THE GRANITIC ROCKS OF FARSUND, SOUTH NORWAY

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The farsundite is a composite granitic body that crops out over an area of some 420 sq. km. in southern Norway. On a local scale the contact between the farsundite and the surrounding country rocks is often discordant; but when observed on a regional scale a broad structural conformity emerges. Three main facies are found within the farsundite body and the mineralogy and chemistry of these units is discussed. The farsundite is regarded as part of the Rogaland anorthosite province. It was emplaced as a magma that was augmented in volume by the incorporation of granitic gneiss. The charnockitic part of the farsundite body is believed to have crystallized under granulite facies conditions at a time when the main mass of rocks of the Rogaland anorthosite province was cooling down.

INTRODUCTION

The present study is a reappraisal of the granitic rocks described as farsundite by Barth (*in* Holtedahl 1960, pp. 41-44). These rocks crop out over an area of approximately 420 sq.km. in south western Vest-Agder, the southern-most county in Norway. Most of the farsundite crops out on a series of peninsulas and islands that are separated from one another by an intricate pattern of fjords. The highest point in the area is at Klåskniben (504 m.) which is 3.5 km east of Drange. The landscape is generally rugged, and it shows considerable evidence of ice sculpturing. Small areas of alluvial flatland are found at the heads of many of the fjords. The Lista coastal plain in the extreme south west of the area is the only extensive (35 sq.km.) plain. During the present study it was discovered that the farsundite lies to the north of the Lister plain. This simplifies the geomorphology of the area as the plain is now seen to have been cut into rocks that were less resistant to the processes of denudation than the farsundite that forms the hills to the north of the plain. The Lister plains is extensively covered by till and farsundite erratics; and it is these erratics that give the superfical impression that the farsundite extends further south than it in fact does. Barth (1939) has written a summary of the geomorphology of the area, while Andersen (1960) has made a more detailed study of the impact of glaciation on the landforms at present found in the area. The end moraine of the Lista glacial substage is the oldest in southern Norway (14,000 years b.p.) and at the present time it forms a submarine ridge that runs parallel to the coast south of the farsundite body, and it only emerges from the sea to form a series of low hills along the south western end of the Lista peninsula. The Spangereid substage end moraine runs right across

Fig. 1. M-type farsundite above Log (8 km. north of Farsund), looking southwest toward Framvaren.

the farsundite body and forms thresholds in both Snigsfjord and Lyngdalsfjord and it blocks the southern end of Lenefjord.

The farsundite is regarded as part of the Precambrian Fennoscandian Shield. Its age and that of one of the pegmatites (Rymteland) associated with it has been determined, but as the significance of these age determinations is still being debated (Neumann 1960, Broch 1964), it would seem prudent at this stage in the debate, to state that the farsundite was probably emplaced, or recrystallized, during the 'Sveconorwegian Regeneration Period' of approximately 900 m.y. before the present.

THE TERM FARSUNDITE

Kolderup (1896, pp. 112-119) produced the first significant paper on the granitic rocks of the Farsund area. His map shows the granitic rocks to the west of Farsund to be adamellites (or hypersthene adamellites, p. 117), and those to the east, banatites. Kolderup (1896, pp. 6-10) also includes a clear summary of all earlier geological work undertaken in the Farsund and Rogaland districts. In 1903 (p. 110) he changed the name of his adamellite from the Farsund district to 'Farsundit'. Later (1935, map facing page 294) he dropped the term farsundite and described the granitic rocks to the west of Farsund as birkremites and those to the east (his earlier banatites) as hornblende granities. Vogt (1924, pp. 61-62) was the first to give the term farsundite a clear definition. He described farsundites as hypersthene-hornblende granites in which plagioclase was more abundant than potassium feldspar. Barth (1935, p. 301), however, believed that the granitic rocks that crop out both to the east and west of Farsund belonged to a single structural unit, and he proposed that the term farsundite should be used to describe all the biotite and hornblende bearing quartz monzonites of the Farsund area. In 1939 Major studied the granitic rocks to the east of Farsund and he called these rocks quartz monzonites. Adamson (1942, p. 100) described the geology of the island of Hitterö and he called the rocks that form the western extremity of the Farsund complex charnockites. The term farsundite was once again used and redefined by Hödal (1945 pp. 137-141). She believes that there is a significant different between the granitic rocks of her 'anorhosite kindred' (the birkremites, charnokites, farsundites, and enderbites) and the normal granitic rocks (the alkaligranites, granites, granodiorites, and quartz diorites). Farsundite is defined as a rock of the anorthosite kindred containing between 25.5% and 65.5% quartz and in which between 50% and 87.5% of the contained felspar is plagioclase. As will be shown later the mean modal composition of farsundite from the type area does not fall within the limits set by this definition. In his 1945 map, Barth called the granitic rocks east of Farsund farsundites, and those to the west, birkremites. It is interesting from a historical point of view to note that Holland (1900, p. 135), the man who introduced the term charnockite, mentions reading a description of the hypersthene-bearing granites of south Norway and he states that the discription applies'. . . .exactly to the rock which is known to us in south India as charnockite'.

From the preceding discussion it is evident that (1) the term farsundite was poorly defined when first used, (2) it had been used to describe the whole Farsund granitic body, and both the eastern and western parts of this body, and (3) the term has been applied to rocks that differ significantly in mineralogy from these of the type area. After considering these facts is is recommended that the term farsundite should not be used as a general term for hypersthene-bearing adamellites, but should be employed as a local specific name for the granitic rocks of the Farsund area.

