. It is usually easy to find the mineral because of the characteristic zones of secondary minerals around it. The mineral is metamict but after heating it to 770°C I got the isometric uraninite pattern on X-ray.

The mineral is found in lumps up to ca. 300 g. Crystal planes are not seen because of the great deformation of the mineral. I think it unlikely that they exist. Most of the mineral is found inside wedges of biotite. Andersen (1926) mentions the same observation from the pegmatites. Feldspar and quartz are destroyed close to uraninite.

Specific gravity = 6.808.

Optic index $n > 1.888$.

In connection with uraninite secondary uranium minerals are developed. These secondary minerals always occur in a defined sequence. M. Sellevold (working with secondary uranium minerals in Norway) has found at Rømteland the same uranium minerals as I:

Black: Uraninite

Brown: Clarkeite

Red: Fuormarierite

Orange: Kassolite

Yellow and green: α -uranophane.

Kassolite is identified by Sellevold.

The minerals have the following formulae (Klockmann-Ramdohr, 1954):

Uraninite: UO_2

Clarkeite: $(\text{Na}_2, \text{Ca}, \text{Pb}): 3\text{UH}_3:3\text{H}_2\text{O}$

Fuormarierite: $\text{PbO}:4\text{UO}_3:5\text{H}_2\text{O}$ (probably $(\text{UO}_2, \text{Pb})\text{O}:\text{H}_2\text{O}$)

Kassolite: $\text{PbU}(\text{O}_2(\text{SiO}_4)) \cdot \text{H}_2\text{O}$

α -uranophane: $\text{CaU}_2((\text{OH})_3(\text{SiO}_4))_2 \cdot 4\text{H}_2\text{O}$.

The minerals occur in this sequence. It seems to me as though the uraninite has been stable until the processes of albitization took place. The Na attacked uraninite and the first two secondary minerals clarkeite and fuormarierite were developed.

I do not think it is necessary to supply Pb, because during the decomposition of uranium Pb will be formed. For the formation of kassolite and uranophane it is, however, necessary to supply Ca and Si. The chemical reaction necessary for the formation of the minerals can be seen below in Fig. 14.

Optical data for the minerals: Clarkeite $n_\alpha \approx 1.888$, $n_\beta > 1.888$, $n_\gamma > 1.888$. Fuormarierite $n_\alpha \approx 1.888$, $n_\beta > 1.888$, $n_\gamma > 1.888$. Yellow α uranophane: optically (+), $2V \approx 30^\circ$, n_α somewhat < 1.644 , $n_\beta \approx 1.664$, n_γ somewhat < 1.674 .

Zircon: ZrSiO_4 .

Zircon is found in thin sections from the farsundite and from the pegmatite graphic granite zone. The zircon has a zonal structure at these places. It can be seen best under crossed nicols because of the play of colour in the mineral.

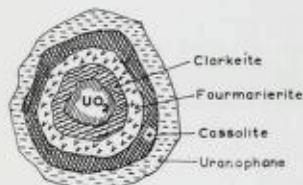
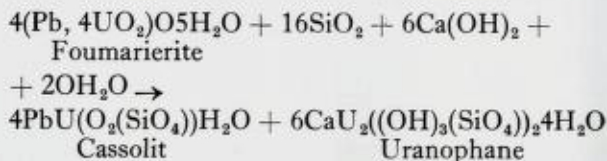
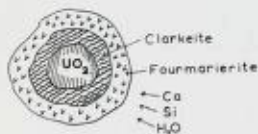
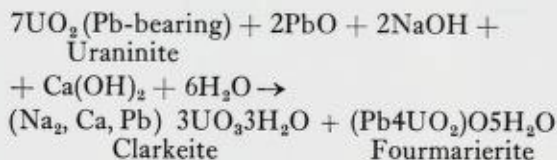


Fig. 14. The figure shows which elements have attacked uraninite together with the reactions which have occurred and their products.

Figuren viser hvilke elementer som har angrepet uraninitt, samt reaksjonene og nydannelsene som har funnet sted.

Zircon

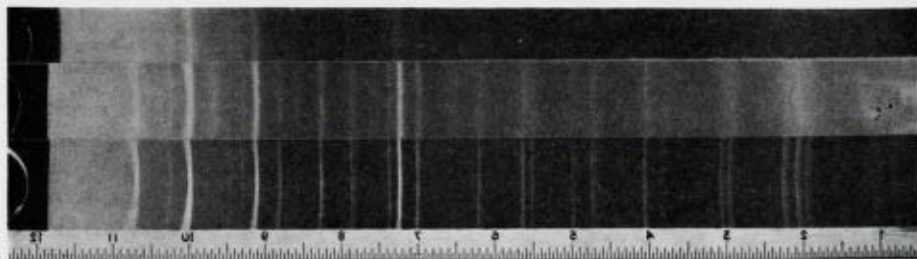


Fig. 15. X-ray powder patterns of malacon and zircon.
 I. Malakon, Rømteland (8282).
 II. Zircon, Rømteland (8393).
 III. Zircon, N. Stavern, S. Norway (3444).

Røntgenfilmer av malacon og zircon.

Zircon is also found in small crystals in the mineralized zones around the amphibolites. Here fresh zircon occurs together with malacon (see the films plate Fig. 15. See also malacon, p. 162). The zircon crystals can be up to 5 mm in length. Zircon occurs on the surface of the platy formed allanite, and the mineral must therefore be of later formation than allanite.

Optically: (+), $n_o \approx 1.888$, $n_e > 1.888$.

In Table VIII, p. 174 and 175 all of the minerals described are shown and it can be seen there in which zones the minerals occur.

Mineral paragenesis at Rømteland.

The two adjacent four component systems with the oxides:

$(Fe, Mn)O - Y_2O_3 - (Nb, Ta)_2O_5 - TiO_2 - SiO_2$.

Most of the minerals at Rømteland occur, as mentioned previously, in two different zones:

- 1) around the amphibolites, and
- 2) the pegmatite's mineral zone between the graphic granite and the quartz feldspar zone.

Inasmuch as the pegmatite has crystallized from a melt (see p. 142), it appears that these two zones have been formed simultaneously. Both zones of mineralization are virtually in contact with the unmelted amphibolite included in the pegmatite and the farsundite surrounding the pegmatite. In the case of the mineralized zone only the zone of graphic granite separates it from farsundite, and the mineralized zones around the amphibolites are in direct contact with amphibolites.

The minerals which occur in the two zones of mineralization are: the mineralized zone of the pegmatite; allanite (orthite), alvite, anatase, anorthite, biotite, columbite, euxenite, ilmenite, quartz, magnetite, microcline, muscovite, plagioclase, samarskite, spessartite, thorite, uraninite with secondary uranium minerals, (yttro) titanite. Around the amphibolite: allanite (orthite), apatite, biotite, bastnäsite, fluorite, ilmenite, quartz, magnetite, microcline, molybdenite, orangite, plagioclase, titanite (yttro) and malacon (zircon).

It would therefore appear that during the crystallization of the melt two main groups of elements have been separated from one another. They are: 1) a Ce rare-earth group with a little Y and Y rare-earths. This group occurs around the amphibolites. The minerals con-

cerned are: a great deal of allanite (orthite) with bastnäsite, and a little Y-bearing titanite. 2) an Y rare-earth group with a little Ce rare-earths. This group occurs in the mineralized zone of the pegmatite. The minerals concerned are: (yttro) titanite, euxenite, samarskite, and a little allanite (orthite). Inasmuch as the mineralization in the two zones is different each will be treated separately.

1) The zones of mineralization around the amphibolites.

As was mentioned earlier microcline is virtually never found, the reason being that the potassium is used up in sericitization of plagioclase in the amphibolite and alteration of hornblende to biotite. Plagioclase was formed early and is always present in large amounts. Ilmenite has also been formed very early. In sections (yttro) titanite can almost always be seen to surrounded ilmenite. This shows that (yttro) titanite is later then the ilmenite. Magnetite is assumed to be simultaneous with ilmenite (see p. 161), but the mineral must have been formed throughout a rather long period of crystallization because it is often found intergrown with fluorite. Fluorite has been formed rather late, as it often surrounds biotite.

