INTERNAL STRUCTURE AND MINERALOGY OF THE GLOSERHEIA GRANITE PEGMATITE, FROLAND, SOUTHERN NORWAY

REIDAR ÅMLI

Åmli, R.: Internal structure and mineralogy of the Gloserheia granite pegmatite, Froland, southern Norway. *Norsk Geologisk Tidsskrift*, Vol. 57, pp. 243–262. Oslo 1977.

The Gloserheia granite pegmatite shows a well developed and regular zoning around the quartz core. Eight different zones have been recognized.

The following minerals occur: Quartz, microcline, plagioclase, biotite, muscovite, muscovite 1 M, chlorite, apatite, calcite, tourmaline, rutile, yttro-titanite, magnetite, hematite, pyrite, beryl, zircon, allanite, uraninite, thorite, xenotime, monazite, euxenite, fourmarierite, kasolite, β-uranophane and uranophane.

R. Åmli, Norges geologisk undersøkelse, Postboks 3006, 7001 Trondheim, Norway.

The Gloserheia pegmatite is located ca. 9 km N of Arendal (8°43'36"E; 58°32'20"N) in the Precambrian Kongsberg-Bamble Formation.

Andersen (1926, 1931) gave a brief description of the pegmatite; similar pegmatites are not reported in the nearby district. Bugge (1943) treated the geology of the Gloserheia-Arendal area; rocks of both granulite and amphibolite facies are present.

The Gloserheia pegmatite forms a V-shaped body with a quartz core located in the NE part (Fig. 1). The shape of the pegmatite body as described by Andersen (1926) is not correct, because he reports it as a uniformly thick body striking WSW.

Scattered strike/dip measurements in the surrounding rocks (Fig. 1) do not indicate a clear structural relationship with the pegmatite.

The southgoing arm of the pegmatite ends irregularly with gneiss fingering into the pegmatite and vice versa. The westgoing arm thins out and disappears under overburden. In accordance with Andersen's description, the pegmatite is observed cross-cutting the country rock. The contacts with the wall rock are very sharp, mm-cm sized (defined by the grain size) and generally very smooth, especially on the larger (metre) scale.

Microscopical signs of stress in the pegmatite are seen in bended twin lamellae in plagioclase and some scattered micro-fracturing. It is difficult to establish whether this has been caused by competing crystallizing minerals or by stress related to deformation of the country rock.

The pegmatite can, according to the above-mentioned observations, be syn- and/or post-tectonic.
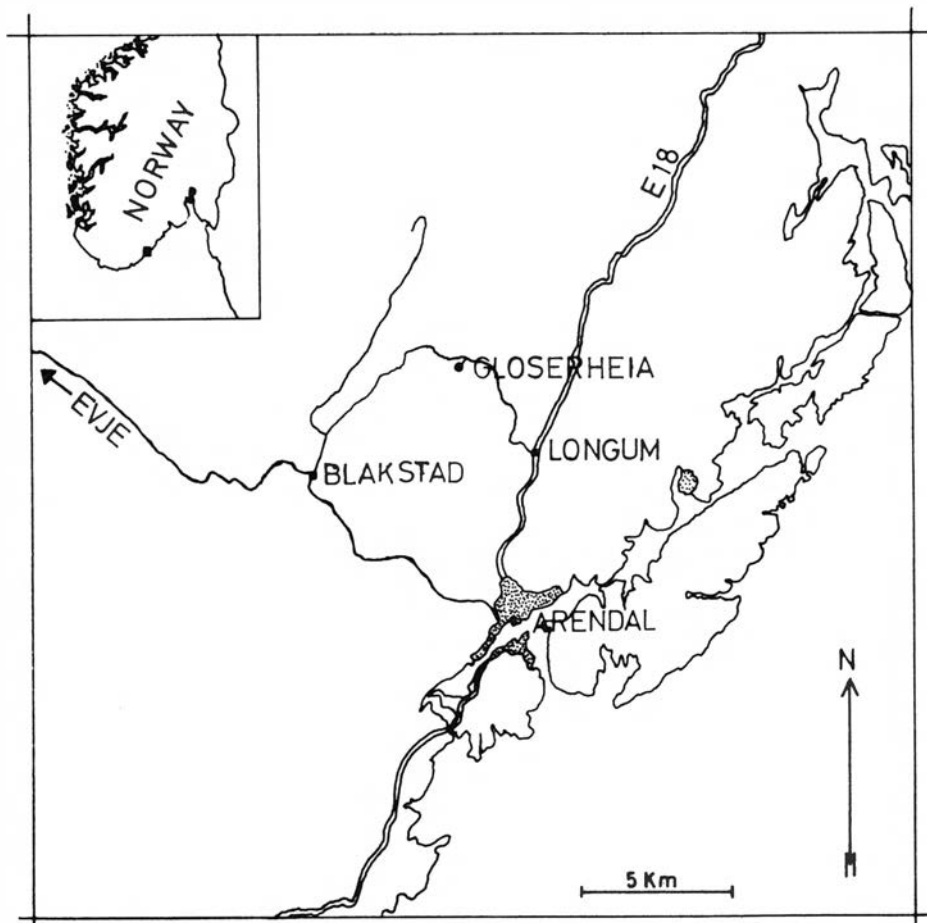
Fig. 1. The location of the Gloserheia pegmatite.

Internal structure

The Gloserheia pegmatite exhibits in general a well-developed and regular zoning in the immediate vicinity of the quartz core. Applying the well-established and frequently used zone nomenclature of Cameron et al. (1949) for granite pegmatites, the following zones can be distinguished: Core, intermediate zones I–V, wall zone, and border zone. The observations and interpretations of the zonal sequences presented here refer to the area exposed around the quartz core, because of the lack of adequate exposures in the other parts of the pegmatite. Intermediate zone V and the wall zone have been observed essentially from the WNW-going tunnel between profile CD and EF on Fig. 3.

