The intrusive granites of the Farsund area, south Norway: Their interrelations and relations with the Precambrian metamorphic envelope

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A new geological map, covering about 1500 km² of the area around Farsund, south Norway, is presented. The country rock gneisses have been subdivided into three major lithostructural units consisting of augen, banded, and granitic gneisses. The intrusive 'farsundite complex' is divided into several distinct bodies and their contact relations are described. The plutons fall mineralogically, texturally, and chemically into two groups: 1. The Farsund charnockite and the strongly differentiated Kleivan granite which show anorthositic affinites. 2. The mineralogically more normal granites such as the Lyngdal hornblende granite. This paper refutes earlier interpretations considering the 'farsundite complex' as one single unit in terms of structure and composition.

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This paper presents a study of the field relations of the intrusive rocks around the town of Farsund in southern Norway. The results are based on geological mapping from 1965–1975 using aerial photographs on the scale of about 1:15,000 together with topographic maps. The field work has been supplemented by petrographic, geophysical, and geochemical studies as well as radiometric age determinations. These investigations allow the distinction of a series of independent intrusive bodies (Fig. 1, A, B).

The largest is the Lyngdal hornblende granite, an elongate E–W body with a major branch extending to the north. This northerly branch is separated from the main body by Lyngdalsfjorden. The Farsund charnockite lies to the west of the Lyngdal hornblende granite, and has an oval shape with the longest axis stretching NW–SE. North of the Lyngdal hornblende granite is the smaller, elongate N–S, Kleivan granite (Petersen 1973, 1977). The peninsulas and islands west of Lindesnes expose two different minor granites which are distinct from the Lyngdal hornblende granite.

The major plutons have been separated on geological and geochemical evidence (Falkum et al. 1972, Falkum & Petersen 1974) and radiometric age determinations from Pedersen & Falkum (1975) and Petersen & Pedersen (1978) are summarized in Table 1.

Earlier investigations are contradictory as regards the field relations of the intrusive rocks of the Farsund area which have been interpreted as comagmatic, and the country rocks which have been considered grossly conformable with the contacts of the plutons. Because of the presumed cogenetic origin of the intrusive rocks they have been grouped together under the term 'farsundite' or 'farsundite complex' and have been described as forming a single star-shaped intrusion.

We have re-investigated the area in detail in an attempt to clarify the field relations as a basis for petrological interpretations. Our studies show that the 'farsundite body with five limbs' (Middlemost 1968a) requires considerable dissection and amputation, resulting in several independent granitic bodies.

Previous investigations

Geological investigations have been carried out in the area around Farsund for about 140 years, going back to Keilhau (1840). There have been considerable differences in interpretation of the intrusive rocks, not least because of their relationship to the so-called 'granite controversy', the 'charnockite problem', and the 'anorthosite kindred' as discussed by Middlemost (1968a:92).