THE SHAPE OF THE FARSUNDITE BODY

The contact between the farsundite and the surrounding country rocks varies from sharp to gradational, and the gradational contacts may form agmatic or migmatitic border zones. The farsundite amphibolite contact in the road-cutting on the north-western side of Framvaren (11 km. NNE. of Vanse) is a good example of a sharp contact that dips inwards towards the centre of the farsundite mass. Such inward dipping contacts are characteristic of most of the farsundite body, but they are perhaps most typical of the southern perimeter of the farsundite. Examples of border areas where the farsundite plays an active, or igneous, rôle in the formation of migmatites, can be observed in the Askeland (9 km. S. of Lyngdal) area, and even along the eastern shore of Rostadvatnet in the north east in an area some 1.5 km. from the main farsundite mass.

Detailed study generally reveals a discordant relationship between the farsundite and the country rocks; however, there is, in many areas (for example the south and west) a broad overall structural conformity. This conformity is well illustrated by the contact north of Vanse. The manner in which this contact moves north eastwards up the valleys and south westwards around the hills clearly shows that the contact dips inwards towards the centre of the farsundite body. The evidence elicited from the study of the contacts between the farsundite and the rocks that envelop it, indicates that the farsundite has the overall form of a broad, irregular, inverted cone. A study of the orientation of the planes of foliation within the farsundite (see Fig. 2) supports this interpretation of the geometry of the farsundite body. The shape of the farsundite is believed to be essentially similar to that portrayed by Barth (*in* Holtedahl 1960, p. 62).

The shape of the farsundite outcrop as it appears in plan consists of an irregular elliptical mass that is elongated in an east-west direction. This shape is, however, distorted from a regular elliptical form by five protruberances or limbs. For descriptive convenience the northern limbs have been designated, from west to east, the Andabelö, Drangsland and Kleivan limbs, while the southern limbs have been called, from west to east, the Skarstein and Hesteland limb.

As in southern Rogaland (Michot 1948 and 1960) the country rocks surrounding the farsundite appear to have been deformed by at least two major tectonic phases. Falkum (1966, p. 19) in his study of the area to the north of the farsundite body recognized '.... four phases of folding, or possibly five'. The relatively plastic manner in which the rocks responded to this polyphase deformation indicates that the folding took place in a catazonal environment. The manner in which the farsundite, and in particular the Drangsland and Kleivan limbs, cut these structures indicates that at least part of the farsundite was emplaced after the main deformational phase. Detailed mapping frequently reveals a significant relationship between the structure of the country rocks and the nature of the farsundite contact. In the Lodshavn area (3,5 km. south of Farsund), for example, the country rocks are intricately contorted, and in this area the farsundite contact is sinuous; but in the Einarneset area, some two kilometers west of Lodshavn the gneisses and meta-supracrustal rocks have regular strikes and dips, and the boundary between the farsundite and country rocks is regular. It is evident from the

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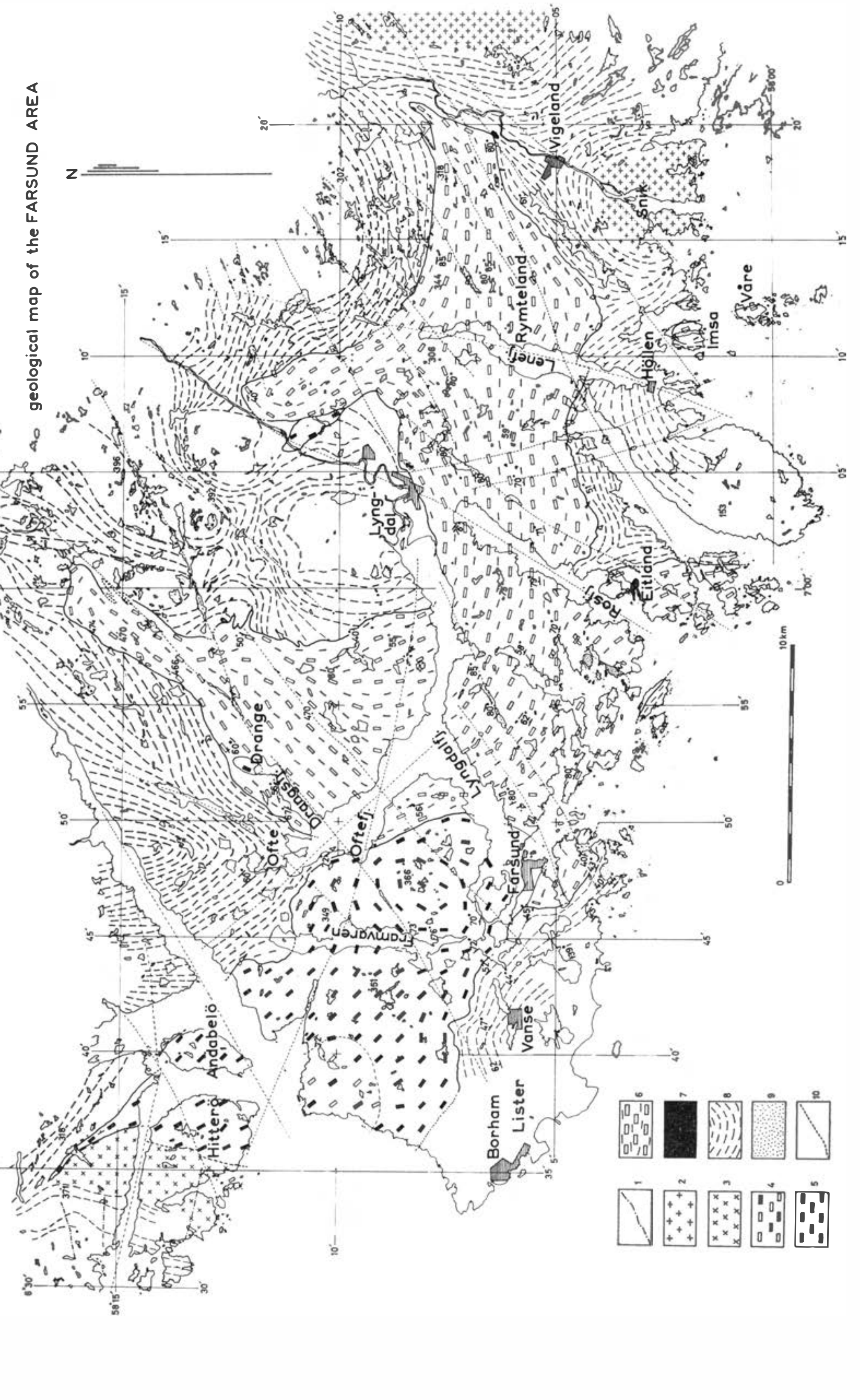
Fig. 2. Geological Map of the Farsund Area.
1=Dolerite; 2=Granite (Holum and Snig);
3=Anorthosite; 4=B-type farsundite;
5=M-type farsundite; 6=L-type farsundite;
7=Mafic bodies; 8=Mixed gneisses;
9=Large xenoliths and enclaves; and 10=Major fracture traces and faults.