A detailed picture of the part of the pegmatite around the quartz core is given by Figs. 3, 4, and 5. Fig. 3 is a plane table map of the quarry; Figs. 4 and 5 show the interpretations of the zonal sequences based on the author's
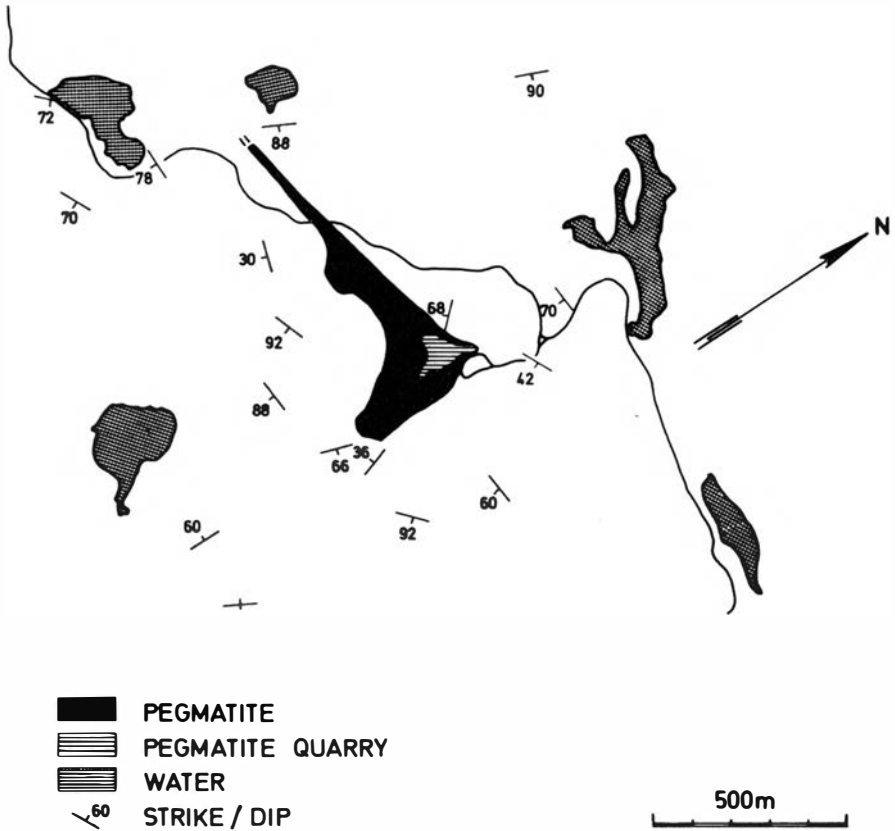
Fig. 2. The shape of the Gloserheia granite pegmatite.

observations and extrapolations, together with drill cuttings data obtained from the mine foreman.

Core
Quartz is estimated to constitute more than 99.9 % of the core. It occurs generally as dense masses, but miarolitic druses are occasionally encountered. The border to intermediate zone I is mostly very irregular due to the coarse crystals that constitute this zone.

Intermediate zone I
The thickness of this zone varies roughly between $\frac{1}{2}$ and 3 m, often changing very rapidly. Biotite and quartz are interstitial to the blocky microcline, and biotite often forms a seam at the contact to the core.

Intermediate zone II
This is an almost monomineralic zone constituted of anhedral plagioclase with a grain size up to a few dm. The thickness of this zone is from several dm to approximately 1 metre.
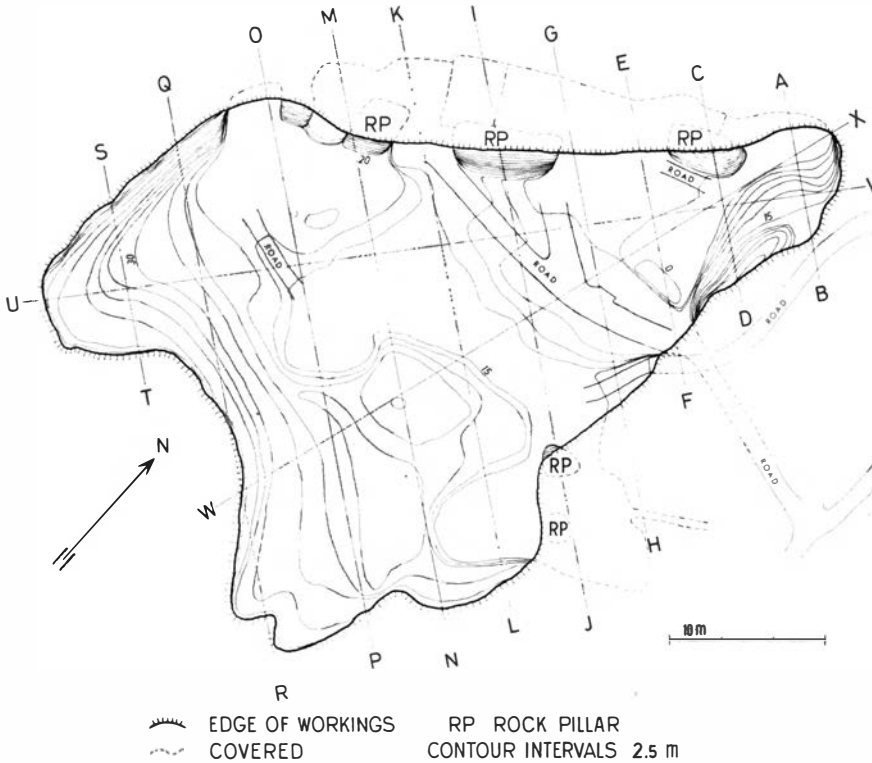
Fig. 3. The Gloserheia pegmatite; plane table map of quarry. A–B to W–X are profiles (see Figs. 4 and 5).

Intermediate zone III

The zone is defined by the presence, in very variable amounts and relative proportions, of the characteristic trace minerals euxenite, allanite, biotite, apatite, zircon, etc. The thickness of this zone is ca. 1 dm. Except for quartz, microcline, biotite, and euxenite, the other accessory and trace minerals in this zone seem to occur exclusively in areas where muscovitization is pronounced. This implies that the formation of these minerals is related to the muscovitization process, or that muscovitization preferably took place where these minerals were present.

Intermediate zone IV

The zone is roughly of dm thickness and shows a graphic to graphic-like texture. Occasionally, at the contact between intermediate zones IV and III, there is a graphic-like intergrowth of microcline and plagioclase (macro-antiperthite?), that texturally is not distinguishable from the associated plagioclase-quartz graphic-like intergrowth.

