Leucogranites in the Pre-Cambrian of Bornholm, Denmark

Leukograniter i Bornholms grundfjæld
(Dansk resumé)

by

Harry Ingvar Micheelsen

Abstract

The Bornholm leucogranites mostly occur as small patches and streaks with diffuse borders, forming the leucocratic, neogene part of migmatites. The undisturbed host rock structures show that leucogranites were formed by replacement. They often occur in flexures and in fields of converging foliation i. e. where stretching of the host rock locally produced pinches in the foliation pattern. Leucogranites and their host rocks are compared with regard to the composition of plagioclase and to the barium content of microcline. It is concluded that the major part of the materials of the leucogranites was derived from the host rocks.

Geology of the Pre-Cambrian Rocks of Bornholm

The island of Bornholm is situated in the Baltic Sea and is part of the border zone of the Fennoscandian shield.

The petrography of the Bornholm rocks has been described by K. Callisen (1934). The geology of the Pre-Cambrian rocks is described in Danish, with a summary in English, in this volume (Micheelsen, 1961, geological map on p. 310). A short summary here will therefore be sufficient to give the geological background of the Bornholm leucogranites.

The earliest rocks which have been recognized in the Pre-Cambrian of Bornholm are metasedimentary inclusions. The sediments were transformed to hypersthene granodiorite at granulite facies conditions during the Rønne stage. Most of the rocks are gneissose: they are unbanded rocks possessing foliation and lineation due to the preferred orientation of individual biotite grains. The gneissose features probably originated during the Rønne stage.

The Bornholm rocks were later influenced to a varying degree by the amphibolite facies "Hammer granitization". This granitization was accompanied by the formation of leucogranite, folds, flexures, and boudinage structures.

Leucogranite occurs mostly in small bodies of irregular shape, forming the leucocratic part of the gneisses in the places were they are migmatitic.

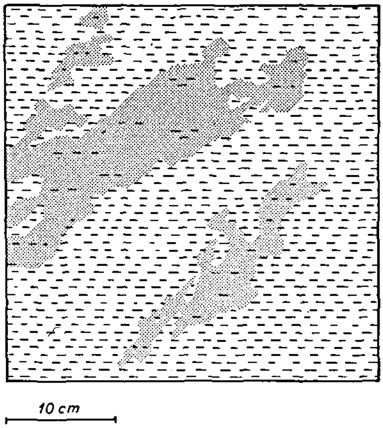

Fig. 1. Leucogranites (dotted) formed in undeformed Paradisbakke migmatite. The foliation is indicated by dashes. Loc.: Lindsvej, Paradisbakkerne.

The leucogranite has more or less the same grain size as the surrounding rock and grades into aplite as well as to pegmatite. For shortness, the term leucogranite will be used for the individual bodies as well as for the rock type.

In the Paradisbakke migmatite, leucogranites are so common as to be the characteristic feature of this rock; they are also frequently found in the gneiss and in the gneissose parts of the Hammer granite. In the Rønne granodiorite, and in the Vang and Svaneke granites, a few veins of leucogranite are found. The leucogranites are generally easily detectable as they are lighter in colour than the host rock. The Hammer granite, however, is poor in dark minerals and leucogranites are found only with difficulty, as unfoliated patches in the very weakly foliated host rock.

The Bornholm pegmatites are post-kinematic and were formed during the last part of the Hammer granitization, often as a continuation of the formation of leucogranites. Aplites seem to have been formed during the granitization, frequently by replacement of mylonites.

The Svaneke granite, in the eastern part of the island, was formed by replacement at a later period.

Structural Relations between Leucogranites and Host Rocks

Leucogranites mostly occur as diffusely bounded, unzoned, irregular streaks, patches, and veinlets, supply channels to which have not been seen. They range in size from ca. $1 \times 10 \times 10$ to $20 \times 100 \times 100$ cm., but occasional larger bodies or dykes are found.

The structural relations to the host rock often provide information concerning the mode of formation of the leucogranites and have been used below as the basis of a classification, although the divisions thus established grade into one another.