Apatite has been formed very early, but has also been formed throughout a long period of time. In sections one sees the mineral included in biotite, but it is also found as crystals on platy formed allanite and together with magnetite and fluorite. Apatite also occurs in the amphibolite, but there only within other minerals. This indicates two generations of apatite.

Malacon (zircon) has been formed somewhat later than the platy formed allanite as it is very often found on the surfaces of the allanite. Molybdenite has also been formed after allanite, as it is almost always found as plates on the surfaces of allanite. It has been formed simultaneously with (yttro) titanite (see the mineral descriptions). Quartz and biotite occur in the same manner as plagioclase, all three minerals having been formed throughout a long period of crystallization. Around the amphibolites, however, the amount of quartz is small.

The phosphates monazite and xenotime have not been found. H. Bjørlykke (1935, p. 281) writes: "The study of the pegmatite minerals shows that in the ordinary magmatic pegmatites, all of the phosphoric acids has been combined with the rare earth elements forming monazite and xenotime; apatite has only been observed in a few of the dikes especially rich in Ca. At the same time excess of Y elements present will react with the niobium and the tantalum present. In these

compounds will also enter some Ti and the minerals formed by this reaction will depend on the relative amounts of the elements present in the magma."

If I understand Bjørlykke correctly, his opinion must be that if in ordinary pegmatites *all* of the phosphoric acids combines with the rare earth elements forming monazite and xenotime, then in Ca-rich pegmatites the (Y-Ce)-phosphates must be formed before or, at the latest, simultaneously with the Ca-phosphate apatite, while any excess of P will react only with Ca to form apatite. An excess of Y or Ce will then react with Nb-Ta-Ti and Si and the other Y and Ce-minerals. (See also H. Bjørlykke 1937, p. 10.)

The pegmatite at Rømteland must be looked upon as a very Ca-rich pegmatite. Ca occurs in the following minerals near the amphibolite: (yttro) titanite, apatite, plagioclase, allanite, and fluorite. However, though both the minerals apatite and the Ce-silicate allanite occur here, monazite is impossible to find.

In ordinary magmatic rocks apatite is always supposed to be an early formed mineral. It seems to me as if the same is the case in the pegmatite. The concentration of Ca must have been so great that all P was used for the formation of apatite. In spite of the great concentration of Ce rare earths it seems that the amount of P was too little in relation to Ca. When all the P was used for formation of apatite much more Ca still remained.

It seems to me that P has greater affinity to Ca than to Ce rare earths. Andersen (1931) found the following for Karlstadgangen and Lindvikkollen: Apatite-euxenite and apatite-yttrotitanite. At Tangenbruddet he found apatite euxenite-columbite and orthite. None of these places has xenotime or monazite.

For the minerals in the mineralized zone around the amphibolite I have made the following observations. Plagioclase (An ca. 26 %) occurs most frequently, and together with quartz, microcline, and biotite must have been formed throughout the history of the pegmatite.

Ilmenite can in thin-section be seen to be surrounded by titanite, and must be an early formed mineral. It is completely intergrown with magnetite, and even after crushing it to a powder it is often impossible to separate them, giving on X-ray a pattern of both the minerals. At other places magnetite occurs together with fluorite.

Titanite, which must be of later formation than ilmenite, is found intergrown with molybdenit (see Fig. 10 p. 162) and these two mine-

Mineral	Period of crystallization	
	Primary minerals	Secondary minerals
Allanite	—————	
Apatite	—————	
Bastnäsité		-----
Biotite	—————	
Fluorite	—————	
Ilmenite	—————	
Magnetite	—————	
Molybdenite	—————	
Orangite	—————	
Plagioclase	—————	
Quartz	—————	
Titanite	—————	
Zircon	—————	

Fig. 16. Schematic representation of the order of crystallization around the amphibolites.

Figuren angir skjematisk mineralenes tid for utkrystallisasjon rundt amfibolittene.

rals must have been formed simultaneously. Allanite is formed earlier than these two minerals, because molybdenite often occurs on the surface of allanite. As a secondary mineral from allanite, bastnäsité is found.

Zircon (malacon) is formed later than allanite. The mineral often occurs around allanite, but I have never found the mineral inside allanite.

The sequence and periods of crystallization on the different minerals can then be seen in Fig. 16.

2. All of the minerals in the mineralized zone in the pegmatite are listed in Table VIII, p. 174 and 175.

The transition minerals in this zone are: quartz, alkali feldspar (microcline), plagioclase (An ca. 26 %), biotite, magnetite, and allanite.

Of the minerals remaning, yttrotitanite, euxenite, samarskite, and columbite, all of which contain more or less of the elements Y-Ti-Nb, seem to be interdependently related during crystallization.

To explain the crystallization of the minerals containing rare-earths Bjørlykke (1935, p. 296) has reached the following conclusions:

Y = the number of atoms of Y minus those necessary for the formation of xenotime.

M = The number of atoms of Nb (— Ta, Ti, W).

The proportion between these two is the basis for division into four types:

$Y:M > 1$, $Y:M = 1-0.5$, $Y:M = 0.5-0.3$ and $Y:M < 0.3$, which are divided into the groups:

a. Nb + Ta: Ti too high for the formation of euxenite,

b. Nb + Ta: Ti agrees with this ratio in euxenite,

c. Nb + Ta: Ti is less than this ration in euxenite.

$Y:M > 1$.

<i>a.</i>	<i>b.</i>	<i>c.</i>
thalenite	thalenite	thalenite
gadolinite	gadolinite	gadolinite
fergusonite	fergusonite	fergusonite
	euxenite	euxenite
		ilmenite
		ilmenorutile

$Y:M = 1-0.5$

<i>a.</i>	<i>b.</i>	<i>c.</i>
fergusonite	fergusonite	fergusonite
yttrotantalite	yttrotantalite	euxenite
samarskite	euxenite	ilmenite
		ilmeorutile

$Y:M = 0.5-0.3$

<i>a.</i>	<i>b.</i>	<i>c.</i>
samarskite	euxenite	euxenite
yttrotantalite		ilmenite
		ilmenorutile

$Y:M < 0.3$

<i>a.</i>	<i>b.</i>	<i>c.</i>
columbite	columbite	columbite
samarskite	ilmenite	ilmenite

In his discussion Bjørlykke, however, mentions that some combinations may be impossible, one of which is euxenite—samarskite.

In group *b*. $Y:M = 1-0.5$ the combination was fergusonite yttrotantalite, and euxenite. If it is possible to have the mineral combination fergusonite—euxenite and yttrotantalite, the combination samarskite—euxenite must also be possible. Chemically fergusonite and yttrotantalite do not have more Ti than samarskite, and in the

group $Y:M = 1-0.5$, *a.*, it can be seen that the relation $Y:(Nb, Ta)$ is inside the area which can give both samarskite and fergusonite.

I agree with Bjørlykke when he discusses the relation $Y:Nb, Ta:Ti$ as critical for the rare-earth minerals formation, but I do not agree with him when he says that the crystallization must have taken place inside the defined interval. In a three component system like this all different amounts of the three components must be considered possible, and it can not be right that the composition of the magma and the course of crystallization must be inside the boundaries set up by Bjørlykke.

If I use his system on the Rømteland pegmatite I have: enough Ti for the formation of ilmenite, yttrötitanite, and euxenite; enough Y for the formation of yttrötitanite, euxenite, and samarskite; and enough (Nb, Ta) for the formation of euxenite, samarskite, and columbite.

It is necessary to use following groups: $Y:M = 0.5-0.3$ *b.*, $Y:M < 0.3$, *a.* and *b.*

As can be seen three groups are necessary (yttrötitanite, which is not placed in these groups, is also found at Rømteland).

At Rømteland the minerals euxenite and samarskite also occur, which Bjørlykke suggested might be an impossible mineralogical combination. Samarskite and yttrötantalite are said to be two closely related minerals. Samarskite is a Nb mineral with a little Ta , while the yttrötantalite is a Ta mineral with a little Nb .

Bjørlykke (1935) has, at Ljosland 11, the minerals euxenite—yttrötantalite, but no pegmatite with the paragenesis euxenite—samarskite.