Intermediate zone V

The texture is graphic to graphic-like with variable grain size (mm-cm) and

pattern. It is quite often found protruding through intermediate zone IV, and thus always shows a cm-sized rim of microcline at the border to intermediate zone III. At the border to intermediate zone IV myrmekite is sometimes developed (Fig. 6). Patches of plagioclase-quartz graphic intergrowth are found sporadically. Areas up to m-size, roughly built up concentrically, with quartz, microcline, and plagioclase (from centre and outwards) are also occasionally met with in this zone (representing formation from trapped liquid?). The thickness of intermediate zone V varies between roughly 5 and 8 m.

Wall zone

The texture is hypidiomorphic granular (part of one specimen collected showed also an aplitic texture), with a grain size from 1 to ca. 10 cm. Minor amounts of microcline and of graphic intergrowth of microcline and quartz have been found. The thickness is between ~ 1 dm and 1.5 m. The wall zone was observed at one place to border intermediate zone II. The situation is shown in Fig. 7 and interpreted in Fig. 5.

Border zone

In mineralogical composition this zone is very similar to the wall zone, but normally shows a pronounced enrichment of magnetite and biotite relative to the latter. It is also much finer grained (chilled margin?) than the wall zone and has a thickness of ca. 1 dm or less.

Mineralogy

The mineral composition of the different zones in the pegmatite is shown in Table 1. Apatite, xenotime, and monazite are described in a separate paper (Åmli 1975).

Quartz

Quartz is the most common mineral in the pegmatite and is found in all zones.

In the core the quartz is partly translucent and the colour is white, less commonly rose and smoky. It shows undulating extinction, implying that it has been subjected to stress after and/or during formation. The rose and smoky milky-quartz sometimes possesses asterism, showing a weak six-rayed star. The only mineral inclusions reported to cause such an effect are rutiles (Frondel 1962), and since rutiles are found in the Gloserheia pegmatite they are probably responsible for the asterism.

In intermediate zone I quartz has sometimes been found as euhedral crystals up to dm size in druses in altered parts of microcline crystals (see below).

Quartz is also found as inclusions in apatite (Åmli 1975) from the core and intermediate zones I and III.