Leucogranites in host rocks with undisturbed, parallel foliation

Many small streaks of leucogranite are situated in host rocks with plane, parallel foliation—fig. 1. The leucogranites cut the foliation without distorting it, and relic patches of dark minerals within the leucogranites are parallel to the foliation in the host rock. The random orientation of a few new-formed biotite porphyroblasts proves that the foliation is older than the leucogranites. Consequently, the leucogranites are considered to have been formed from the pre-existing rock by replacement. Due to the diffuse borders, the relic foliation, and relic, zoned grains of feldspar, the formation of the leucogranites is considered to have taken place on all grain boundaries within a wide border zone, by a dispersed replacement.

Small leucogranite bodies of the above type are numerous in the Paradisbakke migmatite and the gneiss, and the larger bodies and dykes of leucogranite all seem to belong to this type.

In the eastern part of Bornholm, irregularly shaped leucogranites are frequently deformed by flexures, the intense folding and flexuring of the rocks evidently occurring after the formation of the leucogranites. The leucogranites were deformed into long, narrow streaks, arranged in parallel bundles which are a characteristic feature of the Paradisbakke migmatite. The leucogranites deformed by flexures are fully recrystallized, with the quartz showing undulatory extinction to only a slight degree.

Some leucogranites are accompanied by basic fronts, in which biotite and hornblende occur in larger amounts and in bigger grains than is usual in the host rock. It appears that part of the material of the dark minerals was re-deposited in the wall rock, the orientation of the new crystals being controlled by the undisturbed foliation which has consequently become very distinct. In addition, the amount of hornblende relative to that of biotite is larger in the basic front than in the host rock. The leucogranites contain less calcium and more potassium than the host rock. The relative increase of hornblende in the basic front may therefore be due to a surplus of calcium and lack of potassium, resulting in the formation of hornblende at the expense of biotite. These basic fronts are of type 1, as described by P. H. Reitan (1960).

Leucogranites in flexures

The foliation of the gneissic rocks of Bornholm often shows flexural patterns in which leucogranite patches can be found, figs. 2 and 3. The pattern of the foliation is not disturbed by the irregularly shaped leucogranites, and within the leucogranites small relic patches of dark minerals are orientated in accordance with the flexure. The leucogranites were therefore apparently formed by post-kinematic, dispersed replacement of the pre-existing rock, and the flexures have probably acted as centres for the replacement, which often continued outside the flexure.

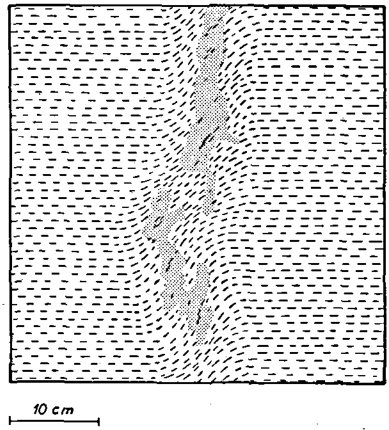

Fig. 2. Leucogranites formed in a flexure zone in Paradisbakke migmatite. Loc. Præstebo.

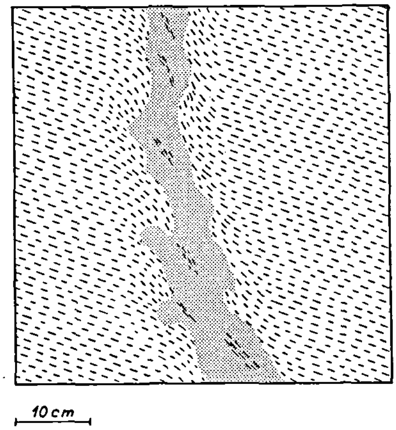

Fig. 3. Leucogranite formed in flexure zone in gneiss. Loc. Knarregård.

The flexures are sometimes so weakly developed that there is a transition to the type described previously, in which the leucogranites are not accompanied by distortion of the host rock foliation.

Leucogranites in fields of converging foliation

In the gneissic rocks of Bornholm, it is common to see the foliation locally showing a transverse convergence forming a structure which is hereafter termed "converging foliation", as shown in fig. 4 and diagrammatically in fig. 5.