geological map of the FARSUND AREA
N
10 km
Hitterö
Andabelö
Borham
Lister
Vanse
Framvaren
Farsund
Ortefj.
Ofte
Drangsfj.
Drange
Lyngdalsfj.
Lyng-dal
Rosfj.
Eitland
Lenefj.
Rymteland
Höllen
Imsa
Våre
Snik
Vigeland

manner in which the farsundite has been accomodated by the structure of the country rocks that it was emplaced by permissive intrusion into country rocks that were in most localities plastic enough to be thrust aside by the intruding magma. The overall complex shape of the farsundite body, however, is believed to have resulted from it being emplaced into country rocks that had undergone polyphase deformation and the form of the farsundite has to a considerable extent been moulded by the structure of these deformed rocks.

The outcrops of the farsundite and the rocks of the Rogaland Anorthosite Province do not reveal any cross-cutting relationship, but rather the reverse, in that both units fit compatibly into the same structural mosaic.

FACIES WITHIN THE FARSUNDITE

In the field the farsundite can be divided on a basis of colour (or more particularly felspar colour) into dark and light facies (see Fig. 1). Most of the farsundite east of Farsund is light in colour and foliated (leucofelspathic or L-type farsundite) while the main body of the dark farsundite crops out in Farsund and north and west of this town (melanofelspathic or M-type farsundite). In detail the picture is more complex, and a body of farsundite that is light coloured and frequently contains fine grained material crops out along the western border of the M-type farsundite in the Heskestad area (12 km. NW of Farsund) and smaller pods of dark farsundite crop out at Kvelland (3.5 km. NNE of Lyngdal), in the border zone of the farsundite south of Lyngdal, and also west of Drange (12 km. NNE of Farsund). The western border (or B-type farsundite) appears to consist of an intermixed mass of farsundite and microgranite. The microgranite cuts the farsundite and it is believed that the microgranite reactivated and locally mobilized the older farsundite and the commingling of these two types produced the B-type farsundite found today. As the B-type farsundite is predominantly leucofelspathic, it ssems likely that it was generated after the process that created the dark feldspars in the M-type farsundite had ceased to operate.

In hand specimen, the M-type farsundite looks like the dark olive brown acid material from the charnockite series of Madras (Holland 1900, p. 135, and Howie 1956, p. 727). When fresh the dark farsundite is so dark that the ferromagnesian minerals cannot be distinguished in hand specimen, yet when the surface is weathered and bleached, as it so often is along sea and lake shores, it looks remarkably like the L-type farsundite. The L-type farsundite has a speckled appearance and contains greenish black mafic minerals set in a framework of light brownish grey felspars and vitreous very light grey quartz. The mafic minerals tend to form clusters and stringers and it is the stringers and irregular bands of mafic minerals that give the L-type farsundite a foliated appearance.

The B-type farsundite is not unique in containing microgranite in that the whole farsundite body is cut by dykes, lenses, and stringers of aplite, red biotite granite and pegmatite. Most of these granitic bodies appear to fill, or heal, cooling fractures both actual or incipient within the farsundite. Their varying textures probably indicate diverse cooling histories. The aplites generally occur as narrow (5—60 cm.) dykes and veins that pinch and swell along strike. Most of them were emplaced parallel to the foliation in the farsundite, but some form sheets at right angles to the plane of foliation. The farsundite body also contains sheets of pseudo-aplites which have the superficial appearance of aplite but on closer inspection they are found to have a granulate texture; and they are thus regarded as being products of crushing, grinding and later recrystallization. The micrograntes and the red biotite granites generally have irregular dyke-like forms and they are particularly common in the south western part of the farsundite outcrop. A study of the pink granite bodies, however, indicates that some of them at least are partly digested and mobilized granitic xenoliths. An example of such a granite body is to be seen in the new road cutting on the western shore of Lenefjord, where a small body of pink granite is surrounded by (and appears to intrude) farsundite, yet is itself cut by a tongue of farsundite. Small, irregular, pegmatitic stringers are ubiquitous throughout the farsundite, and some of them carry veins and clusters of pyrite.