At Tveit 3 Bjørlykke has found the following minerals: quartz, microcline, plagioclase, biotite, muscovite, garnet, beryl, bertrandite, columbite, samarskite, and monazite. Barth (1931) has described a pegmatite, called Tveit, which must be the same as the one Tveit 3 by Bjørlykke, but Barth (1931) mentions that following minerals are found: quartz, microcline, plagioclase, muscovite, garnet, beryl, bertrandite, ilmenorutile, columbite, samarskite, euxenite, molybdenite, and bismuthinite. As can be seen two minerals, euxenite and ilmenorutile, are not mentioned by Bjørlykke. (The mineral combination ilmenorutile—samarskite is also not possible, according to Bjørlykke, 1935, p. 297).

Bjørlykke (1939) has at Tangenbruddet the following paragenesis: *euxenite*, betafite, titanite, allanite, alvite, thorite and phenakite. (In 1937 he mentioned the occurrence of *columbite*, but not *euxenite*).

For the same pegmatite O. Andersen (1931) found the paragenesis: tourmaline, magnetite, hematite, apatite, pyrite, chalcopyrite, a mineral in druses which seems to be kaolin together with calcite, *columbite*, phenakite, alvite, thorite, (orangite), allanite and *euxenite*. (The combination *euxenite*—*columbite* is not possible according to Bjørlykke (1935).)

The pegmatite at Helle 1 is described by Bjørlykke (1939), and here the following minerals were found: *euxenite*, allanite, *fergusonite*, uraninite, thorite and *yttrotantalite*.

My opinion is that this review of several pegmatites shows that the parageneses:

euxenite—*yttrotantalite*,
euxenite—*samarskite*,
euxenite—*columbite*,

and also *ilmenorutile*—*samarskite* are not impossible. The mineral combinations are, as can be seen, observed at several places. To this list Rømteland can also be added with the paragenesis *euxenite*—*samarskite* and *columbite*.

Instead of using a three component system, as Bjørlykke did, I have put the minerals *ilmenite*, *columbite* — *tantalite*, *fergusonite*, *euxenite*, *samarskite* — *yttrotantalite*, *rutile* — *ilmenorutile*, *titanite*, *yttrotitanite*, *yttrialite*—*thalenite* into two four component systems. The five oxides used are: $(\text{Fe, Mn})\text{O}-\text{Y}_2\text{O}_3-(\text{Nb, Ta})_2\text{O}_5-\text{TiO}_2-\text{SiO}_2$. See Fig. 17 a, p. 182.

The two adjacent four component system with the oxides:

$(\text{Fe, Mn})\text{O}-\text{Y}_2\text{O}_3-(\text{Nb, Ta})_2\text{O}_5-\text{TiO}_2-\text{SiO}_2$.

In the two adjacent four component systems I have shown all the minerals which are pertinent in this case. The minerals are placed in the systems according to their molecular proportions insofar as this is possible. *Ilmenite* (FeTiO_3) has one molecule of FeO and one of TiO_2 . This means that *ilmenite* will be placed at the mid-point between the pure oxides $(\text{Fe, Mn})\text{O}$ and TiO_2 . The same procedure has been followed for the other minerals. Between the minerals lines can be drawn, and the two four component systems will then be divided into

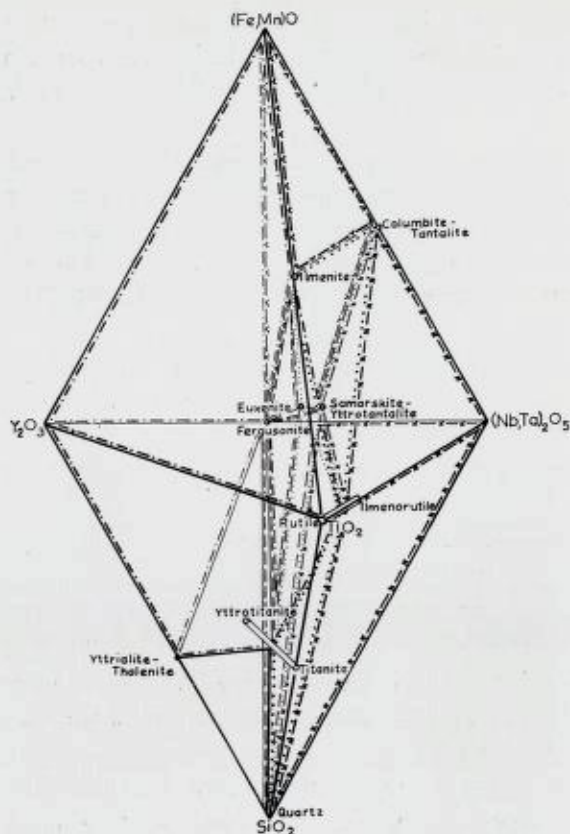


Fig. 17 a. Two adjacent four component systems consisting of the oxides $(\text{Fe, Mn})\text{O}-\text{TiO}_2-\text{Y}_2\text{O}_3-(\text{Nb, Ta})_2\text{O}_5-\text{SiO}_2$.

To firekomponentsystem satt sammen av de fem oksydene $(\text{Fe, Mn})\text{O}-\text{TiO}_2-\text{Y}_2\text{O}_3-(\text{Nb, Ta})_2\text{O}_5-\text{SiO}_2$.

different volumes. As can be seen Fig. 17 b inside volume 1, it is possible to get the following paragenesis: thalenite—yttrotitanite, titanite—rutile, ilmenorutile—ilmenite—euxenite—fergusonite.

If the proportions of the components are such that the “magma” can be placed on a line between two minerals, then both of these minerals will be formed, but it will not be possible for the composition of the “magma” to move over into another volume. The minerals which can be formed in the different volumes can be seen below.

Volume 1: Ytttrialite—thalenite, yttrotitanite—titanite, rutile—ilmenorutile, ilmenite, euxenite, fergusonite.