CORE

INTERMEDIATE ZONE I

——— II ——— II-IV

——— II ——— V

10m
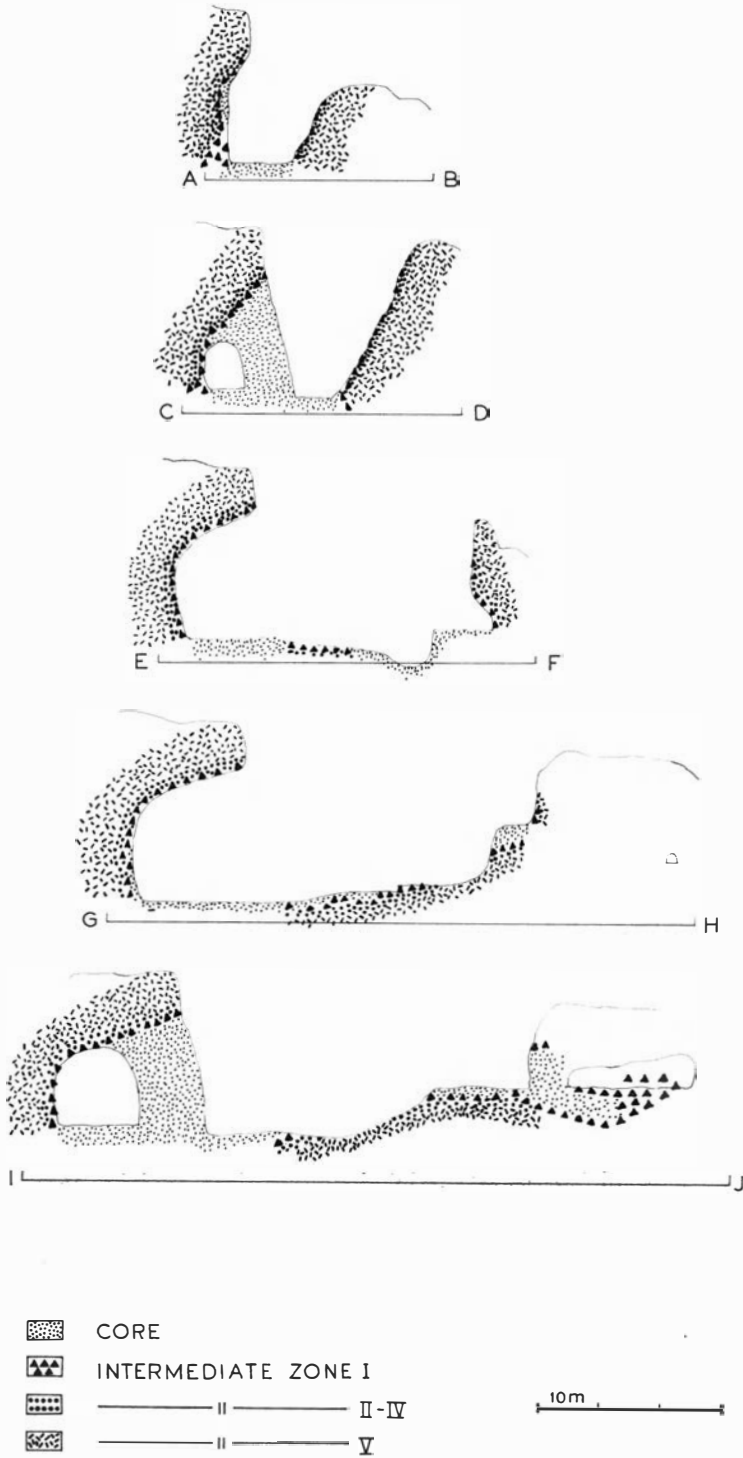
Fig. 4. The Gloserheia pegmatite. Profiles
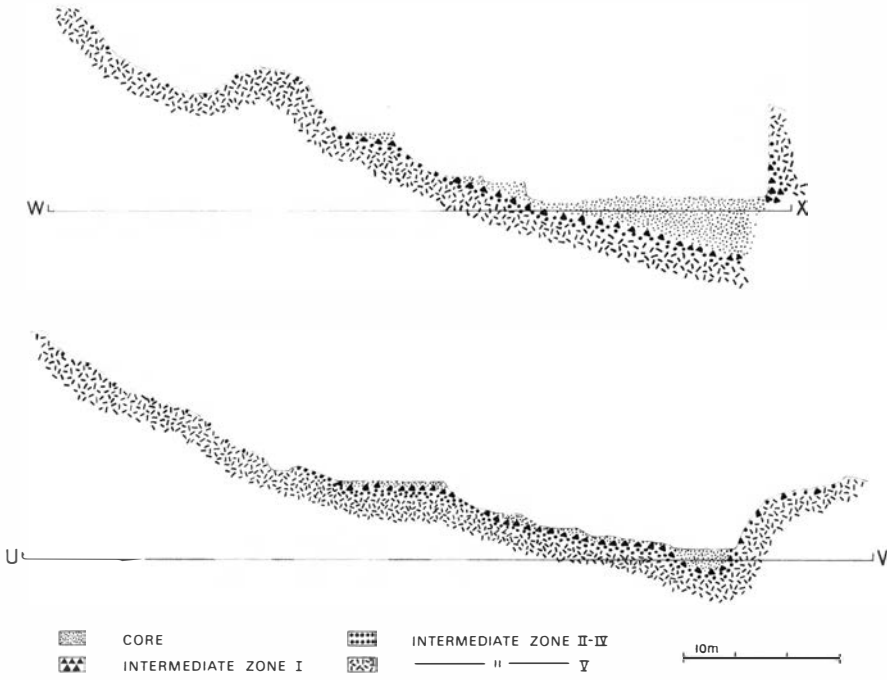A–B to S–T.
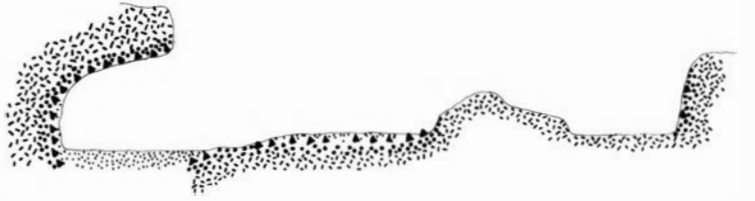
Fig. 5. The Gloserheia pegmatite. Profiles W–X and U–V.
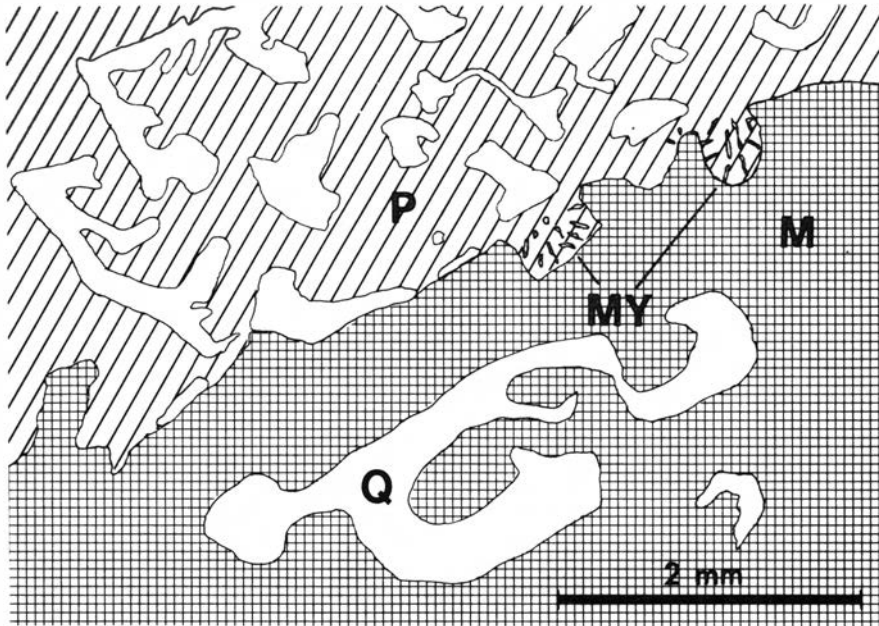

Fig. 6. Sketch showing myrmekite (MY) at contact between intermediate zone IV and V. P: plagioclase, M: microcline, Q: quartz.

Fig. 7. The only observed protrusion of the wall zone to intermediate zone II. The picture is taken parallel to and between profile G–H and I–J.

Elsewhere in the pegmatite quartz occurs as anhedral grains of variable size.

Microcline

Microcline is the most common mineral in the pegmatite next to quartz. It is found in varying amounts in all zones except for intermediate zone II.

In the core it occurs as euhedral to subhedral crystals of cm size. It is occasionally partly to totally altered to 1 M muscovite. When apatite occurs in the core it is almost always found associated with microcline.

In intermediate zone I, microcline occurs as euhedral to subhedral crystals ∼ 1 dm – 2 m in diameter. Irregular patches are here developed as a microcline-aventurine (inclusions of hematite). In the wall zone and intermediate zones III and IV, microcline occurs in small amounts as euhedral crystals and anhedral grains. In intermediate zone V it is a constituent of the graphic granite.

The microcline is perthitic throughout the pegmatite, and the grid-iron structure is always seen.

The colours observed are light to dark grey, brownish black, and light to dark red.

A dominant feature of the microcline in intermediate zone I is the alteration to muscovite and quartz, which is occasionally accompanied by small amounts of rutile, xenotime, magnetite, apatite, and tourmaline, where replacement is very extensive (druses up to 30–40 cm across are occasionally

Table 1. Mineral composition of the different zones in the Gloserheia pegmatite.