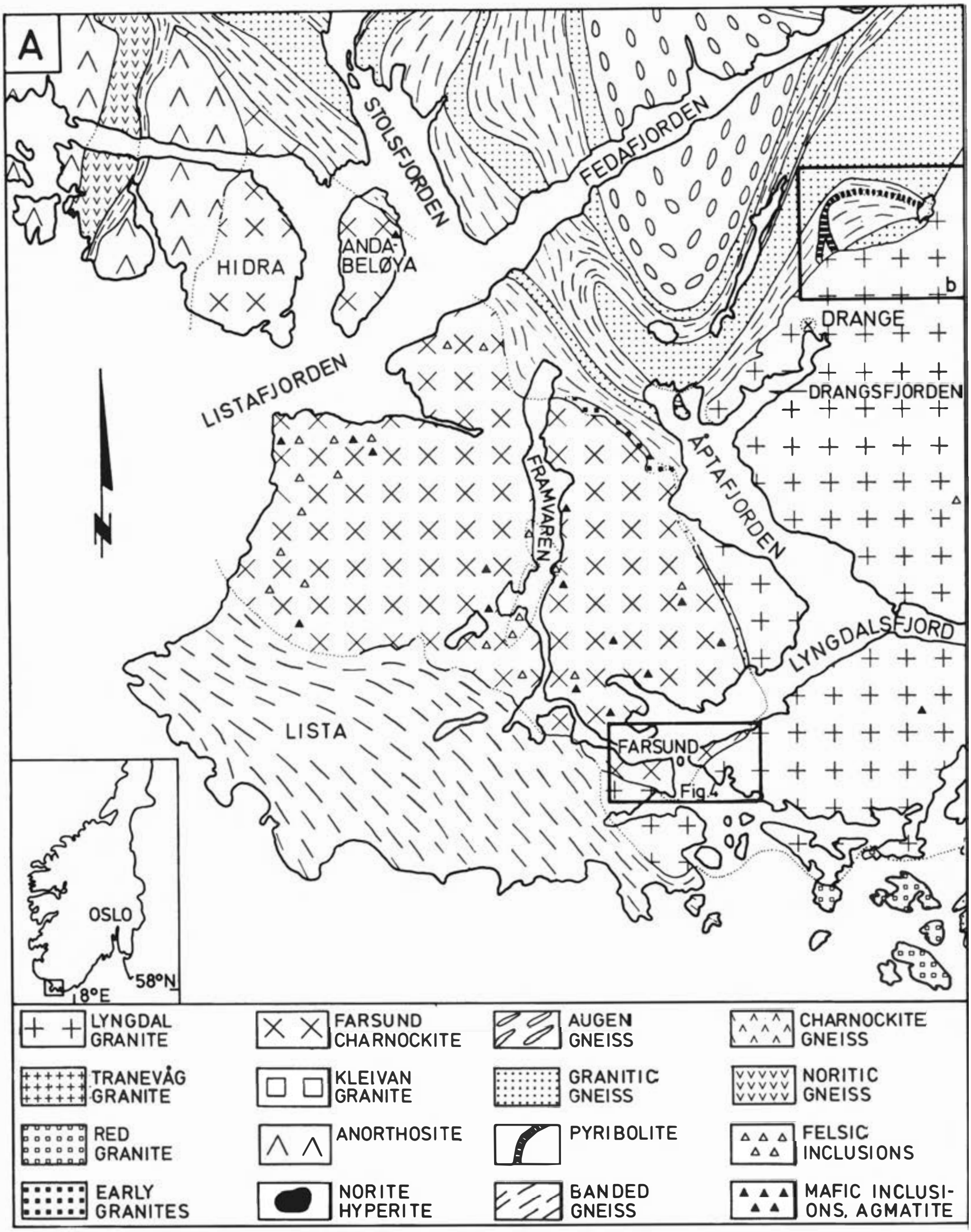

Fig. 1, A and B. Geological map of the Farsund area in south Norway. The geology of the areas a, b, c and d are shown in more detail in Fig. 3, and the area around Farsund town is shown in Fig. 4. The X near Drange is the Drange charnockite.