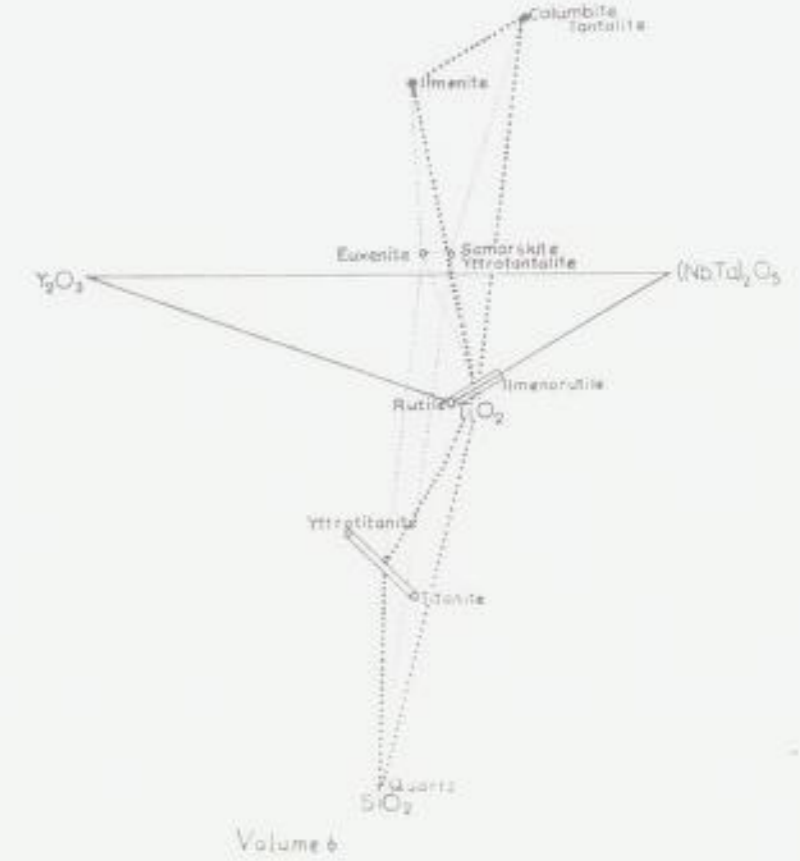
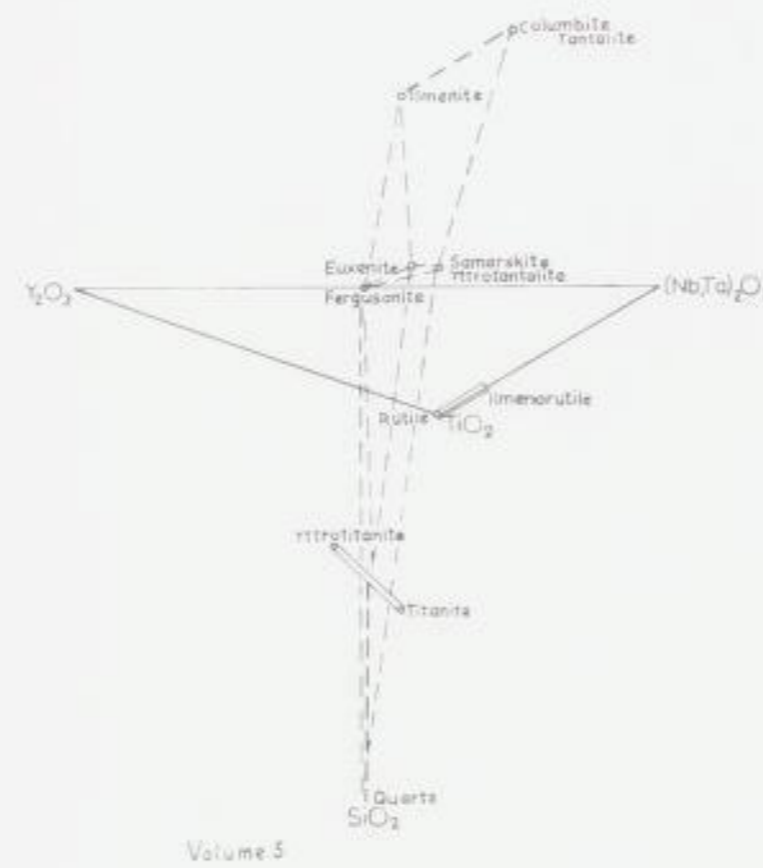
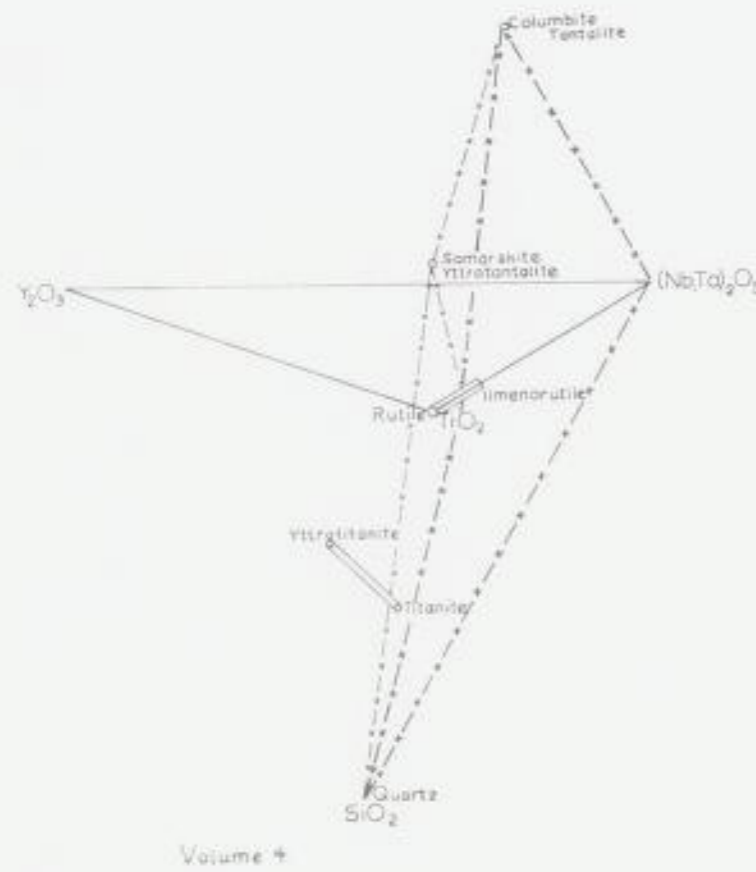
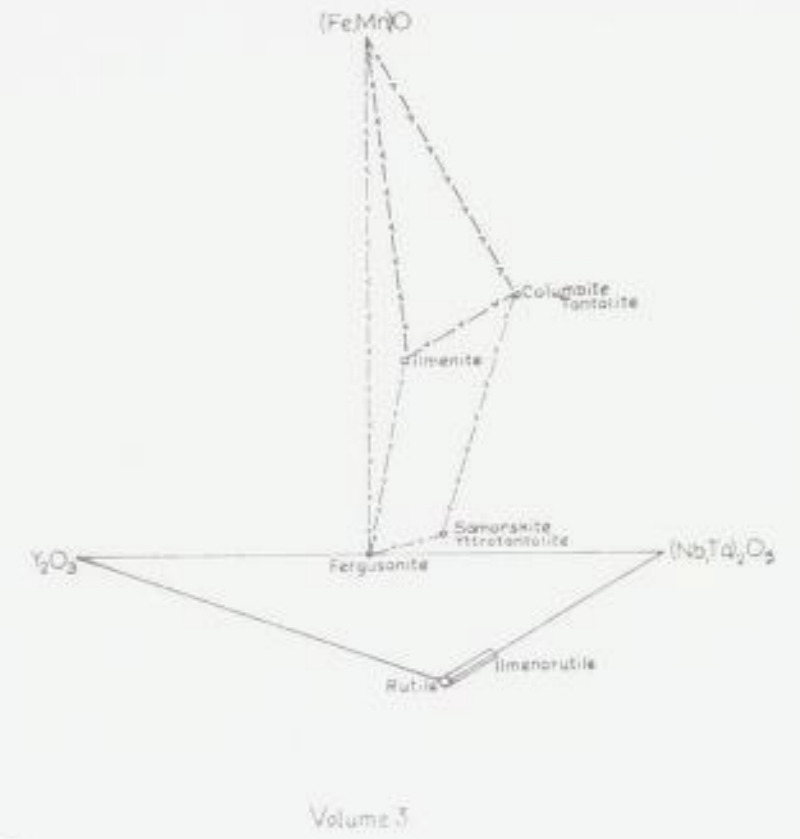
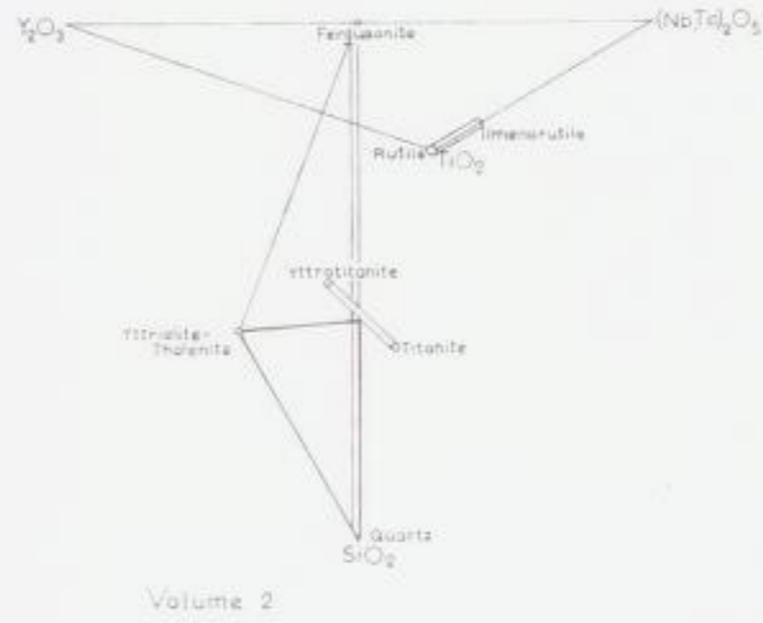
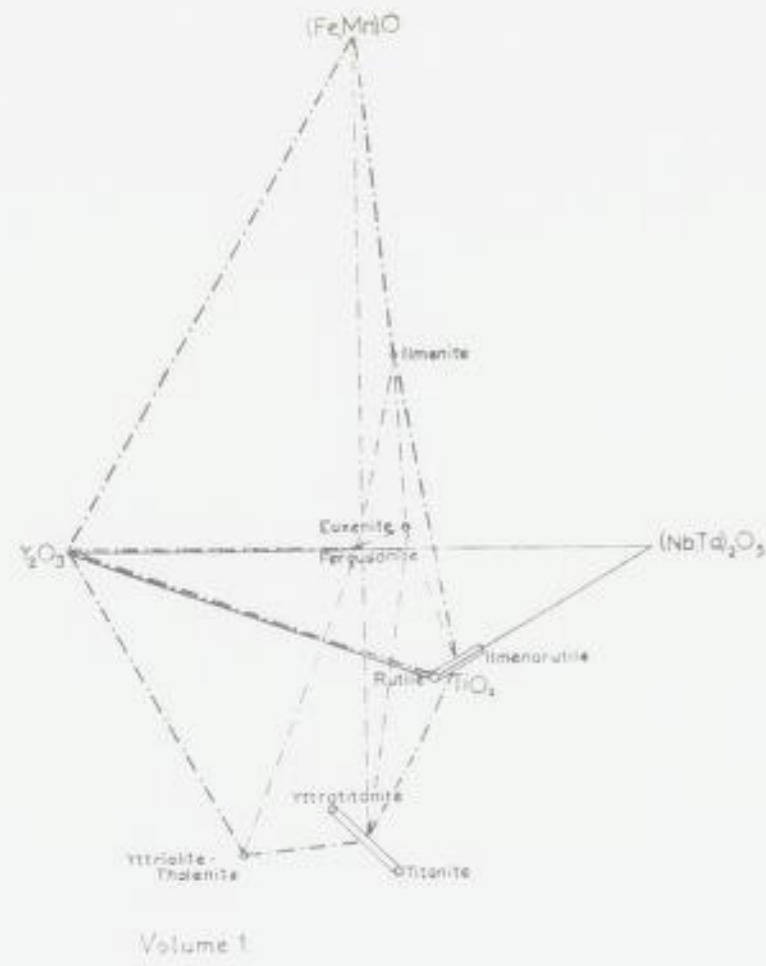