Some 10 pegmatites have been mined on the island of Hitterö which is crossed by the western border of the farsundite body. These pegmatites, however, lie just outside of the farsundite and they were emplaced into anorthosites. Adamson (1942) has described these pegmatites and summarized the quite extensive literature that has grown up to describe the many unusual minerals that have been found in these pegmatites. In fact, the Hitterö pegmatites are the type localities for polycrase, xenotime, kainosite and blomstrandine.

Major pegmatites are also found at Rymteland (Römteland), Eitland, Eikjeland (Eikeland), Rudjord, and Egeland (Barth 1931). The Rymteland and Eitland pegmatites are complex zoned bodies that have in the past been worked. Sverdrup (1959) has published a detailed description of the Rymteland pegmatite. It has a well developed zonal structure; and besides the common rock forming elements it contains significant consentrations of Be, Y, Nb, Mo, La, Ce, Yb, Ta, Th, and U.

XENOLITHS AND ENCLAVES

The great number of xenoliths and enclaves (both roof pendants and floor pinnacles) found throughout the farsundite outcrop are believed to indicate that all parts of the farsundite body are relatively near at least one contact with the surrounding country rocks. Over a large area the nearest contact was either the floor or roof of the farsundite body; thus this supports the concept that the farsundite body is sheet-like when viewed in three dimensions. Both felsic and mafic xenoliths are found but mafic xenoliths are the most common even although granitic gneiss is the most abundant country rock.

This enigma can be solved if one was to postulate that a large proportion of the granitic country rock that had become engulfed in the farsundite was incorporated into the farsundite magma. Barth (1935, p. 288), has described some most interesting armoured amphibolite xenoliths from the Hesteland limb of the farsundite. These xenoliths are rimmed by pyroxene and a plagioclase that is more sodic than that found in the amphibolite. The farsundite contains a number of large enclaves. One such enclave crops out on the shores of a small bay south west of Lyngsvåg, on the northern border of the Skarstein limb, and it consists of farsundite impregnated biotite schist, banded gneiss and garnet-rich gneiss.

Another interesting enclave is found at Eitland (10 km. SSW of Lyngdal). It is interpreted as a floor pinnacle consisting mainly of norite rimmed to the north by banded gneiss and farsundite migmatite. A large, complex, zoned pegmatite, that cuts both the norite and the farsundite crops out along the south eastern contact of the enclave. The refractory nature of the mafic material may account for the resistance of the enclave to the invading farsundite, while the pegmatite probably fills a fracture that developed with the cooling of the farsundite and the country rocks, and the dissimilar rates of contraction of the farsundite and the noritic body.

THE COUNTRY ROCKS

The country rocks into which the farsundite was emplaced consist mainly of mixed gneisses, migmatites, amphibolites and metasupracrustal rocks. A general description of the gneissic rocks of southern Norway is given by Barth & Reitan (1963). Falkum is at present making a detailer study of the main mass of these rocks that outcrop to the north of the farsundite body. He has recently (1966, p. 21) published a preliminary report on this work in which he divided the essentially gneissic rocks of the Flekkefjord area into 6 lithostratigraphic formations. A summary of the geology of the Egersund-Sokndal district to the west of the area mapped by Falkum has been published by Tobi (1965, pp. 208—217). Rocks of essentially the same type are found to the south of the farsundite, while the rocks to the east of this body have recently been described by Smithson & Barth (1967).

JOINTS AND FAULTS

A characteristic feature of the landscape, in areas of farsundite outcrops, is the occurrence of lineaments, or structurally controlled topographic lines. They take the form of an alignment of valleys, fjords and clefts through the farsundite hills. Some of these lineaments are undoubtedly faults, and like the fault, with a significant wrench component that traverses the length of Lenefjord, the fault zones may display slicken-sinding, be deeply weathered, and contain secondary products such as vein quartz, epidote, and hematite. The Lene fault is similar to most of the other postulated faults in the farsundite area in that for most of its length the fault plane is hidden beneath the waters of a fjord, valley alluvium or scree. The faults and joints commonly develop at right angles to, ar parallel to, the foliation in the farsundite. Some lineaments, however, commence outside the farsundite body and are related to the structure of the country rocks adjacent to, and one suspects beneath, the farsundite A significant feature of these joints and faults (which it must be remembered occur in Precambrian catazonal rocks) is the frequency with which they are found to be open. It is believed that they are open as a result of crustal stretching and the tension generated by epeirogenic movements related to the removal of the ice burden of Pleistocene times. This crustal stretching was probably responsible for some of the fractures that cut obliquely across the foliation in the farsundite.