Mineral / ~ Thickness	Core	Int. zone I	Int. zone II	Int. zone III	Int. zone IV	Int. zone V	Wall zone	Border zone
		0.5–3 m	0.2–1 m	0.1 dm	0.1 dm	5–8 m	0.1–1.5 m	0.1 dm
Quartz	M	A	T	A	M	M	M	M
Microcline	T	M		A	A	M	A	
Plagioclase			M	M	M	A	M	M
Biotite		A		A	A	A	A	A
Muscovite		A	A/T	A/T	T(?)	T(?)	T(?)	T(?)
Muscovite 1 M	T							
Tourmaline	T	T		T				
Allanite		T		T				T
Apatite	T	T		T				
Euxenite				T				
Calcite		T	T	T				
Pyrite	T	T		T				
Magnetite		T					T	T
Rutile	T	T		T				
Xenotime	T	T		T				
Zircon				T				
Yttrotitanite				T				
Goethite	T	T		T				
Chlorite				T				
β-uranophane				T				
Uranophane				T				
Kasolite				T				
Fourmarierite				T				
Uraninite				T				
Thorite		T		T				
Beryl			T	T				
Monazite	T	T						
Hematite		T						

M: Main mineral
A: Accessory mineral
T: Trace mineral

met with). Eugster (1970) gives the following equation for the replacement of K-feldspar:

$$3KAlSi_3O_8 + 2H^+ \lessgtr KAl_2AlSi_3O_{10}(OH)_2 + 6SiO_2 + 2K^+.$$

He states that removal of potassium ions from the solution co-existing with the K-feldspar, caused by crystallization of a potassic phase in the environment, could produce muscovite and quartz from K-feldspar. He also suggests lowering of the pH by crystallization of OH-bearing silicates, provided that there is no external OH-reservoir, as a possible driving force for alteration of K-feldspars, and that all these reactions most probably take place during the post-crystallization.

Korzhinskii (1970) states in his model for isothermal metasomatism that

the reaction of solutions of low potassium content with K-feldspars can cause replacement by muscovite and quartz.

Another explanation, proposed by Carmichael (1969), involves simultaneous replacement of K-feldspar by muscovite and quartz in one microscopic domain, and garnet by chlorite, micas, and quartz in an adjacent microscopic domain with accompanying exchange of H^+ and K^+.

The reactions suggested by Carmichael have not taken place in the Gloserheia pegmatite because no garnet or other anhydrous silicates occur. The mechanism proposed by Eugster is not likely to be responsible for the alteration because altered parts of microcline (since it is very irregularly distributed) should be more frequently found near the biotites, the only mineral coexisting with microcline whose crystallization quantitatively would effect the concentration of K^+ and H^+ according to his theory. This association is not observed.

It is possible that Korzhinskii's model can explain the alteration of microcline; at least it is not contradicted by what is observed.

The same replacement that occurs in intermediate zone I has also been observed in microcline from intermediate zone V, but no clear picture has been obtained concerning the amount and distribution of replacement except that it is found along minor cracks in the graphic granite. Alteration along small cracks is also found in intermediate zone I, suggesting that at least part of the replacement of microcline by muscovite and quartz throughout the pegmatite was caused by solutions percolating cracks in the pegmatite.

Plagioclase

Plagioclase is found in the intermediate zones II–V, wall- and border zones. It is the overall dominant mineral in intermediate zones II and III, occurring as densely intergrown anhedral masses up to some dm in diameter. In intermediate zone IV it occurs in a graphic intergrowth with quartz. In intermediate zone V, wall- and border zone, plagioclase is found as subhedral to anhedral grains in variable amounts.

Sericitization is characteristic for the plagioclase throughout the pegmatite (in intermediate zone II the mica was confirmed as muscovite). No clear picture of the amount and distribution of the serizitization was obtained, but it seems to be irregular. In the intermediate zone II, cavities filled with calcite and rimmed by coarse muscovite (up to 3 cm across) are occasionally found in heavily muscovitized plagioclase. In intermediate zone II red coloured (stained?) calcite occurs frequently, but is irregularly distributed in areas with heavy muscovitization of plagioclase.

The albite-twins in the plagioclase shows signs of stress, bending, and displacement.

Determination of three samples from intermediate zone II all gave Ab_{84}; one sample from intermediate zone III gave Ab_{82}, and one extensively sericitized sample, probably from the wall zone, gave Ab_{96}. This indicates that

the fresh plagioclase is an oligoclase, while sericitization creates a more sodic phase.

Biotite

Except for the core and intermediate zone II, biotite is a constituent of all zones.

In intermediate zone I, biotite forms sheets some few dm in size. They are generally somewhat bent, indicating influence of stress during and/or after crystallization.

Biotite from intermediate zones III, IV, and V is developed as thin laths approximately 1–4 mm × 1–2 cm. Some of the biotite in intermediate zone III is altered to a chlorite mineral.

In the wall and border zones biotite laths are not elongated.

Muscovite

This mineral was identified (by its X-ray powder pattern and optics) from intermediate zone I, II, and III, where it occurs as euhedral to subhedral crystals up to a few centimetres across, related to feldspar replacement. Zoning is expressed by varying shades of green. Muscovite is, however, believed to occur throughout the pegmatite in varying amounts, representing sericitization of the feldspars.

Muscovite 1M

This secondary mineral was found in the core as coatings on and in vugs in slightly altered microcline, and is considered to have formed from this. The colour is light yellow.

It was identified from its X-ray powder pattern.

Calcite

Besides the occurrences described under plagioclase, calcite (?) has also been observed occurring as anhedral grains < 100 μm in trace amounts in apatite from the core and intermediate zones I and III (Åmli 1975).

Tourmaline

Tourmaline is found characteristically in the core, intermediate zone I and intermediate zone III. The colour is always black.

It is the most abundant macroscopic trace mineral in the core, occurring as radiating crystals more or less aggregated to masses up to dm-size. Pyramid faces have never been observed, and prism faces are relatively scarce.

Tourmaline is very rare in intermediate zone I. Only two specimens have been found; one is an anhedral mass enclosing cm-sized greyish euhedral apatites, and the other an idiomorphic long-prismatic crystal in a druse in a heavily altered (mainly to quartz and muscovite) microcline crystal.

In intermediate zone III tourmaline occurs mostly as long-prismatic (up ~ ½ dm) euhedral to subhedral crystals. Here it is characteristically associated with muscovite, rutile, and occasionally xenotime.

Rutile

Rutile occurs in trace amounts in the core, intermediate zone I and III.

Only one subhedral rutile crystal, $\frac{1}{2}$ cm in length, has been found in the core.