Leucogranites in fields of converging foliation are generally oblong with their long axes more or less athwart the general trend of the foliation; some leucogranites of this type have a central core of pegmatite. The convergence of the foliation is usually developed to a different degree at opposite ends of the leucogranites. In many cases the convergence is very slight and the leucogranites have rather irregular shapes. In some cases the relatively slight convergence is due to the face of the exposure being nearly parallel to the foliation plane. The convergence seen on the foliation plane must be a convergence of the lineation, and these exposures therefore show that besides the constriction normal to the plane of foliation, a slight deformation took place within this plane. Other examples are transitional to the type of leucogranite which is not accompanied by deformation of the host rock foliation.

The converging pattern shows that the foliation was plastically deformed in the directions of the arrows in fig. 5, and a region of low pressure has therefore existed at the site of the leucogranite. Such a low pressure region in a plastically deformable rock was probably due to a stretching approximately parallel to the foliation.

The converging foliation around a leucogranite looks like boudinage

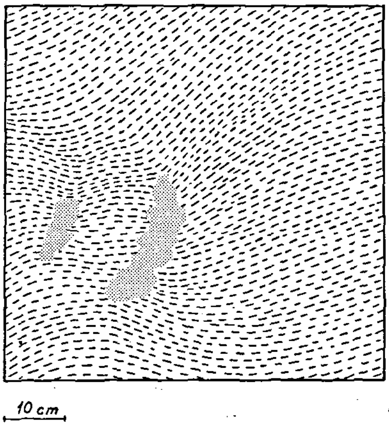

Fig. 4. Two leucogranites in fields of converging foliation in gneiss. Loc. Løkkegård.

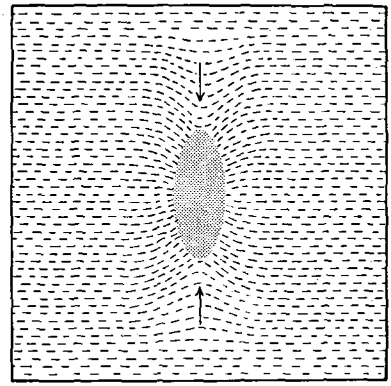

Fig. 5. Leucogranite in a field of converging foliation—principal sketch.

structure, as described by H. RAMBERG (1955), but they differ in the following respects:

1) The central part of the structure is occupied by leucogranite and not by a coarse-grained body.
2) The converging foliation is found in a completely homogenous rock, whereas true boudinage is confined to competent layers within incompetent rocks.
3) Converging foliation was formed, at least in the main part, by plastic deformation and in most cases there is no evidence of actual breaking of the host rock. True boudinage, however, is characterized by a rupture of the competent layer, and the corners of the boudins may or may not be deformed plastically.

The converging foliation is therefore less analogous to boudinage than to the pinch-and-swell structures formed experimentally by H. RAMBERG (1955), (but not analogous to the pinch-and-swell structures formed by pegmatites (MICHEELSEN, 1960)). H. RAMBERG (1955) and K. COE (1959) have shown that boudins change from rectangular to lensoid shapes as the difference in competency between the competent and the incompetent layers decreases. The converging foliation thus seems to be a further development of this in a milieu of complete homogeneity with regard to the competency.

According to the above interpretation, leucogranites of this type have not grown during dilation in an opening but by dispersed replacement in fields of low pressure, i.e. synkinematically. The interpretation is supported by the fact that there is a gradual transition from this type of occurrence of leucogranite, to the type which is not accompanied by deformation of the host rock foliation.