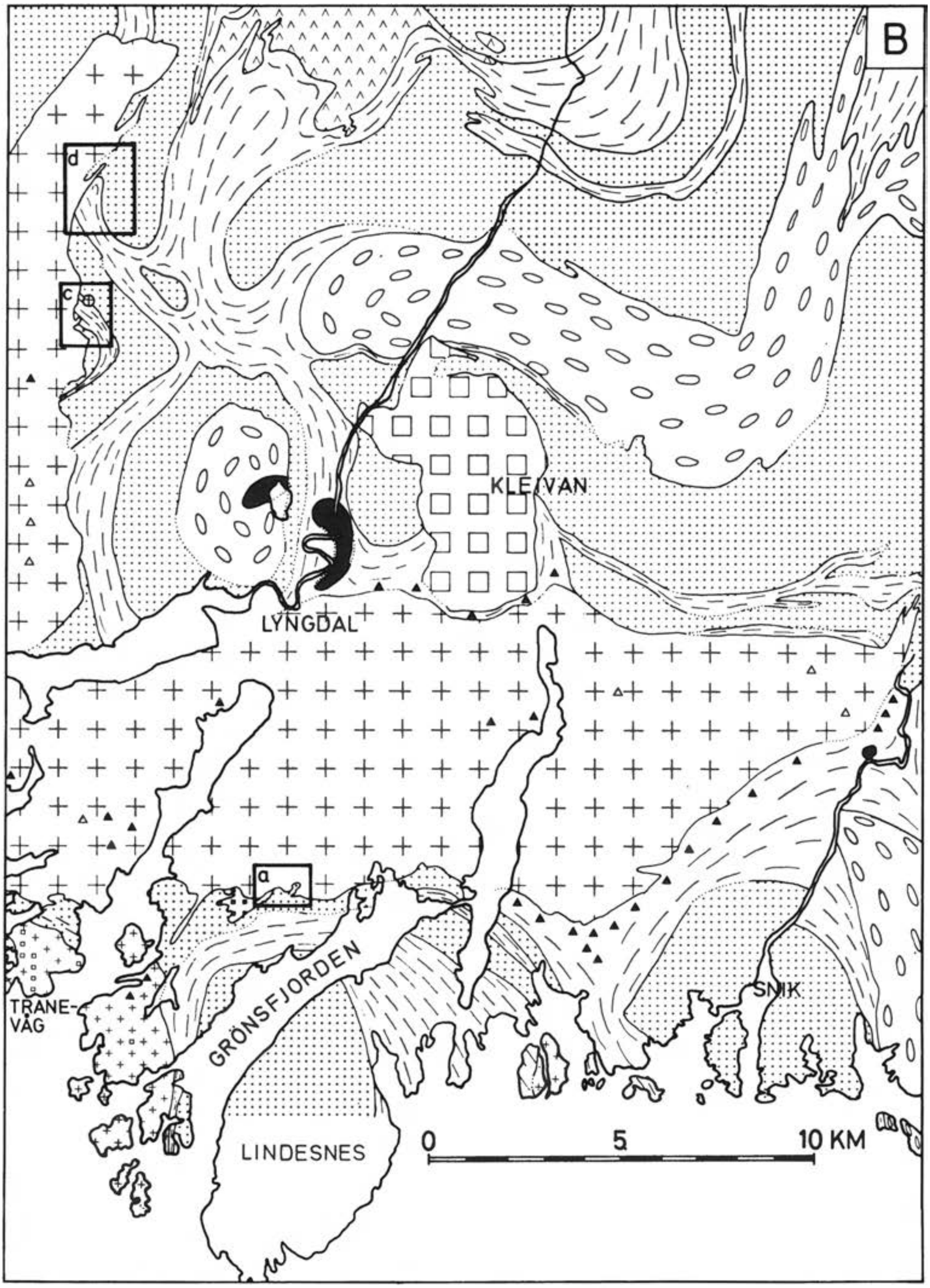
B
d
c
a
KLEIVAN
LYNGDAL
TRANE-
VÅG
GRÖNSFJORDEN
LINDESNES
SNIK
0
5
10 KM

Table 1. Rb-Sr ages and initial Sr^{87}/Sr^{86} ratios for some of the intrusions in the Farsund area, south Norway.

	Rb-Sr age	Initial ratio	Reference
Farsund charnockite	852 ± 41 my.	0.7128 ± 0.0009	Pedersen & Falkum (1975)
Lyngdal hornblende granite	932 ± 38 my.	0.7054 ± 0.0005	Pedersen & Falkum (1975)
Kleivan granite	930 ± 7 my.	0.7053 ± 0.0002	Petersen & Pedersen (1978)

We have summarized the main contributions to the historical development of interpretation of the intrusive rocks in terms of geological maps in Fig. 2.

The Lyngdal hornblende granite was discovered by Keilhau (1840) and the first geological map of southern Norway by Kjerulf & Dahll (1858–1865) includes both the Lyngdal hornblende granite and the Farsund charnockite as separate plutons (Fig. 2A). The quality of this map is excellent, particularly concerning the contact relations around Farsund town, and several of the later maps show little improvement.

The next map, produced by Kolderup (1897) (Fig. 2B) in connection with a thorough petrographic description which includes the Egersund anorthositic rocks, seems to be largely based on that of Kjerulf & Dahll, though Kolderup correctly interprets the granite to the north of Lyngdalsfjorden as being different from the Farsund charnockite to the west. Kolderup's (1935) later map (Fig. 2C) has undergone some alterations, especially in the northwest where the Farsund charnockite is made continuous with the country rocks enveloping the anorthosite complex.