Fig. 17 b. Figures 1—6 parts of Fig. 17 a.
Figurene 1—6 er utsnitt figur 17 a.

Volume 2: Quartz, yttrialite—thalenite, yttrotitanite—titanite, fergusonite.

Volume 3: Columbite—tantalite, ilmenite, fergusonite, samarskite—yttrotantalite.

Volume 4: Columbite—tantalite, samarskite—yttrotantalite, rutile—ilmenorutile, quartz.

Volume 5: Columbite—tantalite, ilmenite, fergusonite, samarskite—yttrotantalite, euxenite, yttrotitanite—titanite, quartz.

Volume 6: Columbite—tantalite, ilmenite, samarskite—yttrotantalite, euxenite, rutile—ilmenorutile, yttrotitanite—titanite, quartz.

Let us for a moment assume that the minerals euxenite and samarskite can not occur together and see what this would imply concerning the two-component system represented by the join connecting these two minerals in Fig. 18. There are two possibilities. 1, a system in which the liquidus curve passes through a maximum (or minimum) between the two end members and in which the solubility (of euxenite in samarskite and vice versa — a function of the TiO_2 content) of the solid phase is greater (or less) than in the liquid phase (see Fig. 18). However, this would require a situation in which there was a structural change in a system miscible in all proportions. Analyses of the minerals also refute this possibility, euxenite having $\text{TiO}_2 > 20\%$ and samarskite $\text{TiO}_2 < 5\%$ (Dana, 1898) and at Rømteland euxenite having 23.5% TiO_2 and samarskite 2.4% TiO_2 . 2. a system in which there occurs a third mineral with a TiO_2 content intermediate between euxenite and samarskite, in which case the minerals euxenite and samarskite, clearly would not occur together. However, I know of no mineral of such composition, nor is any such mineral reported in the literature. As these two possibilities are the only ones which would not result in the co-existence of euxenite and samarskite, and as there are not supported by but rather confuted by experience, we must conclude that euxenite and samarskite can stably co-exist.

Euxenite and fergusonite can co-exist (e. g. Bjørlykke, 1935). However, fergusonite and samarskite are alike in the components which they contain, differing only in ratio Y: (Nb,Ta). If the composition w.r.t. Y:Nb and Ta:Ti is such that euxenite and fergusonite will form, one need only reduce the amount of Y in proportion to (Nb, Ta) and the association euxenite and samarskite *must* form. (In the absence of Ti the minerals fergusonite and samarskite will form.) Thus

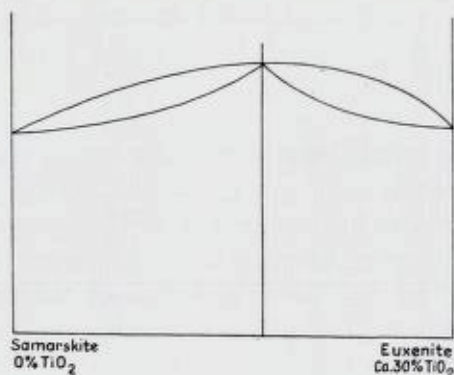


Fig. 18. The two component system Samarskite—Euxenite.

To komponentsystemet samarskite — euxenite.

by another line of reasoning we have arrived at the conclusion that euxenite and samarskite must be stable together.

Of course, insofar as one can assume that equilibrium has been attained — which seems likely — the fact that the associations euxenite—samarskite and euxenite—columbite have been observed is decisive.

It may be protested that samarskite and columbite do not belong to the same parageneses as euxenite, but for the pegmatite at Rømteland I believe that they do.

None of the three occurs in the graphic granite zone of the pegmatite. In the mineralized zone euxenite is quite abundant and samarskite rather rare. In the quartz feldspar zone euxenite becomes less abundant and samarskite more abundant. Columbite usually occurs around samarskite and is therefore assumed to be younger. However, this would suggest that euxenite began crystallizing out first, after which samarskite began crystallizing out, the two partly crystallizing out simultaneously. But as this is not decisively proved, a spectrographic analysis for Nb and Ta in the columbite from Rømteland was performed (at Sentralinstitutt for Industriell Forskning). This analysis showed that the columbite contains 76 % Nb_2O_5 and 2 % Ta_2O_5 (see the description of the mineral, p. 158) which indicates that the columbite from Rømteland is of magmatic and not of late hydrothermal origin (Nb being characteristic of magmatic and Ta of hydrothermal veins (see Bjørlykke, 1935; Goldschmidt, 1954)). Inasmuch as the columbite

crystallized from the magma, so must also the two earlier minerals have crystallized from the magma. In other words, the field observations and chemical data show that euxenite, samarskite, and columbite belong to the same period of crystallization and have formed in that order.

In order to check the reliability of the boundaries which I have given the volumes (Fig. 17 b). I have examined the descriptions of 48 pegmatites from Norway (Andersen 1931; Barth 1931; Bjørlykke 1939). All the mineral associations mentioned in these descriptions accord with the system I have set up. In some cases, when only two of the minerals within this system were mentioned, it is impossible to say into which volume the pegmatite falls. However, in a number of cases the volume could be determined with certainty. For example:

Tveit 3 (Barth, 1931): Ilmenorutile—columbite—samarskite—euxenite. Volume 6.

Rosås 1 (Bjørlykke, 1939): Thalenite, fergusonite, euxenite. Volume 1.

Rosås 3 (Bjørlykke, 1939): Thalenite, fergusonite, euxenite. Volume 1.

Støledalen 1 (Bjørlykke, 1939): Thalenite, fergusonite, euxenite. Volume 1.

Hundholmen (Bjørlykke, 1939): Thalenite, fergusonite, euxenite. Volume 1.

Helle (Bjørlykke, 1939): Euxenite, fergusonite, yttrotantalite. Volume 5.

(Later than 1939 columbite was identified at the Mineralogisk Museum in a sample from Hundholmen, but Neumann (personal communication) says that the thalenite and columbite probably belong to two different mineralizations and are not in paragenetic equilibrium.)