SPECIFIC GRAVITY OF THE FARSUNDITE

The specific gravities (S.G. i.e. density of rock/density of water) of 46 samples collected from all over the farsundite outcrop were determined; and the arithmetic mean ($\bar{x}$) was found to be 2.765 (s=0.050). Of the specimens studied, 28 were of the L-type farsundite and they had a mean S.G. of 2.773 (s=0.037) and 14 belonged to the M-type and they had a mean S.G. of 2.735 (s=0.047) However, when the S.G.'s of all the specimens were plotted om a map, and isopleths were drawn showing $\bar{x}$, ($\bar{x}$ + s) and ($\bar{x}$ — s) the pattern that emerged showed that the isopleths did not coincide with, nor were they parallel to, the facies boundaries within the farsundite body. In brief, the map showed the farsundite to be most dense in the east and south, and least dense in the north-west, with a low density trough cutting the boundary between the M- and L-type farsundite in the area south of Ofte. The relatively high density of the farsundite at the eastern end of the outcrop is believed to be a partial explanation for the positive gravity anomaly reported by Smithson & Barth (1967, pp. 44-47) for this area, as they use a density of 2.17 g/cm^3 to make their Bouguer reduction and terrain corrections.

It is of interest to note that Kopf (1966 & 1967) has indicated that as granitic rocks (excluding syenites and aplites) increase in density there is a systematic increase in the plagioclase and femic minerals and a decrease in K(Na)-felspar and quartz (1967, p. 5. Fig. 2). He has used this relationship between the mineralogy and density of granitic rocks to classify them into 'density classes' (1966, p. 74). The farsundite falls into his density class 4-granodiorite in which the density ranges from 2.67-2.77g.cm^3. The density distribution pattern found within the farsundite body indicates that one should anticipate an increase in Si and K in the north-west of the body and also in the Ofte low density trough, and an increase in Ca, Mg and Fe in the south and east of the body. With regards to the bulk density of the farsundite body it is probably in excess of 2.765 g/cm^3 because it contains innumerable mafix xenoliths which were not taken into account when determining the mean density of the farsundite.

PETROGRAPHY

Field observations indicate that the farsundite is an inhomogeneous body. Not only does it contain the major facies, or sub-types, that have already been described, but it also contains innumerable xenoliths of diverse composition and sizes, and it is inhomogeneous on a local scale in that the distribution and abundance of mafic minerals frequently changes over relatively short distances. The farsundite often displays a streaky banding due to the uneven distribution of mafic minerals. This banding is typical of the L-type farsundite but appears to be less common and is more difficult to observe in fresh specimens of the dark M-type farsundite.

The texture of the farsundite varies from hypidiormorphic granular to gneissic or banded, and patches composed of myrmekitic or micrographic intergrowths are characteristic of many specimens, particularly those belonging to the M-type farsundite.

The mean modal composition (vol. %) and the standard deviations of the major constituent mineral species of 'typical' specimens of farsundite collected from all over the outcrop area (F), of the M-type farsundite from the main outcrop (M), and of the L-type farsundite (L), are all presented in Table 1. The B-type farsundite is similar to the L-type except that it carries more quartz. Perhaps the most significant feature of Table 1 is the presence of pyroxene in the M-type farsundite which can be regarded as a granulite facies charnockitic body. The smaller bodies of M-type material have a mineralogical composition that is similar to the main mass of M-type material.

As one proceeds from the M- into the L-type farsundite the felspars change

Table 1. *Mean modes*

n=	21		6		11	
	F	(s)	M	(s)	L	(s)
alkalic felspar*	41.6	(11.5)	50.0	(10.7)	39.0	(8.3)
quartz	23.1	(4.5)	21.6	(6.6)	22.9	(3.0)
plagioclase	22.7	(9.4)	19.4	(5.2)	24.6	(11.2)
hornblende	5.7	(4.2)	1.5	(0.9)	7.0	(3.2)
ore minerals	2.9	(1.5)	2.2	(0.9)	3.0	(1.2)
biotite	1.6	(1.9)			2.6	(1.8)
pyroxene	1.0	(1.7)	3.3	(1.6)		
chlorite group	0.7		1.6	(1.7)	0.1	
apatite	0.4		0.2		0.5	
zircon	0.1		Tr		0.1	
sphene	0.1				0.2	
sericite	0.1				Tr	
allanite	Tr				Tr	
epidote	Tr				Tr	
calcite	Tr		Tr		Tr	

*includes K-felspar, perthite and modal albite (An_0-An_{10}); after Peterson 1961, p. 32.
F=*Mean farsundite* M=*Mean M- type farsundite* L=*Mean L- type farsundite*

in colour from dark olive brown with a resinous lustre to light brownish or pinkish grey. The dominant alkalic felspar is microline microperthite, and the plagioclase is generally a basic oligoclase. The plagioclase varies in composition from An_{22}-An_{36} ($\bar{x}$ =An 28), with varieties more albitic than that being found in the pegmatites. The plagioclase is sometimes antiperthitic and contains irregular blebs of potash felspar.

The quartz grains are characteristically anhedral and in specimens of the M-type farsundite they are generally bluish grey and clouded with rod-like inclusions. The hornblende is generally strongly pleochroic in shades of green (α moderate yellowish green, β dark yellowish green, and γ deep olive green). In some specimens biotite appears to have formed after the hornblende. The ore minerals are mainly magnetite and ilmenite (plus leucoxene) and they occur in approximately equal amounts. Pyrite occurs sporadically and it is usually found associated with pegmatitic stringers. Orthopyroxene is the dominant pyroxene and it seems to be similar in appearance to the ferrohypersthene described by Howie (1964, pp. 397—301) from Hitterö. It sometimes contains lamellar intergrowths of clinopyroxene. A little clinopyroxene is also found in some specimens of the M-type farsundite. The chlorite found in the M-type is characteristically pennine. Apatite was found in all specimens studied, and it is interesting to record that some specimens carry over 2% of this mineral.