Barth's (1945) map (Fig. 2D) also shows the Farsund charnockite as merging into these gneisses; the 'northern limb' of the Lyngdal hornblende granite grades into the surrounding granitic gneisses; the contact between the two plutons is shown as gradational; the southwest contact of his birkremite is considerably further south than on the earlier maps; and at the eastern end of the complex, northern and southern 'limbs' are introduced.

The map of Middlemost (1968a) (Fig. 2E) is very similar to that of Kjerulf & Dahll in the area around Farsund town and none of the country rock contacts are drawn as gradational. Generally the western part of map (Fig. 2E) agrees with ours (Fig. 2F) except that Middlemost considers a part of the Farsund charnockite to be intermixed with microgranite, and calls it 'B-type' farsundite.

In contrast to Middlemost we separate his 'Kleivan limb' from the main pluton and refer to it as the Kleivan granite, and have mapped the southern boundary of the Lyngdal hornblende granite as running approximately east–west.

There has been considerable confusion as to the nomenclature of the rocks of the area, and a chronological summary is presented in Table 2 which also refers to Fig. 2. Table 2 is self explanatory in illustrating the variety of names used for the eastern and western parts of the complex, and since the use of the term 'farsundite' has been reviewed by Middlemost (1968a, b) we will not discuss the historical development further here.

Field relations

Country rocks

The plutons around Farsund have intruded a high-grade metamorphic sequence of Precambrian migmatitic rocks, ranging from granulite to amphibolite facies. They have been divided into three major litho-structural formations, established as the Flekkefjord Group (Falkum 1966). These three formations make up most of the country rock envelope around the plutons and are augen gneisses, banded gneisses, and granitic gneisses. Detailed accounts of these rocks from the Flekkefjord area and the area northeast of Lyngdal will appear soon, and consequently only a brief simplified description of