The mineral combinations yttrialite—thalenite, samarskite—yttrotantalite, and yttrialite—thalenite, columbite—tantalite which, according to my system, cannot occur together have not been observed.

Before I discuss the position of the pegmatite at Rømteland in this system I will simplify the system. First the Fe content in the minerals samarskite, yttrotantalite, and euxenite is ignored. These minerals then lie in the plane defined by $Y_2O_3-(Nb,Ta)_2O_5-TiO_2$. Second, the minerals rutile and ilmenorutile, and titanite and yttrotitanite are taken together and each pair considered as occupying only

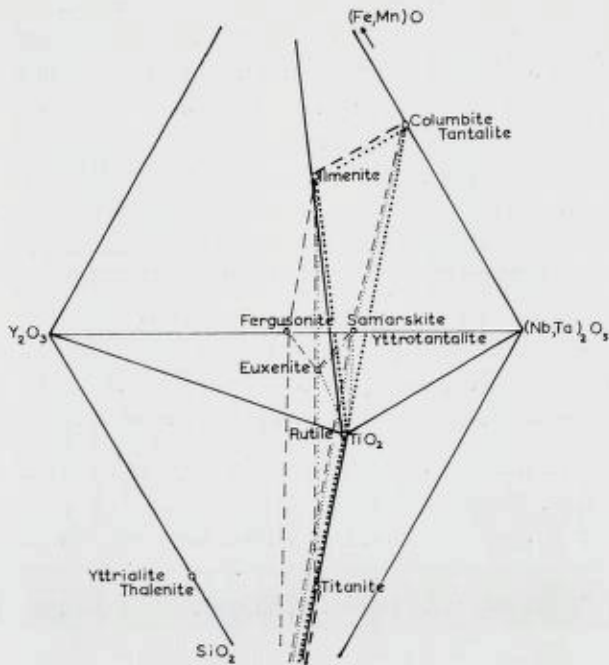
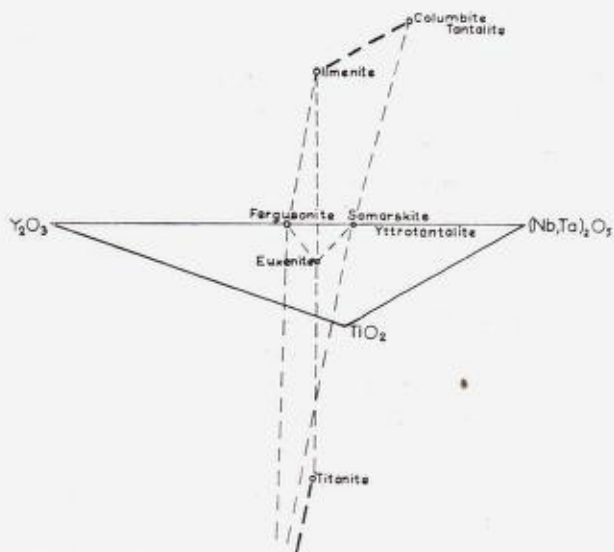


Fig. 19 a. A simplified part of Fig. 17 a; Fe content of samarskite and euxenite is ignored and rutile—ilmenorutile and titanite—yttrotitanite are combined.

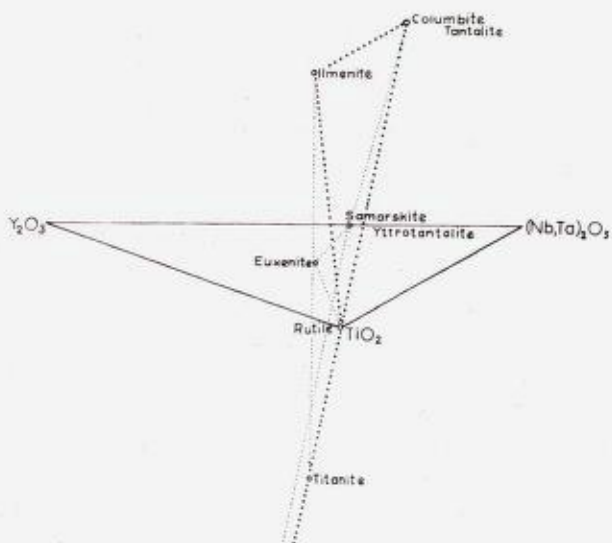
Et forenklet utsnitt av Fig. 17 a; for samarskitt og euxenitt tas ikke hensyn til Fe-innholdet. Rutil—ilmenorutil og titanitt—yttrotitanitt slåes sammen.

a point. The system then contains the following minerals: columbite—tantalite, ilmenite, fergusonite, samarskite—yttrotantalite, euxenite, rutile, (yttro)titanite, and yttrialite—thalenite (see Fig. 19 a). Volume 6 now contains: columbite—tantalite, ilmenite, euxenite, samarskite—yttrotantalite, rutile, and (yttro)titanite. Volume 5 contains: columbite—tantalite, ilmenite, fergusonite, samarskite—yttrotantalite, euxenite, and (yttro)titanite. The difference between them is that volume 6 contains rutile and volume 5 contains fergusonite. See Fig. 19 b.

The pegmatite at Rømteland contains the minerals: ilmenite, yttrotitanite, euxenite, samarskite, and columbite. It is, of course, not possible to represent the composition of the magma from which these minerals formed by a single point in the diagram (Fig. 19 a). Two points simultaneously, one in each of two four component systems, would be necessary.



Volume 5



Volume 6

Fig. 19 b. Figures are parts of Fig. 19 a.
Figurene er utsnitt av Fig. 19 a.

The pegmatite at Rømteland apparently does not contain either rutile or fergusonite; despite careful search neither of them has been found. It seems, therefore, that the position of the two points necessary to represent the composition of the magma must lie in the plane defined by the minerals which were found at Rømteland, i. e. the plane which is common to both volume 6 and volume 5.

This may be seen more easily by considering only the three component system Y_2O_3 - $(Nb,Ta)_2O_5$ - TiO_2 , thus ignoring both FeO and SiO_2 . In this plane the composition of the magma is represented by a point along the join between euxenite and samarskite (Fig. 19 a).

The order of crystallization of the minerals involved in the diagram (Fig. 21) which have been found at Rømteland is apparently: ilmenite, yttrotitanite, euxenite, samarskite, and columbite, as implied by the following evidence.

Ilmenite is found in the farsundite, in the graphic granite zone, in the mineralized zone, and in the quartz feldspar zone. In thin-section it is almost always seen to be surrounded by titanite, and the largest crystals of titanite always occur close to ilmenite.

In one large crystal of euxenite the euxenite was seen to surround titanite and alvite.

The contact relations between euxenite, samarskite, and columbite have been previously described (p. 184), and the conclusions was reached that they crystallized in the order named.

The relative change in the concentration of the oxides TiO_2 , Y_2O_3 , and Nb_2O_5 with time resulting from this sequence of crystallization is diagrammatically shown in Fig. 20.

As ilmenite crystallizes out the TiO_2 content in the magma will decrease relative to Y_2O_3 and Nb_2O_5 . Later, as yttrotitanite also begins to crystallize out the Y_2O_3 content in the magma will increase less than Nb_2O_5 in relation to TiO_2 . Eventually the ratios of the oxides $TiO_2:Y_2O_3:Nb_2O_5$ will reach 1:2:3, and euxenite will begin to crystallize. Later, after the TiO_2 content has been strongly reduced and while the ratio $Y_2O_3:Nb_2O_5$ remains $\approx 2:3$ samarskite will form. In time the Y_2O_3 will be used up and the magma is left with an excess of Nb_2O_5 ; columbite is then formed as the last mineral of the series. See Fig. 22.