CHEMISTRY

The chemistry of the farsundite is summarized in Table 2, and it can be seen that many of these data could have been anticipated from the sections of specific gravity and petrography. When the chemical data on the farsundite are plotted on a map, the overall trend is an increase in Si, Al, and K in the north with a concomitant increase in Ti, Fe, Mg, and Ca in the south and east. The manner in which isopleths showing the relative concentrations of the different elements cut across the facies boundary between the M- and L-type farsundite is taken as an indication that the whole farsundite body is a valid, single rock unit with regards to major element chemistry. Table 2 reveals that when the L- and M-types of farsundite are compared the M-type tends to be relatively enriched in Si, Al, and K and depleted in Ti and Ca. The Fe contents of both types deviate significantly from their mean values. The higher proportion of Fe in the ferric state in the L-type farsundite is of considerable interest. If the mean chemical composition of the farsundite is compared with Turekian & Wedepohl's (1961, p. 186) high Ca-granite it is found to be significantly high in Ti and Fe, slightly high in K and P and slightly low in Al and Mg. The M-type farsundite was compared with Nockold's (1964, p. 1014) hypersthene-bearing adamellite and found to be high in FeO, Mn, and P and low in Mg and Na. A specimen of farsundite from the northern extremity of the Andabelö limb was found to differ more

Table 2. *Chemistry of the farsundite*

	F_1	M_1	L_1	F_2	(s)	M_2	(s)	L_2	(s)
n=	8	4	2	21		5		11	
SiO_2	66.93	67.36	64.36						
TiO_2	1.09	0.88	1.76	1.05	(0.43)	0.89	(0.31)	1.31	(0.18)
Al_2O_3	13.86	14.15	13.42						
Fe_2O_3	2.07	1.37	3.57	6.59*	(1.37)	6.75*	(1.09)	6.57*	(0.81)
FeO	3.84	4.26	3.89						
MnO	nd.	nd.	nd.	0.106		0.098		0.107	
MgO	0.75	0.55	1.38						
CaO	3.03	2.90	3.73	3.60	(0.87)	2.77	(0.55)	4.12	(0.62)
Na_2O	3.41	3.46	3.09	3.77	(0.09)	3.71	(0.04)	3.81	(0.09)
K_2O	4.15	4.23	3.71	3.85	(0.54)	3.98	(0.58)	3.71	(0.17)
H_2O	0.57	0.52	0.59						
P_2O_5	0.28	0.21	0.51						
	99.98	99.89	100.01						

*Total Fe as Fe_2O_3

F_1: Average of farsundite specimens from all over the outcrop area (after Barth *in* Holtedahl 1960, p. 43).

M_1: Average M-type farsundite (after Barth *in* Holtedahl 1960, p. 43).

L_1: Average L-type farsundite (after Barth *in* Holtedahl 1960, p. 43).

F_2: Average of 21 new partial analyses of specimens collected from all over the farsundite outcrop (Na and Mn by neutron activation, other elements x-ray fluorescence).

M_2: Average of 5 new partial analyses of M-type farsundite (anal. proc. as above).

L_2: Average of 11 new partial analyses of L-type farsundite (anal. proc. as above).

in chemical composition from the average farsundite (Table 2, F_2) than any of the other specimens studied. It was significantly enriched in K and was low in Ti, Fe, and Ca.

PETROGENESIS

The genesis of the farsundite appears to be linked to three major geological enigmas; (1) 'the granite controversy' (Read 1957), (2) 'the charnockite problem' (Pichamuthu 1953) and (3) the evolution of the rocks of the 'anorthosite kindred' (Hödal 1945). As more detailed descriptions of areas containing rocks of the 'anorthosite kindred' (or charnokite-anorthosite series, Rosenbusch 1910, p. 183; and Goldsmidt 1916) became available it is evident that large volumes of granitic rocks, particularly melanofelspathic, hypersthene-bearing granitic rocks, belong to this kindred. In 1924 Vogt (p. 53) drew attention to the large volumes of granitic rocks associated with the Rogaland anorthosite province. While Philpotts (1966, pp. 1-64), in his paper on the anorthosite mangerite association of southern Quebec, shows that large volumes of granitic rocks are characteristic of the anorthosite kindred as found in many parts of the world.

If one accepts the concept of the anorthosite kindred, then all meaningful discussions of the genesis of the granitic rocks belonging to the kindred must perforce include a discussion of the evolution of the other major rock units that belong to this kindred. Many different ideas on the genesis of these rocks have been proposed. This is, however, to be expected as rocks of the anorthosite kindred are characteristically Precambrian in age and products of a true plutonic environment; and in some areas these rocks have clearly been subjected to post-emplacement metamorphism and deformation.

Field studies have revealed that the farsundite was emplaced as a mobile, probably magmatic, body. This is probably also true of many of the other rock units belonging to the Rogaland anorthosite kindred. Accepting that magma played an active role in the genesis of these rocks, an attempt will now be made to construct a petrogenetic model capable of accounting for their significant charateristics. The characteristic textural, structural and petrographic features, and the mutual relationships that exist between the different units of the anorthosite kindred will not be described, as Berrangé (1965, pp. 617-642) and Philpotts (1966) have recently published such desciptions. It is instructive to note that Philpotts (1966, p. 4) belives that the '..problems associated with the origin of anorthosites are due largely to the lack of the surrounding more acid rocks and their relationship to the anorthosite'.