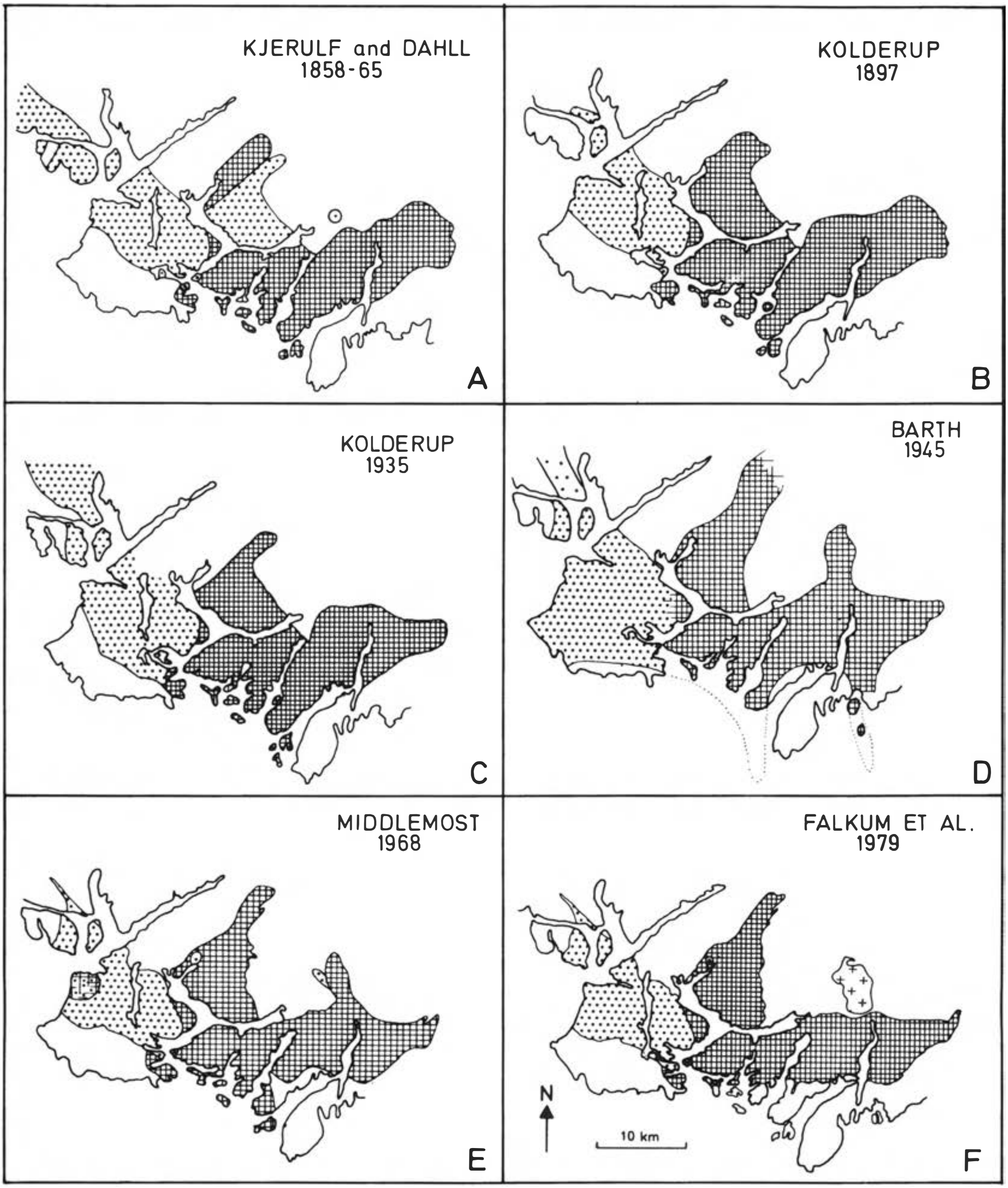

Fig. 2. Simplified geological maps of the 'Farsundite complex', showing different interpretations from 1858 to the present day. For legend and nomenclature see Table 2. In 2E Middlemost (1968a:86) considered the northwest part of the complex, shown as dots and gridiron pattern together, to be 'B-type farsundite consisting of an intermixed mass of farsundite and microgranite'.

the major units will be presented here (Fig. 1, A, B).

The structural evolution of the country rocks has been extremely complicated with plastic deformations acting on high grade granulite- and amphibolite-facies rocks. Several major phases of deformation have been recognized and the first is expressed by the overall foliation and small scale isoclinal folds. A later deformation folded this foliation round large isoclinal folds, one of which can be seen on the map (Fig. 1, A, B) to the northwest of Åptafjorden where its core consists of granitic gneiss. These folds were deformed during subsequent deformations producing folds with near north–south axial planes which normally dip gently eastwards, and often yield dome and basin structures, as can be seen in the northeast part of the map. Extensive migmatisation and metamorphism in amphibolite facies conditions occurred during the next period of deformation, while no regional metamorphism was associated with the last deformation.

Augen gneiss occurs in four separate areas:

the Flekkefjord region (Falkum 1966) in the north of Fig. 1A;

in a dome-like body just north of Lyngdal;

in a refolded antiform (Petersen 1977) in the northeast of Fig. 1B;

and flanked by banded gneiss in the extreme southeast of Fig. 1B. Whether these four geographically separate areas of augen gneiss in fact belong to one or more different units has not yet been established.

The augen gneisses are coarse-grained gneissic rocks with a distinct foliation wrapping around feldspar megacrysts of varying size and shape. The normal shape of these megacrysts is augen-formed; rectangular feldspars occur quite often. The augen gneisses are occasionally severely deformed and the feldspars are then found as thin elongated lenses consisting of a few crystals or as aggregates with a mosaic texture. The augen texture gradually disappears, resulting in a layered rock with feldspathic layers and lenses.

The feldspar megacrysts are normally alkali feldspar, microcline or orthoclase, although large plagioclases also occur. The size normally ranges from 1–5 cm, though crystals up to 20 cm in length have been recorded. Quartz, plagioclase (An_{20-45}), and some alkali feldspar make up the medium-grained matrix, together with the mafic minerals which rarely exceed 30% of the rock. Biotite and hornblende are the most common mafics, either of which may dominate, and they wrap around the megacrysts, thus making the augen texture more pronounced. Ortho- and clinopyroxene may occur, especially in the western part of the region where granulite facies metamorphism prevails.