With respect to the entire mineral assemblage in the mineralized zone the following can be said. Quartz, microcline, plagioclase, and biotite together with magnetite and ilmenite are minerals which have

Diagram showing the dependence of crystallization of the ratios between the oxides $(\text{NbTa})_2\text{O}_5\text{—Y}_2\text{O}_3\text{—TiO}_2$. The minerals are arranged from left to right in the order of their appearance in the paragenesis

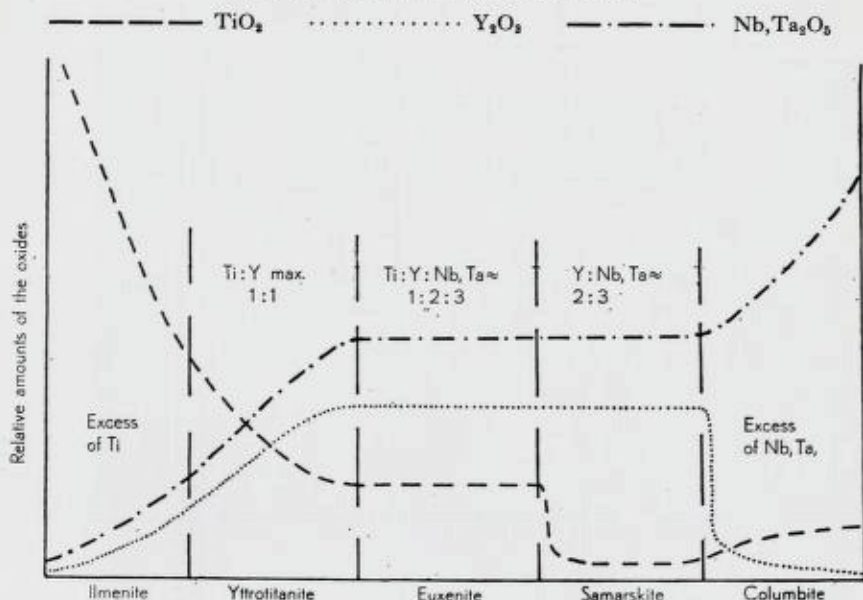


Fig. 20. The figures show the relative concentration variations of $(\text{Nb, Ta})_2\text{O}_5\text{—Y}_2\text{O}_3\text{—TiO}_2$ during crystallization.

Figuren angir de relative konsentrasjonsvariasjoner av oksydene $(\text{Nb, Ta})_2\text{O}_5\text{—Y}_2\text{O}_3\text{—TiO}_2$ under utkrystalliseringen.

crystallized throughout the entire period during which the mineralized zone formed, having been found in the surrounding farsundite and all of the zones of the pegmatite. Allanite is also found throughout the pegmatite and, through rare in all of the zones, occurs in large crystals in the mineralized zone. Yttrotitanite, which began crystallizing after ilmenite and gradually supplanted it, also began crystallizing later than the first biotite; it can often be found in the acute angle formed by wedges of biotite flakes (see also titanite, p. 169). Alvitte is apparently simultaneous with yttrotitanite and earlier than euxenite. Together with euxenite occur fine, tetragonal crystals of thorite. The age relations between these two is uncertain, though they appear most likely to have formed at the same time. Together with these two occurs uraninite which was formed later than biotite. Uraninite seems to be

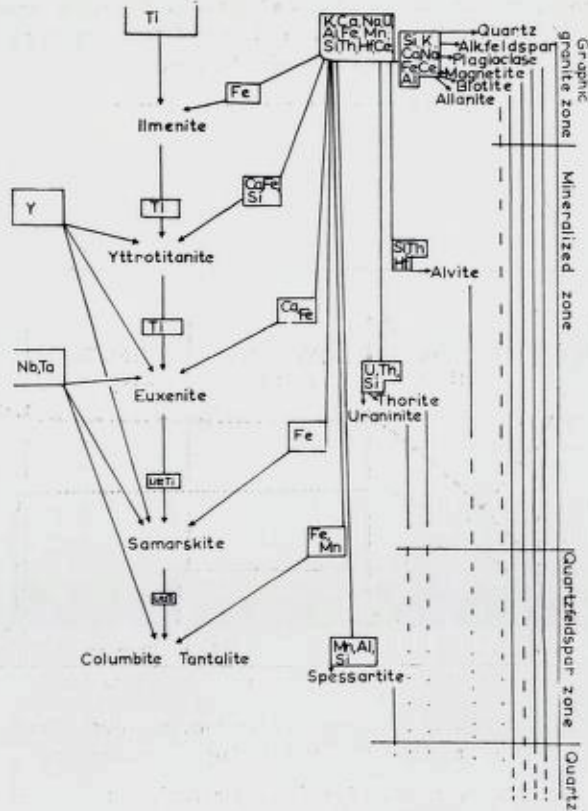


Fig. 21. Diagram showing the course of crystallization of the minerals in the zones of the pegmatite.

Skjematisk fremstilling av utkrystalliseringen for mineralene i pegmatittens hovedsone.

associated with biotite and is very often found in the acute angle formed between biotite flakes. Yttrotitanite occurs in a similar fashion, but is also often found within biotite flakes. It seems to me that uraninite is somewhat later than yttrotitanite.

Together with samarskite and columbite I have found spessartite. It appears to be the case that in the latest period of the magmatic history of the pegmatite there has been a great concentration of Mn which has resulted in the formation of the minerals columbite and spessartite.

The magma at the close of crystallization will have been enriched in fugitive materials such as H_2O and CO_2 . One passes then over into the hydrothermal phase which has led to the formation of the young, cross-cutting dike (see p. 142).

The order and periods of crystallization of the minerals in the pegmatite, excluding the mineralized zones around the amphibolites and the hydrothermal phase, are shown diagrammatically in Fig. 21.

Sammendrag.

Diskusjon over mineralparagenesen i pegmatitten på Rømteland.

Pegmatitten som her er beskrevet ligger på Rømteland, ca. 7 km V for Vigeland i Vest-Agder fylke, Syd-Norge. Feltobservasjoner er gjort sommeren 1955 og 1956 og laboratoriearbeider er blitt utført under ledelse av prof. Dr. Tom F. W. Barth, og Dr. H. Neumann.

Pegmatitten på Rømteland ligger i en kvarts-monzonitt (farsunditt), som innehar følgende mineraler: Kvarts, mikroklin, plagioklas, hornblende og biotitt. Accessoriske mineraler: Muskovitt, myrmikitt, titanitt, zirkon, apatitt, magnetitt, ilmenitt og svovelkis. Farsunditten er i øst og i sydvest i kontakt med gneis. (Se kart side 128). Ca. 3 km syd for Rømteland får farsunditten og pegmatitten en mere gneispreget struktur. Gneisene, farsunditten og pegmatitten har blitt aldersbestemt. Metoden har vært alkalifeltspat og biotittens kalium som går til argon. Resultatene av aldersbestemmelsene se side 128. Videre har det fra pegmatitten vært gjort aldersbestemmelse av uraninitt, euxenitt og thoritt fra Rømtelandpegmatitten. Se side 129. Konklusjonen av aldersbestemmelsene har vært at metoden kalium til argon er lite å stole på i dette område som tildels er sterkt tektonisert. Argonet er flyktig og vil under tektoniseringen forsvinne.

Historikk.

Av pegmatittens nåværende eier A. Tverstøl, Lyngdal har jeg fått oppgitt følgende data angående pegmatittens historie. Pegmatitten ble i perioden 1916—1922 drevet av Gustav Lundevoll, Vennesla. Han drev fra uthuset (se perspektivtegning side 132), horisontalt innover i fjellveggen d.v.s. mot øst. Feltspaten var av god kvalitet, men mengden som ble tatt ut oversteg neppe 500 tonn. Driften ble sluttet 1922 og lå nede til 1930.

I 1930 gjenopptok Johannes Torjussen, Sør-Audnedal driften. Til 1940 regner man at også han tok ut ca. 500 tonn feltspat.

I 1953 ble eiendommen med bruddet kjøpt av A. Tverstøl. Gruben ble straks rensert opp og kjørevei lagt frem til bruddet. Innen årsskiftet ble 150 tonn feltspat tatt ut. I løpet av 1954 og 1955 ble det drevet ut ca. 800 tonn feltspat og 700 tonn kvarts. Driften måtte ved årsskiftet 1955/56 stoppes p.g.a. sykdom. Den samlede mengde feltspat som er tatt ut på Rømteland er da ca. 1950 tonn mens den samlede solgte kvartsmengden minst er 700 tonn. Nedfaringen er 52 m nord for pegmatittens tilsynekomsst i dagen. Da gruben sist ble drevet arbeidet de på ca. 13,5 m dyp. 5 m under begynnende nedfaring har man mot øst et lite tverrslag hvor man i hengen blant annet har en kraftig mineralisert sone.