Rutile from intermediate zone I has three different modes of occurrence. As euhedral to anhedral crystals associated with the alteration of microcline to quartz and muscovite; as euhedral to subhedral crystals of mm-cm size embedded in V-shaped calcite pockets between biotite sheets and in trace amounts as anhedral grains (up to $200-300\,\mu m$) included in or from the faces of apatite (identified from the mineral fraction dissolved out of apatite; Åmli 1975).

Rutile from intermediate zone III exhibits a reddish colour and is developed as anhedral-subhedral crystals of mm-size. It is characteristically found in an association of tourmaline, muscovite, and xenotime.

The colour of the rutile varies between yellow, brownish red, and black when viewed in binocular microscope ($\times$ 65). A mass spectrogram of a brownish red rutile from the replacement in microcline gave Nb, Sn, and W as minor/trace elements (0.01–1 wt. %). Rutile was identified from its X-ray powder pattern.

Yttrotitanite

Two different types of yttrotitanite have been found. One being millimetre-sized light yellow crystal aggregates occurring in intermediate zone III in a small cavity in the plagioclase. The other type is a part of a wedge-shaped euhedral crystal ($\sim 7 \times 7$ cm) with dark brown colour. The occurrence within the pegmatite is not known for this sample.

The larger crystal is likely to be primary, related to the formation of the main pegmatite units, while the obviously different other type could be a later stage product.

They were both identified from their X-ray powder pattern.

Magnetite

Magnetite is found in intermediate zone I, wall- and border zone.

In intermediate zone I it was found in one specimen only as mm sized octaedra together with rutile. The specimen was mainly composed of quartz and muscovite, the characteristic replacement minerals of microcline.

It is also found as subhedral to anhedral crystals in the wall- and border zones.

Pyrite

Pyrite is relatively scarce in the pegmatite. It is found in the core, intermediate zone I, and intermediate zone III.

It is always developed as euhedral crystals ($\sim 1/10 - 1$ cm), with the pyritohedron being the characteristic form. Smaller octahedral and cube faces can be observed sporadically.

Throughout the pegmatite the pyrite is to a variable degree altered to goetite. This is probably related to the 'metasomatic' alteration of microcline to quartz and muscovite, since goetite pseudomorphs, rather than fresh pyrite, are characteristically found in these 'metasomatized' microclines.

Beryl

Beryl is very rare in the pegmatite. Two different types are observed, occurring in intermediate zones II and III respectively.

The intermediate zone II type was found as 1–3 cm long hexagonal crystals with light green colour and a distinct parting parallel to the prism. It was closely associated with calcite in sericitized plagioclase. The beryl is therefore believed to have formed in a late stage, related to sericitization of the plagioclase and deposition of calcite.

Of the intermediate zone III type, only a small (< 1 cm) crystal fragment was found, associated with allanite, pyrite, and zircon in a sericitized plagioclase. The colour of this beryl was deep golden yellow, implying that it was the heliodor type.

Both beryls were uniaxial negative and showed no pleochroism. The ω_{Na} was as follows: ω yellow beryl $= 1.584 \pm 0.004$ and ω green beryl $= 1.579 \pm 0.004$. By comparing the two beryls in the same refractive liquid it was found that ω yellow $> \omega$ green.

A semiquantitative X-ray spectrogram of the green beryl gave Fe, Mn, Zn, Ca and doubtfully As as trace elements (the spectrogram covered K and heavier elements).

Zircon

Zircon occurs intimately associated, frequently in an intergrowth with or as inclusions in euxenite and apatite in intermediate zone III, as grey to greyish brown euhedral crystals ($\frac{1}{4}$–4 mm) or as crystal aggregates. The prism and pyramidal faces are of the first and second or second and first order respectively.

Allanite

Allanite is the most abundant rare-earth mineral in the Gloserheia pegmatite. It occurs in both intermediate zones I and III.

In intermediate zone I it is found as subhedral to anhedral crystals and clusters of crystals of cm to m size. The colour is black to dark greenish black. In larger crystals flesh red inclusions (mm-sized), which are probably thorite, are observed.

In intermediate zone III it occurs as cm sized anhedral masses and as mm-thick plates. The colour is brown to reddish brown.

Seven different allanites from both zones were subjected to X-ray powder diffraction studies (Debye-Scherrer camera), but no pattern was obtained. Five of these samples were heated to 900–1000°C for 15–25 hours, after

which they gave a pattern, interpreted to be a composite pattern of hematite, rare-earth oxides (mainly CeO_2) and probably Ca-Al silicates.

Optical spectrograms show that beside the main elements (Ca, Fe, Al, Si, rare earths, Mn and Mg) B, Be, Sc and Ti are characteristic trace elements in all types of allanite.

Identification of allanite is based on its chemistry, X-ray powder pattern after heating, colour, habit, and occurrence.

Uraninite

Only one specimen of uraninite has been found in the pegmatite. It was an anhedral grain approximately 4 mm across embedded in plagioclase in intermediate zone III. Associated minerals were euxenite, zircon, and secondary uranium minerals. The plagioclase matrix is somewhat sericitized.

The uraninite was identified from its X-ray powder pattern.

Thorite

Apart from the occurrence mentioned under allanite, thorite is also found as inclusions in apatite from intermediate zone III. It occurs as anhedral grains up to ~ 100 μm across, being isotropic and showing high relief in the apatite. The colour is yellow. Semiquantitative electron microprobe analysis gave Th and Si as main elements. Identity is assumed from composition and 'optics'.

Euxenite

Euxenite is found only in intermediate zone III, generally intergrown with small amounts of zircon and associated to a very variable degree with other minor to trace minerals in this zone. It is found, with black and brown colour, as euhedral to subhedral crystals and aggregates of crystals (sometimes radiating) up to a size of approximately 1 cm; also as anhedral masses up to a few cm.

XRF-wavelength scans (covering K and heavier elements) of two samples with black and brown colour respectively gave rare earths, U, Th, Nb and Ti as main elements and Ta, Pb, Fe, Mn, Ca and Sn as minor elements. In addition, optical spectrograms showed minor to trace amounts of B, Mg, Si and Al. Comparison of the two scans showed the brown variety to be a little higher in Ca, Fe, and Mn, and a little lower in Pb, than the black one. For the other elements, the diagrams were identical.