Banded gneisses make up a large proportion of the country rocks surrounding the plutons of the Farsund area. They consist of interlayered felsic and mafic rocks, the layers ranging in thickness from a few millimetres to several metres and exhibiting a large compositional and textural variation. A few ultramafic rocks, such as pyroxenites and hornblendites, are found. The most common mafic rock is amphibolite or pyribolite, while biotite-rich lenses occur more sporadically. The felsic layers usually dominate and range in composition from granitic to quartz-dioritic and occasionally to monzonitic and syenitic. Several other rock types occur within the banded gneiss formations, such as garnetiferous biotite gneiss (see, for example, Fig. 3), often containing sillimanite and cordierite. Thin layers of quartzite and calc-silicates are often interbedded with these peraluminous rocks. Severe polyphase deformation, metamorphism, and anatexis have thoroughly altered the banded gneiss into diversified migmatites of all the classes described by Mehnert (1968).

Granitic gneisses dominate the gneissic rocks in the area. They sometimes grade into banded gneisses. Both granitic and banded gneisses often wrap around the augen gneiss, as is clearly seen in Fig. 1. In the southeast of our map there is a circular dome-like structure, the core of which consists of granitic gneiss. This area of granitic gneiss, about 5 km in diameter, has been referred to as the 'Snik granite' by Smithson & Barth (1967) and Middlemost (1968a).

The granitic gneisses exhibit a wide range in composition, dominated by a variety of medium-grained pink biotite gneisses of granitic composition. To the west of Flekkefjord and around the western part of the Farsund plutons these gneisses contain orthopyroxene and their colour becomes brownish-green, typical for the granulite facies rocks. In many cases, these gneisses are very homogeneous medium-grained rocks with a patchily developed foliation, and occasionally very leucocratic quartzo-feldspathic gneisses occur, either as discrete bodies or as zones within the other rocks. The granitic gneisses occasionally contain irregular zones or inclusions of mafic schlieren which are normally concentrated within narrow zones. A distinct foliation can often be observed and most of the granitic gneisses have suffered deformation and metamorphism, and anatexis has been significant over large areas. As can be seen in Fig. 1, granitic and banded gneisses are normally in contact with the Farsund plutons.

Other country rocks. – The Farsund charnockite intruded the southernmost part of the Rogaland anorthosite province (Michot & Michot 1969) and on Hidra and on the mainland farther north it borders an anorthositic body which

TABLE 2

REF. TO FIG. 2	AUTHOR(S)	YEAR	ROCK TERM (dotted)	ROCK TERM (grid)	ROCK TERM (crosses)
A	KJERULF & DAHLL	1858-65	LABRADOR ROCK (NORITE)	HORNBLENDE GRANITE	
B	KOLDERUP	1897	ADAMELLITE	BANATITE	
	KOLDERUP	1904	FARSUNDITE		
C	KOLDERUP	1935	BIRKREMITE	HORNBLENDE GRANITE	
	BARTH	1935	BRONZITE GRANITE (BIRKREMITE)	FARSUNDITE (QUARTZ MONZONITE)	
	ADAMSON[1)]	1942	(CHARNOCKITE)		
D	BARTH	1945	BIRKREMITE	FARSUNDITE (QUARTZ MONZONITE)	
	BARTH	1960	F A R S U N D I T E		
E	MIDDLEMOST	1968 A,B	"M-TYPE" FARSUNDITE	"L-TYPE" FARSUNDITE	
F	FALKUM ET AL.[2)]	1979	FARSUND CHARNOCKITE	LYNGDAL HORNBLENDE GRANITE	KLEIVAN GRANITE

1) ADAMSON USED THE TERM CHARNOCKITE FOR THE ROCKS ON THE EASTERN PART OF THE ISLAND OF HIDRA (FIG. 1).

2) SEE ALSO FALKUM ET AL. (1972) AND FALKUM & PETERSEN (1974).

grades into leuconorite and further into a monzonoritic and noritic border facies with planar mineral orientation parallel to the contact as described by Demaiffe et al. (1973).

The northwestern part of our map consists of granulite facies banded gneisses, a complex zone with norites and mangerites, and part of the Åna-Sira anorthosite body (Fig. 1).

The charnockitic gneiss situated in banded gneiss in the northern part of our map is a deformed and metamorphosed, partly discordant, intrusive pluton with pronounced foliation along the borders but more faintly developed in the central part. The olive-green rock contains up to 6 cm large alkali-feldspar megacrysts, oligoclase, hornblende, ortho- and clinopyroxene, occasional quartz and accessory magnetite, ilmenite, zircon, apatite, and allanite.