In the present model a gabbroic-dioritic magma is believed to have come to rest, or have been trapped in a crustal domain located between the relatively rigid upper crust and a more plastic lower layer. This magma may have formed with a gabbroic composition in the region of the Moho, but on rising through the crust by a mechanism assisted by zone melting (Dickson 1958) or solution stoping (Harris 1957), the composition may have changed with the preferential incorporation of elements derived from phases with low melting temperatures, and other elements, '..too large or too small, or differing too much in valency and bond type to replace the ions and minerals being deposited, and not sufficiently abundant for their own minerals phases to crystallize' (Harris 1957, p.200). Other factors that may have changed the composition of the magma during transit through the crust might include the quantities of volatile material incorporated and retained by the magma, structural factors that accelerate or retard the movement of the magma, and the physical and chemical nature of the country rocks encountered by the magma.

With continued crystallization the magma envelope would become filled, or partly filled, with a loose mush of crystals and melt. While the crystal-mush developed, the magma spread laterally and deformed the country rocks outside the envelope. This deformation would generate shock waves, particularly in the more rigid roof zone. These shock waves would agitate the magma and the shaking might result in the downward migration or sieving of mafic phases, complexes and perhaps even globules of immiscible ore magma (Gibbon & Tuttle 1967), through the interlocking crystal-mush. Volatiles carrying elements such as Si, Na, and K, which are highly soluble in water (Morey & Hesselgesser 1951), would also be expected to rise towards the top of the magma chamber when the magma was subjected to a swarm of shock waves. The upward surge of volatiles would result in a further stirring and agitation of the magma mush, thus also promoting the process of 'magma-mush-sieving'. This process might convert the upper layers of the crystal-mush into a three dimensional lattice-like structure consisting essentially of interlocking felspar crystals. The intermittent seismic activity might also produce changes in the rate of crystal nucleation and growth within the magma as suggested by Hoffer (1965 and 1966), and increase the density of the packing of the solid phases in the crystal-mush (Wager, Brown, and Wadsworth 1960).

The concept of magma envelopes of variable geometry is also believed to be of considerable importance in the evolution of plutonic complexes containing diverse consanguineous rock species. The internal geometry of an igneous complex may in many examples be related to the relative flexibility or inflexibility of the surrounding magma envelope, and this in turn is probably a function of emplacement depth in the crust. The banded complexes with regular internal layers are considered to have been emplaced in rigid or semi-rigid crustal environments, while the rocks of the Rogaland anorthosite province, for example, are considered to have been emplaced into a more plastic crustal environment where the shape of the magma envelope changed continually during the development of the rocks of the anorthosite kindred. With crystallization and the operation of magma-mush-sieving in a simple basin shaped magma envelope, a gabbroic-dioritic magma might produce a layered body with the following layered sequence from the base upwards : (1) a zone consisting of ore magma, ultramafic and mafic material, (2) an anorthosite zone, (3) a zone of relatively undifferentiated magma, and (4) a granitic layer at the top.

If this layered sequence was emplaced into a magma envelope that was continually changing in shape, with for example, the lateral and outward spread of the upper and late crystallizing magma fractions and the rise of the base of the magma envelope, this would frequently result in the formation of an igneous body containing consanguineous rock units that displayed complex contact relationships with one another. Local assimilation of country rocks, further differentiation, and complex changes in the geometry of the magma envelope are all factors considered capable of producing the wide variety of rock types and the interfolded geometry found in so many areas where rocks of the anorthosite kindred were emplaced at depth.

In the model just described one would expect large volumes of high density material to collect at the base of the complex; however, geophysical data indicate that such material does not occur in significant quantities beneath the Rogaland anorthosite kindred (Norges geografiske oppmåling 1961). It is suggested that these rocks were emplaced into a plastic catazonal environment and that much of the high density magma that collected, plunged through the plastic rocks at the base of the magma envelope and migrated down towards the mantle. If one accepts that granitic plutons or saltdomes can push their way up through the crust, then perhaps one should accept that bodies of high density can push their way down through less dense plastic crustal layers.

In the petrogenetic model of the evolution of the anorthosite kindred that has just been outlined granitic materal is believed to concentrate at the top of the magma chamber. With changes in the shape of the magma chamber, however, this granitic fraction may well have been decanted laterally and emplaced alongside the main crystallizing mass. This process of lateral decantation is believed to account for the position of the farsundite which at the present level of erosion crops out to the south of the main mass of Rogaland anorthosite kindred rocks. A characteristic feature of the farsundite is the large number of mafic xenoliths that it contains. As the country rock is predominantly granitic gneiss it is believed that large quantities of this granitic material now form part of the farsundite body. The process of incorporating felsic or granitic material probably began with the emplacement of the original gabbroic-dioritic magma. A magma of this composition would react with the granitic wall rocks and inclusions, incorporating granitic material into the magma and precipitating those phases with which the magma was saturated. During the crystallization of a body of rocks of the size of Rogaland anorthosite province, the incorporation of country rock material later in the reaction series than the phases crystallizing at any particular time, could greatly augment the amount of granitic differentiate that was finally produced. The volume of granitic material that was eventually to crystallize as farsundite was probably also augmented by a filter pressing mechanism that operated as the main magma envelope changed in geometry and lighter fractions were decanted laterally.