Investigations by H. Neumann and B. Nilssen (pers. comm.) showed that black and brown euxenites gave slightly different X-ray powder patterns. This difference was also found for the black and brown euxenite from Gloserheia. Table 2 gives X-ray powder data for black and brown euxenite from Gloserheia, together with data from Arnott (1950) and Komkov (1960) (synthetic euxenite). The Gloserheia euxenites are X-ray amorphous. The X-ray patterns were obtained after heating in air at $\sim 1000°C$ for 20 hours.

The identity of euxenite from Gloserheia is clearly established from the

Table 2. X-ray powder diffraction data (9 cm camera) for brown and black euxenite (heated to ∿ 1000 °C for 20 hours) from Gloserheia, euxenite from Nippissing, Ontario (Arnott 1950), and synthetic euxenite (Komkov 1960). Since the exposures of the Gloserheia euxenites give weak lines, only those which could be measured with reasonable exactness, and corresponding values for the Nippissing-euxenite and the synthetic one are listed. Intensities are visually estimated.

Euxenite (brown) Gloserheia		Euxenite (black) Gloserheia		Euxenite Nippissing Ontario		Euxenite (synthetic)	
d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I
3.66	5	3.66	5	3.66	3	3.69	2
3.35	1	3.34	1	3.36	2	3.38	1
3.26*	1						
2.97	10	2.97	10	2.98	10	3.01	10
2.95*	6						
2.77	2	2.77	3	2.77	2	2.80	4
2.59	3	2.59	2	2.58	2	2.59	2(b)
2.54*(?)	3	2.55*(?)	2	2.54*(?)	½		
2.11	2	2.10	3	2.106	2	2.11	2(b)
1.89	2	1.89	2	1.889	2	1.907	5
1.82	3	1.82	5	1.823	4	1.839	6
1.80*	5						
1.77	3	1.77	4	1.769	3	1.782	6
1.72	4	1.72	6	1.723	4	1.737	7
1.64	4	1.64	5	1.635	3	1.631	1
1.56	3	1.56	4	1.560	1	1.566	4
1.54*	5	1.54*	4				
1.48	4	1.48	5	1.487	4	1.495	8
1.43	3	1.43	2	1.436	2	1.438	2(b)
1.17	4	1.17	3	1.173	2		

b – broad.
* – lines not belonging to the euxenite structure.

X-ray powder diffraction data and the chemistry. Further it is evident from the data of Arnott and Komkov that some of the lines do not belong to the structure. The 3.26 Å-line, decreasing in intensity from brown to black euxenite, corresponds to the strongest line for rutile. The four other lines correspond well to the four strongest lines for a betafite-type pyrochlore. The status of the 2.54/2.55 Å-line is, however, a little uncertain since it is not reported by Komkov, and is the only 'pyrochloreline' present in Arnott's data. The most probable explanation, partly because of the difference in relative intensity between the Gloserheia and Nippissing euxenite, is perhaps that it represents overlapping of two lines, a pyrochlore and a weak euxenite line not obtained by Komkov for his synthetic euxenite. The above observations are in accordance with the composite pattern (euxenite, pyrochlore-like structure, and rutile) reported by Van Wambeke (1970).

It is apparent from Table 2 that the black and brown euxenites have the same cell size.

Table 3. X-ray powder diffraction data for β-uranophane from Joachimstal and Glose-rheia, and uranophane from Ruggles pegmatite and Gloserheia. Only the strongest lines are listed. Intensities are visually estimated for the Gloserheia samples.

β-uranophane Joachimstal		β-uranophane Gloserheia		Uranophane Ruggles pegmatite		Uranophane Gloserheia	
d (Å)	I	d (Å)	I	d (Å)	I	d (Å)	I
7.83	10	7.76	10	7.88	10	7.90	10
6.66	4	6.60	2	6.61	4	6.62	3
6.15	4	6.10	2	5.42	4	5.38	3
5.07	4	5.10	1	4.76	5	4.83	7
4.85	4	4.8	1	3.94	9	3.95	8
4.55	4	4.55	3	3.51	4	3.53	3
3.90	9	3.85	5	3.20	5	3.21	7
3.51	6	3.49	5	2.99	8	2.97	6
3.19	5	3.18	6	2.91	8	2.90	5
3.04	4	3.03	5	2.69	4	2.68	4
2.83	4	2.80	4	2.63	5	2.63	4
2.59	5	2.58	4	2.20	4	2.21	4
				2.10	5	2.10	5
				1.969	7	1.97	2

Determination of specific gravity (by the pycnometer method) on material from Gloserheia purified by separation with a Franz isodynamic separator, heavy liquids, and hand picking under a binocular microscope gave 4.90 and 4.85 for brown, in contrast to 5.03 and 5.08 for black euxenite. From this it seems that the brown euxenites have lower specific gravities than the black euxenites. This is an accordance with observations by van Wambeke (1970), which show a colour-change from black to brown and correspond-ing lowering of specific gravity with increasing alternation. He believes the main reason for this to be leaching of the 'A-ions' (rare earths, Ca, U, Th) and to a smaller degree replacement of O by OH or H_2O. If this is so for the Gloserheia euxenites, why is uranium in some leached out (to form β-uranophane; see below) and in others concentrated (to form fourmarierite; see below)? The answer could be that small amounts of ions in both A and B positions (Nb, Ta, Ti, Fe^{3+} ...) are leached out, and B-ions somewhat more than A-ions. By this mechanism there would be A-ions present to form β-uranophane, and, as alteration proceeds, the residue will enriched in A-ions to form fourmarierite. This would, however, be contradictory to the leaching mechanism proposed by van Wambeke; any definite conclusion requires further study.

β-uranophane and uranophane
These two dimorphs of $CaH_2 (UO_2|SiO_4)_2 \cdot 5H_2O$ occur in intermediate zone III, closely associated with euxenite (more frequently the brown than the black variety), especially in areas with sericitization and pigmentation (red) of plagioclase. The semiquantitative XRF data for the brown and

Table 4. X-ray powder diffraction data for fourmarierite from Wölsendorf (Frondel 1958) and Gloserheia. The 5 strongest lines are listed for the Wölsendorf fourmarierite and compared with the Gloserheia pattern. X-ray powder patterns for hydrated lead diuranate (Frondel 1958) are also given (5 strongest lines). Intensities are visually estimated.