There occur several isolated gabbroic bodies in the gneiss complex. The two largest are situated north of Lyngdal (Barth 1950, 1960, Lavreau 1970). A smaller one (Jernkleiva) lies south of the easternmost nose of the Lyngdal hornblende granite and has been described as a quartz-hornblende gabbro by Barth (1960).

Contact relations of the plutons

As can be seen from the geological map, the Lyngdal hornblende granite has a cross-cutting relationship to the country rock gneisses. Some detailed contact relations of this pluton are shown in Fig. 3, all of which illustrate the transgressive nature of the Lyngdal hornblende granite. The pluton sometimes has angular, step-like contacts (Fig. 3a); there are occasionally zones crowded with country rock inclusions (Fig. 3c); apophyses of granite can penetrate the gneisses, as shown on the southern border of the Lyngdal hornblende granite to the south of Lyngdal (Fig. 1B) where a finger of coarse-grained granite about 20 m wide extends about 1.5 km into granitic gneiss. Other apophyses in various orientations are illustrated in detail in Fig. 3a, c and d. Along the southeast contact and opposite the Kleivan granite a contact agmatite is developed in the mafic banded gneisses with angular mafic fragments occurring in a medium-grained grey granitic to monzonitic matrix. In Fig. 3a the Lyngdal hornblende granite discordantly cuts a small augen-textured granite, similar in appearance to a zone along the northern contact of the Farsund charnockite.

The granite contact is everywhere believed to be steep, as is evidenced by its running in a more or less straight line across country for considerable distances in spite of the topography. Where direct estimates of the contact can be made it is near vertical or dips steeply inwards.

Field relations give no indication as to the relative ages of the Lyngdal hornblende granite and the Kleivan granite since they are separated by a 200–300 metre wide zone of gneiss. The Kleivan granite has sharp, cross-cutting contacts to the gneisses and is clearly post-kinematic. The field relations of the Kleivan granite have been discussed elsewhere (Falkum & Petersen 1974).

To the south of the Lyngdal hornblende granite there occurs another hornblende granite (Fig. 1B) which is sometimes deformed, here named the Tranevåg granite. Like the Kleivan granite, this was included as part of the 'L-type' farsundite by Middlemost (1968a), but is separated from the main pluton by a zone of country rock. The Tranevåg granite discordantly cuts the banded and granitic gneisses and contains frequent inclusions. A coarse-grained notably red granite, very poor in mafic minerals, occurs in several areas. It seems to post-date the Tranevåg granite although their mutual contact relations and ages relative to the Lyngdal hornblende granite have not been established. The 'red granite' dominates on the islands to the west of Tranevåg.

To the west of the town of Farsund the charnockite has a steep irregular contact with granitic and charnockitic gneiss. Exposures are poor north of Lista where the pluton is in contact with fairly homogeneous orthopyroxene gneisses which appear to have recrystallized. The contact is transgressive to the gneissic foliation on a local scale.

The northern contact of the Farsund charnockite is partly with a weakly deformed zone of an augen-textured granitic rock, termed 'early granite' in Fig. 1, and to the northwest the charnockite is discordant at a low angle to the foliation in banded gneiss. The contact continues in a northwesterly direction across Andabeløya where gneissic inclusions are abundant. On Hidra and to the north the charnockite is flanked by a banded gneiss to the NE and a leuconoritic anorthosite to the west.

The Farsund charnockite and the Lyngdal hornblende granite are in direct contact south of Lyngdalsfjorden in the vicinity of Farsund, while to the north of the fjord there is a zone of granitic gneiss between them. The contact relations