Beskrivelse av pegmatitten.

Pegmatittens mineralogi er meget lik farsundittens, bortsett fra av at hovedmineralene bytter hornblende og biotitt plass. Pegmatitten har nesten bare biotitt. Videre opptrer mange sjeldne mineraler i pegmatitten se Tabell side 174 og 175. Pegmatittens kontakt med farsunditten er nesten alltid helt jevn, men enkelte steder sender pegmatitten utløpere ut i farsunditten. Disse utløperne skiller seg markert ut makroskopisk i fjellveggen som grovkrystallinske årer. Utløperne blir smalere jo lenger bort fra pegmatitten en kommer.

I dagen kan pegmatitten sees langs en vegg av farsunditt som stryker nord 385° , fall ca. 85° mot vest. Farsundittveggen reiser seg opp fra overdekket, ca. 15 m høy og flere hundre meter lang. Se perspektivtegning side 132. Pegmatitten kan følges ca. 68 m i dagen, mektigheten tiltar mot nord.

Nedfaringen er lagt helt i nordenden av pegmatitten.

Pegmatitten viser en jevn overgang til farsunditten. Dette gjelder ikke bare makroskopisk, men også ved studier av slip får man en helt jevn overgang fra farsunditten til pegmatitten.

1. Kornstørrelsen av de forskjellige mineraler tiltar jevnt inn imot pegmatitten.

2. Myrmekitt som has jevnt fordelt i farsunditten har man også i nærheten av pegmatitten og innover mot denne blir myrmekitten grovere og grovere inntil man er i skriftgranittsonen i pegmatitten. Her er det makroskopisk skriftgranitt man har av kvarts og mikroclin.

3. Hornblende blir det mindre av jo nærmere man kommer pegmatitten. I pegmatitten har jeg kun ett sted funnet hornblende og da i meget store krystaller. Tilsvarende øker biotittmengden inn imot pegmatitten og i denne er det praktisk talt bare biotitt. Også kornstørrelsen tiltar for biotitt. Pegmatitten ligger i en svakhetssone i farsundtitten.

Ca. 16 m nord for nedfaringen forsvinner pegmatitten i dagen under overdekket, og herifra er det umulig å finne den igjen lenger nord. Av terrenget kan den gå to veier, enten fortsette nordover i samme retning, d.v.s. nord 385° , eller svinge mot vest nord 340° , d.v.s. nedover mot myren. Det synes for meg som det siste er det riktige samtidig som den kryper mot dypet. Det synes som man har en pegmatittkropp. Pegmatitten er sterkt sonebygd, men tykkelsen av de forskjellige sonene kan variere fra sted til sted.

Fra farsundtitten mot pegmatitten has følgende soner, nærmest farsundtitten en skriftgranitt-sone med gjennomsnittlig mektighet ca. 5 m. Mineralene som er funnet i skriftgranittsonen kan sees i Tabell nr. VIII, side 174 og 175.

Skriftgranitten har igjen en helt jevn overgang til en kraftig mineralisert sone i pegmatitten. Skriftgranitten forsvinner etter hvert og man får i steden adskilt kvarts, mikroklin og plagioklas. Fra denne sonen skyter det så ut årer som går gjennom skriftgranittsonen og ut i farsundtitten. Mineralene i den mineraliserte sonen kan sees i Tabell nr. VIII side 174 og 175. Den gjennomsnittlige tykkelsen av denne sonen er ca. 4 m.

Mineralen i denne sonen forsvinner og vi får en jevn overgang til kvarts-feltspatsonen hvor de enkelte stolper av kvarts og feltspat kan bli meget store. Mineralene i denne sonen er satt opp i Tabell VIII side 174 og 175. Mektigheten av kvarts-feltspatsonen er ikke med enn 8 m. Mer sentralt i pegmatitten, forsvinner mikroklin og plagioklas og en får som en central sone en kvartsmasse. Mektigheten av denne er det umulig å uttale seg om.

I og utenfor pegmatitten opptrer amfibolittklumper eller drag. Klumpene ligger noe uorientert og er alltid omgitt av en kraftig mineralisert sone. Mineralene i sonene rundt amfibolittene kan sees i Tabell nr. VIII side 174 og 175.

I pegmatittens nordlige del has en yngre gjennomsettende gang. Denne stryker nord 300° , fall ca. 80° syd.

Gangen er svært rik på mikroklin og kvarts. Videre finner man i denne klumper av fin sukkerkornet albitt. For øvrig se Tabell nr. VIII

side 174 og 175. I en liten spalte i denne gangen har jeg som det senest dannete mineral funnet palygorskitt.

I pegmatitten opptrer i flere druserom, hvor man finner kvarts i pene krystaller, kloritt, klar gul kalkspat, og et leirlignende mineral som en mass. Kvartskrystallene finnes her ofte med hematittovtrekk.

I sonen mellom skriftgranittsonen og farsundditten viser mineralene sterkt undulerende utslukning, men denne avtar såvel innover i pegmatitten som ut i farsundditten. Parallelt med denne oppknusning har man en sterk albittisering av plagioklasen. Albitt ligger som en sone rundt plagioklas og i sprekker i denne, se foto side 135. Alkalifeltspaten er ikke albittisert tilsvarende.

I pegmatitten er det funnet over 40 forskjellige mineraler som kan sees i Tabell nr. VIII side 174 og 175.

Temperaturbestemmelser er gjort for å forsøke å forklare pegmatitten dannelse, se Tabell nr. III side 136 og 137. Replacement, hydrothermal og magmatisk diskusjon er blitt ført for å forsøke å forklare dannelsen. Konklusjonen som er blitt tatt er at farsundditten som hadde en temperatur meget nær smeltepunktet, på enkelte steder har smeltet opp. Et av disse stedene er Rømteland. En mulig forklaring for lokal oppsmeltning kan være en anriking av radioaktive elementer.

Smelten har større volum enn de opprinnelige krystaller har. Resultatet har vært at farsundditten nær pegmatitten har sprukket opp og er fylt med et smeltet materiale som nå kan bli sett som årer som skyter ut i farsundditten fra pegmatitten. Det første som smelter opp er en eutektisk blanding av kvarts og feltspat. Denne blanding opptrer nå som skriftgranittsoner mellom pegmatitten og farsundditten. Etter at området igjen ble avkjølt har en kalirik løsning beveget seg ut i farsundditten og ut i amfibolitten fra pegmatitten. Plagioklas er blitt serisitisert og hornblende omvandlet til biotitt. Begge disse prosesser kan forklares ut fra den samme kalirike løsningen. Se de kjemiske ligninger side 138 og 139. Denne omdannelsen avtar bort fra pegmatitten. Ved å anta en langsom avkjøling av området kan også den sonare strukturen bli forklart. Da ekspansjonen under smeltningen førte til at noe av smelten ble injisert inn i farsundditten (årene som er nevnt ovenfor) vil det gjenstående materiale når det igjen utkrystalliserer innta en mindre plass enn det opprinnelige volum. Druseromet kan av den grunn forklares. Restløstningen etter en slik krystallisasjon vil være en meget sur plagioklas, som nå kan sees i den yngre gang som krysser pegmatitten. Temperaturen i denne gangen og også

mineralparagenesen indikerer en hydrotherm dannelselse for denne. En tektonisering av pegmatitten fant sted ved ca 450°—460°, og en natriumrik hødrothermal løsning har beveget seg inn i og krystallisert i alle sprekker. Denne rekrystallisering har opptrådt samtidig med dannelsen av en yngre gjennomsettende gang.

Tiden for de forskjellige mineralers utkrystallisasjon har vært diskutert i detalj, spesielt systemet $\text{TiO}_2\text{-Y}_2\text{O}_3\text{-(Nb,Ta)}_2\text{O}_5\text{-(Fe-Mn)O-SiO}_2$. Den fullstendige paragnese er vist skjematisk i Fig. 21 side 190 og Fig. 16 side 178.

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