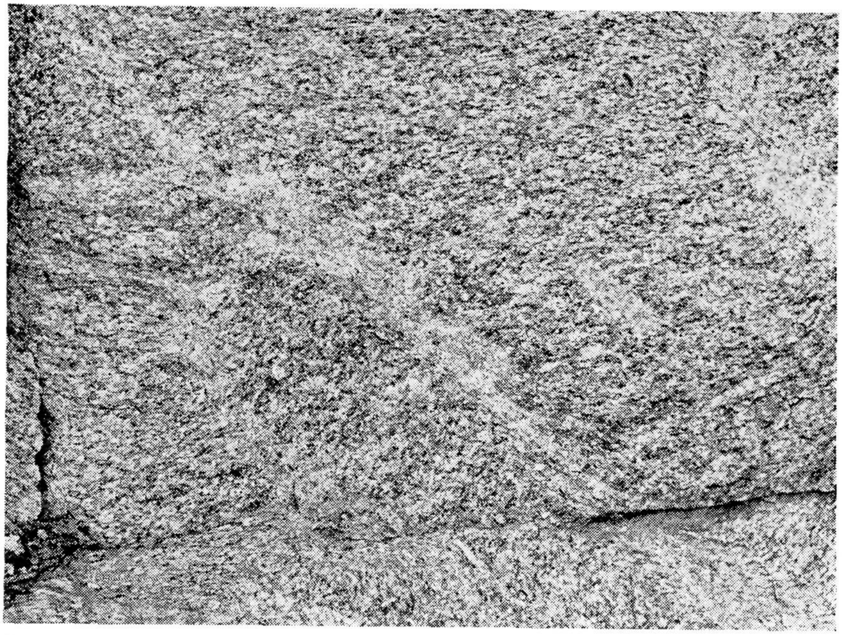

Fig. 6. Gneiss with leucogranites. Length of picture ca. 1 m. The central leucogranite was formed in a flexure. To the right and halfway to the left smaller leucogranites are found in fields of converging foliation. The little leucogranite halfway to the right is not accompanied by distortion of the host rock foliation. Loc. Knarregård.

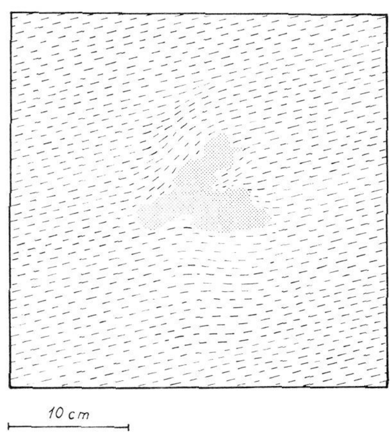

Fig. 7. Leucogranite at one end of a boudin in Paradisbakke migmatite. Loc. Lindsvej, Paradisbakkerne.

In only one case, in the Paradisbakke migmatite, was it observed that a leucogranite was formed at the end of a boudin—fig. 7.

Leucogranites accompanied by conformably deformed foliation and basic fronts

Some leucogranites in the Paradisbakke migmatite are found together with conformably deformed foliation and basic fronts. These features, which are characteristic of many of the Bornholm pegmatites, have been described by the writer (MICHEELSEN, 1960) and interpreted as being the result of selective resorption of the wall rock. Selective resorption is a process by which leucocratic minerals, particularly microcline, are dissolved and mafic minerals are pushed aside by growth of the pegmatite, forming a basic front and deforming the foliation of the host rock conformably with the pegmatite walls.

These features are only slightly developed in connection with the leucogranites, and although selective resorption took place, it is probable that dispersed replacement was the more important process.

Mineralogy of the Leucogranites

The leucogranites of Bornholm consist of microcline-perthite, quartz, oligoclase and small amounts (less than 5 %) of mafic minerals and fluorite. All the minerals are xenomorphic and quartz occasionally forms myrmekitic intergrowths with both types of feldspar.

The microcline-perthite, which constitutes 45–60 % of the leucogranite, has $2V_x = 75°–83°$, corresponding to an albite content of ca. 25–45 % (W. E. TRÖGER, 1956).

The barium content of the microcline-perthite of the leucogranite is a little below that of the host rock microcline, as shown by table 1. From pegmatite studies it is known that the barium content of the microcline introduced by the Hammer granitization amounts to 50 ppm (H. MICHEELSEN, 1960). Furthermore it is shown that the higher barium contents of the potassium feldspars of the granites are due to the potassium feldspars of the original granulite facies rocks, possessing a barium content of 7000 ppm (H. MICHEELSEN, 1961). The potassium feldspars of the granites are therefore mixtures of the granulite facies feldspars and of the microcline added during the Hammer granitization. The decrease in the concentration of barium affords a method of estimating the relative amount of barium-poor feldspar which was added, and hence the degree of granitization: according to table 1, a 30–70 % exchange of material took place in the Bornholm rocks. In the leucogranites, the barium concentration is higher than would be expected from consideration of the degree of the granitization with addition of barium-poor feldspar. The microcline added during the formation of the bodies of leucogranite, must have had a higher barium content than the microline introduced to the rocks by the