Chayes (1957 p. 58) in his discussion of the classification of granite states that the name granite '. . . could usefully be reserved for massive or weakly oriented rocks of colour index less than twenty, and containing not less than 20 per cent nor more than 40 per cent of quartz by volume'. As can be seen from Table I some specimens of farsundite contain less than 20 per cent quartz and not 'normal' granites. Over large areas the farsundite is also found to be contrary to the proviso that granite should be massive or weakly oriented. Quartz syenites and granites deficient in quartz are, however, characteristic of the quartz-bearing rock species found in the anorthosite kindred rocks from many areas. Strange to relate, anorthosite kindred rocks may also contain silexite, or bodies of pure, or nearly pure, silica of igneous or aqueo-igneous origin (Hödal 1945, p. 138). If these facts are considered in conjunction with the shattered appearence (Higgs 1954, p. 205) and low water content of some anorthosite kindred rocks, it seems likely that all these features could be accounted for by a sudden release of confining pressure after the bulk of the rocks of the anorthosite kindred had crystallized. As crystallization progressed, the crustal segment into which the anorthosite kindred rocks were emplaced would become more rigid and amenable to fracture and the intruded rocks would begin to contract. This would result in the development of fractures and a release of confining pressure. Higgs (1954, pp. 205-206) has shown how such a relace of confining pressure can produce '. . . internal-explosion shattering' in rocks of the anorthosite kindred. The opening up of fractures would also result in volatiles, particularly water, being removed from the residual crystallizing magma. Bowen & Tuttle (1949, p. 459) and Walton (1960, p. 641) have indicated that this escaping magmatic fluid is generally preferentially enriched in silica. Such a tenuous water-and silica-rich magma is believed to have produced the silexite bodies; and the resulting partial removal of silica from the residual granitic magma may have produced the low quartz content found in many parts of the farsundite body. Buddington (1939, p. 160) and Emmons (1940 and 1953) have proposed similar silica depletion mechanisms for producing syenites.

The higher mafic content of the south eastern part of the farsundite body is believed to result from it being emplaced first, and as intrusion continued, the magma became progressively enriched in K and Si.

When one considers the origin of the charnickitic M-type farsundite it seems likely that it formed either as a product of regional metamorphism, or that it was emplaced deep within the crust and it crystallized under granulite facies conditions. It seems probable that the farsundite as a whole was emplaced into a crustal environment where pressure and temperatures were approaching those required for the granulite facies, and that true granulite facies conditions were generated and maintained for a significant period of time in the rocks adjoining the main body of cooling anorthosite and noritic rocks. As a result of this we now have the M-type farsundite, and the boundary between charnockitic and non-charnockitic rocks can be traced northwards through the gneisses of the Flekkefjord area (Tobi 1965, pp. 210—211).

The smaller outcrops of M-type farsundite may be regarded as areas where the temperature was locally held above the amphibolite-granulite facies transition during sufficient time for the M-type farsundite to develop. Considering their small size, it seems likely that they represent areas where a local release of pressure produced the required temperature increase.

The dark colour of the felspars and quartz in the M-type farsundite appears to be related to the presence of minute particles of iron and titanium ore. Ramberg (1948, p. 557) has shown that the mafic minerals that develop under granulite facies conditions tend to contain less iron and titanium than normal mafic minerals; thus the darkening of the granulite facies felspar might be produced by the migration of Fe and Ti, liberated when granulite facies conditions prevail. Poldervaart (1965, p. 142) belives that such '. . immigration of foreign particles into crystals can take place during solid phase inversions (e.g. high-low inversion of plagioclase), as Hedvall effects . . . '.

The B-type farsundite consists of an intermixed mass of farsundite and microgranite. The finer grained microgranite is believed to have been intruded after the farsundite host rock had cooled, and the M-type had formed. The intrusion of the microgranite is believed to have reactivated and locally mobilized the older farsundite, and the commingling of these two rocks types produced the B-type farsundite found today. As the microgranite is believed to be older than the process that generated the M-type farsundite, it seems likely that it represents an intrusive episode younger than the episode that produced the anorthosite kindred, and thus it may be consanguineous with the Holum and Snig granites (Smithson & Barth 1967, pp. 21-55).

The shrinkage fractures that developed with the crystallization and cooling of the farsundite were filled (or healed) by dykes, stringers and lenses of micro-granite, granite and pegmatite. The variations in texture and composition found within these bodies is probably related to their cooling histories and the nature of the introduced materials. The volatile content of the introduced material, the sizes and shape of the fractures into which it was channelled and the physical and chemical nature of the rocks that bounded the fractures, all influenced the evolution of these granitic pods. The complex zoned pegmatites with their concentrations of Be, Y, NB, Mo, La, Ce, Yb, Ta, Th, and U are regarded as special cases that are not directly related to the other minor granitic bodies.

The pegmatites are believed to have formed from a volatile-rich residual granitic magma that developed after the bulk of the rocks of the anorthosite kindred had crystallized. The rare elements are considered to have concentraded in this residual magma because when the anorthosite kindred magma rose through the Earth and began to crystallize these elements were precluded from entry into the lattices of the common rock forming minerals by size, valency or bond type, and they concentrated in the liquid phase rather like the impurities that concentrate in the molten zone during zone refining (Harris 1957).

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