Fourmarierite Wölsendorf		Fourmarierite Gloserheia		Synthetic hydrated lead diuranate $PbU_2O_7 \cdot nH_2O$	
d (Å)	I	d (Å)	I	d (Å)	I
3.45	9	3.42	7	3.43	9
3.09	10	3.09	10	3.08	10
1.996	6	1.99	1	1.99	6
1.907	8	1.92	2	1.903	7
1.729	7	1.74	3	1.719	6

black euxenite do not confirm (nor deny) the assumption that ß-uranophane and uranophane are formed from elements leached out of euxenite.

X-ray powder data are given in Table 3 for β-uranophane from Joachimstal and for uranophane from Ruggles pegmatite (Frondel 1958) and for β-uranophane and uranophane from Gloserheia.

The X-ray powder patterns for both minerals from Gloserheia are very weak due to poor crystallinity.

Steinocher & Nováček (1939) point out the interesting fact that β-uranophane is transformed to uranophane when subjected to fine crushing. For this reason the identity of uranophane from Gloserheia is considered somewhat uncertain.

A semiquantitative mass spectrogram of β-uranophane (dense crystal aggregate in veinlet ca. 2 mm thick) gave Ca, U, and Si as major elements. Besides minor amounts of Pb and K, trace amounts of Al, P, Cl, Cr, Fe, As, Sr, rare earths, Ba, Sc, Ti, V, Mn, Ni, Cu, Zn, and W were found. Some of these elements could be attributed to inclusions of foreign mineral phases, although examination of the material subjected to analysis with a binocular microscope ($\times$ 60) showed no impurities on that scale.

Fourmarierite $8(UO_2(OH)_2) \cdot 2Pb(OH)_2 \cdot 4H_2O$

This mineral occurs exclusively in intermediate zone III, intimately associated with euxenite and constituting partial or complete pseudomorphs after this phase. The colours is deep orange red, which is typical for fourmarierite according to Frondel (1958). Other constituents of the peudomorphs are X-ray amorphous, glassy to waxy yellow-orange-red materials. X-ray powder data are shown in Table 4.

The weak diffraction pattern obtained for the Gloserheia material fits the pattern for the Wölsendorf-fourmarierite as well as that for the hydrated lead diuranate. Frondel (1958) has pointed out the possible existence of a

Table 5. X-ray powder diffraction data for kasolite from Shinkolobwe (strongest lines) and from Gloserheia. Intensities are visually estimated for the Gloserheia kasolite.

Kasolite Shinkolobwe		Kasolite Gloserheia	
d (Å)	I	d (Å)	I
6.61	6	–	–
5.31	4	–	–
4.76	2	4.7	4
4.19	8	4.21	5
3.53	7	3.53	6
3.26	10	3.25	6
3.07	5	3.06	8
2.93	9	2.92	10
2.18	3	2.17	3
1.962	5	1.96	3
1.876	2	1.88	1
1.741	4	–	–
1.677	5	–	–

solid solution series between fourmarierite and hydrated lead diuranate, and the Gloserheia mineral might well be somewhere within such a series. The identity of the Gloserheia material is therefore somewhat uncertain also because the chemical composition is not known.

Fourmarierite is known to occur as pseudomorphs only after uraninite, so in the case of the Gloserheia material the occurrence as pseudomorphs after euxenite is unusual. Its mode of formation might be as that mentioned under euxenite.

Kasolite ($Pb_2(UO_2|SiO_4)_2 \cdot 2H_2O$)

This mineral was found in intermediate zone III in one specimen only. It occurs as an earthy pesudomorph, most probably after euxenite. The colour is light lemon yellow. A semiquantitative optical spectrogram revealed Pb and Si as main elements (the instrument arrangement allowed no U-detection). Minor to trace elements included Al, Mg, Fe, Mn, rare earths, Th and with some doubt Ta and As. The occurrence of some of the minor to trace elements could possibly be due to impurities.

X-ray powder data are given in Table 5 for kasolite from Shinkolobwe, Katanga (Frondel 1958) and from Gloserheia. The Gloserheia material gave a very weak film, considered to be the reason for the absence of many lines.

According to Frondel (1958), kasolite is formed by silica-bearing solutions acting on earlier formed secondary uranium minerals. This can well have been the way the Gloserheia kasolite was formed.

REFERENCES

Andersen, O. 1926: Feltspat I. *Norg Geol. Unders., 128 a.*

Andersen, O. 1931: Feltspat II. *Norg. Geol. Unders., 128 b.*

Arnott, R. J. 1950: X-ray diffraction data on some radioactive oxide minerals. *Am. Mineral. 35.*

Bugge, J. A. W. 1943: Geological and petrographical investigations in the Kongsberg-Bamble formation. *Norg. Geol. Unders. 160.*

Cameron, E. N., Jahns, R. H., McNair, A. H. & Page, L. R. 1949: Internal structure of granite pegmatites. *Econ. Geol. Monogr. 2.*

Carmichael, D M. 1969: On the mechanism of prograde metamorphic reactions in quartz-bearing pelitic rocks. *Contr. Mineral. Petrol. 20.*

Eugster, H. P. 1970: Thermal and ionic equilibria among muscovite, K-feldspar, and alumosilicate assemblages. *Fortschr. Miner. 47, 1.*

Frondel, C. 1958: Systematic mineralogy of uranium and thorium. *Geol. Survey Bull. 1064.*

Frondel, C. 1962: *Dana's System of Mineralogy.* 7th ed., Vol. III. John Wiley & Sons, Inc.

Komkov, A. I. 1960: *In Powder Diffraction File, Joint Committee on Powder Diffraction standards.* Philadelphia 1972.

Korzhinskij, D. S. 1970: *Theory of Metasomatic Zoning.* Clarendon Press, Oxford.

Steinocher, V. & Nováček, R. 1939: On β-uranotil. *Am. Mineral. 24.*

Wambeke, L. van 1970: The alteration processes of the complex titano-niobo-tantalates and their consequences. *N. Jb. Miner. Abh. 112, 2.*

Åmli, R. 1975: Mineralogy and Rare Earth Geochemistry of Apatite and Xenotime from the Gloserheia Granite Pegmatite, Froland, Southern Norway. *Amer. Mineral. 60.*