Table 1
Chemical composition of the feldspars in leucogranites and their host rocks

Host rock:	Ungranitized hypersthene granodiorite	Paradisbakke migmatite	Gneiss and Vang granite	Hammer granite	Material introduced by the Hammer granitization
Barium content in ppm of potassium feldspar from:					
Host rock	7500	2000–6000	2000–5000	2000–2500	50
Leucogranite		2000–5000	2000–5000	2000	
Anorthite content in mol % of plagioclase from:					
Host rock:					
Centres of host rock grains	39	26–29	23–28	14–18	8
Outer zone of host rock grains		20	14–20	8–12	2
Leucogranites		18–22	18–23	10–14	

The barium content has been determined semi-quantitatively with a relative accuracy of 25%; analyst Mr. IB SØRENSEN, cand. polyt. The anorthite content has been determined optically with an accuracy of ±2% anorthite.

granitization, and is therefore considered to have included barium-rich feldspar dissolved from the country rocks during the granitization.

Although the barium content of the leucogranite microcline indicates the ratio between the amounts of old and new materials present, it gives no indication of the extent to which materials of the rock replaced by the leucogranite, entered into the latter. The fact that some of the individual mineral grains of the replaced rock form part of the new rock, is shown by the relic dark microcline grains which are found in the leucogranite.

The leucogranite contains 30–40% quartz and 10–20% oligoclase. The oligoclase is in general normally zoned, but the zoning is much less pronounced than the oligoclase of the host rock. The anorthite content of the leucogranite oligoclase is equal to that of the outer zone of the host rock oligoclase. The zoning of the host rock feldspars happened during the Hammer granitization (H. MICHEELSEN, 1961). The leucogranites are therefore considered to have been formed at that period.

In the leucogranite, large, 2–8 mm, dark grains of plagioclase are occasionally found. They are considered to be relics from the host rock, as they have ca. 30% anorthite, are strongly zoned, and have corroded outlines, fig. 8.

The mafic minerals of the leucogranites are the same as those of the host rocks; they are in order of importance: biotite, titano-magnetite, hornblende, and sphene. Due to the diffuse borders of leucogranites, the

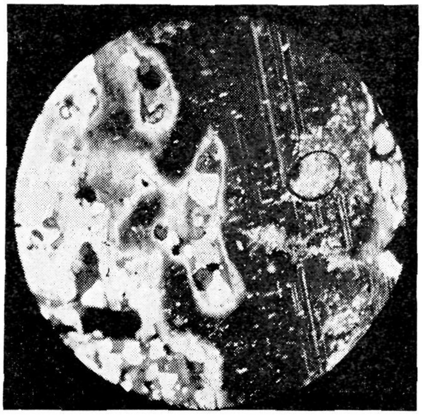

Fig. 8. Leucogranite from Paradisbakke migmatite. 2 + nic., 28 ×. The large, zoned grain of plagioclase is marginally corroded by fine-grained quartz and microcline. The plagioclase is a relic from the replaced host rock. Loc. Slamrebjerg.

concentration of dark minerals is greatest near the margins and in very small bodies (up to ca. 5 %). In large bodies the concentration of mafics is $^1/_2$–1 %. Most of the dark mineral grains, especially those near the borders, are relics from the host rock. Occasional large, 2–10 mm., new-formed porphyroblasts are found within the leucogranites; these porphyroblasts are of biotite and are often pseudomorphs after hornblende; they are frequently more or less altered to chlorite.

The structures show that the leucogranites were formed by a dispersed replacement. The grain size of the leucogranites is therefore assumed to be a relic structure from the host rock.

Conclusion

The structural relations between the leucogranites and their host rocks, show that a large majority of the leucogranites were formed by dispersed replacement. The barium content of the microcline in the leucogranites indicates that about $^3/_4$ of the leucogranite material was derived from the country rock during the replacement. Not all of it comes necessarily from the rock replaced by the leucogranite, and it probably includes some material from the surrounding country rock dissolved during the granitization.

The relation between the composition of the plagioclase of the leucogranites and that of the host rocks is considered to be good evidence in favour of the supposition that the leucogranites were formed during the Hammer granitization. The structural relations between leucogranites and flexures and tension structures in the host rocks, show that the leucogranites are pre-, syn-, and post-kinematic. Therefore the deformation of the Bornholm Pre-Cambrian took place during the period of Hammer-granitization.

Many of the leucogranites started to form in flexures and in fields of converging foliation, but replacement frequently extended beyond these structures. The formation of leucogranites thus seems to be favoured in zones of tension and low pressure, but the replacement outside the deformation structures shows that the leucogranites were more stable than the undeformed, and usually granitic host rock; the stable end product of the Hammer granitization was therefore leucogranite and not granite. This is valid for the Hammer granitization only: pegmatites formed during the Hammer granitization were replaced by the younger, post-kinematic Svaneke-granite. The stable end product of the Svaneke granitization was therefore granite and not leucogranite (H. MICHEELSEN, 1961).

The abundance of leucogranite in the Bornholm Pre-Cambrian—up to 25 % of the Paradisbakke migmatite—implies that leucogranite formation is an essential part of the Hammer granitization.

Acknowledgements

The author is very grateful to Mr. IB SØRENSEN, cand. polyt., for carrying out a large number of spectrographic analyses. Many thanks are also due to Mr. A. BERTHELSEN, mag. scient., Mr. H. SØRENSEN, mag. scient., and Mr. J. WATTERSON, B. Sc., for kind and critical reading of the manuscript.

RESUMÉ

På Bornholm findes leukogranit ofte som små, lyse, uregelmæssige legemer og slirer med diffuse grænser. I Paradisbakke-migmatiten er de så hyppige, at de er karakteristiske for denne bjergart. De er også almindelige i gnejsen og i Hammer-granitens gnejsoide dele.

De leukogranitiske legemer må være dannet ved replacering, da deres uregelmæssige grænser overskærer værtsbjergartens foliation uden at forstyrre denne. Leukograniterne er ofte dannet, hvor foliationen forløber plant; i andre tilfælde findes de i flexurer og i bjergartspartier med konvergent foliation, d.v.s. hvor der lokalt er sket en indsnævring som følge af forlængelse på grund af træk parallelt med foliationen.

Leukograniterne består af mikroklinperthit, kvarts og plagioklas. Mineralernes mængdeforhold, mikroklinens indhold af barium og plagioklasens anorthitindhold viser, at leukograniterne er dannet som et led i Hammer-granitiseringen, og at det meste af deres mineraler er taget fra værtsbjergarten. Strukturerne viser, at leukograniter er dannet både før, under og efter de tektoniske deformationer.

REFERENCES

CALLISEN, K. (1934): Beiträge zur Kenntnis des Granitgrundgebirges von Bornholm. Danmarks Geol. Undersøgelse. II række, nr. 50.

COE, K. (1959): Boudinage structure in West Cork, Ireland. Geol. Mag. Vol. 96, p 191–200.

MICHEELSEN, H. (1960): Pegmatites in the Pre-Cambrian of Bornholm, Denmark. Report from the International Geological Congress, XXI Session, Norden 1960, Part XVII, p. 128–136.

— (1961): Bornholms grundfjæld. The Pre-Cambrian of Bornholm, Denmark. Medd. Dansk Geol. Forening. Bd. 14, Hefte 4, p. 308–349.

RAMBERG, H. (1956): Natural and Experimental Boudinage and Pinch-and-Swell Structures. *Journ. of Geol. Vol. 63, No. 6, p. 512–526.*
REITAN, P. H. (1960): The Genetic Significance of Two Kinds of Basified Zones Near Small Pegmatite Veins. Report from the International Geological Congress, XXI Session, Norden 1960, Part XVII, p. 102–108.
TRÖGER, W. E. (1956): Optische Bestimmung der gesteinsbildenden Minerale. Teil 1. Stuttgart.

Færdig fra trykkeriet den 30. januar 1961.