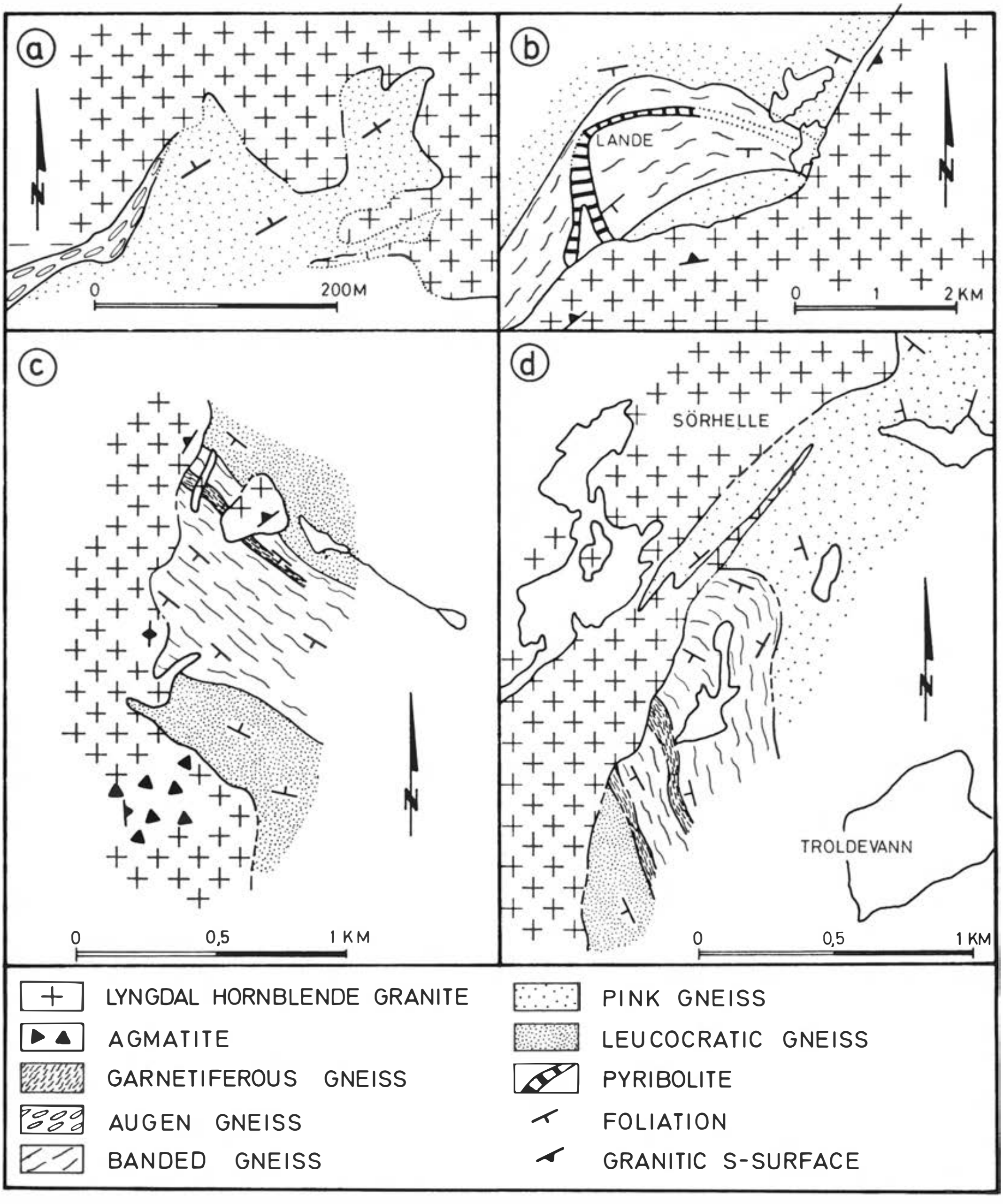

*Fig. 3*a. Zig-zag stoping-type contact between Lyngdal hornblende granite and gneissic country rocks.
b. Clear cross-cutting relationships between the Lyngdal hornblende granite and the Lande synform structure. The pyribolite is a metamorphosed and deformed dyke and discordant to a banded gneiss. The banded gneiss may continue on the east side of the northern extension of the Lyngdal hornblende granite (see Fig. 1B).
c. Highly discordant and irregular contact with apophyses. The agmatite zone is characterized by abundant angular gneissic inclusions.
d. Highly discordant contact west of Troldevann, similar to (c) above, extends northeastwards where a narrow apophyse protrudes almost a kilometre into granitic gneiss. Both granite and gneiss are strongly sheared.
In Fig. 1, garnetiferous gneiss is included in banded gneiss and pink and leucocratic gneiss are shown as granitic gneiss.

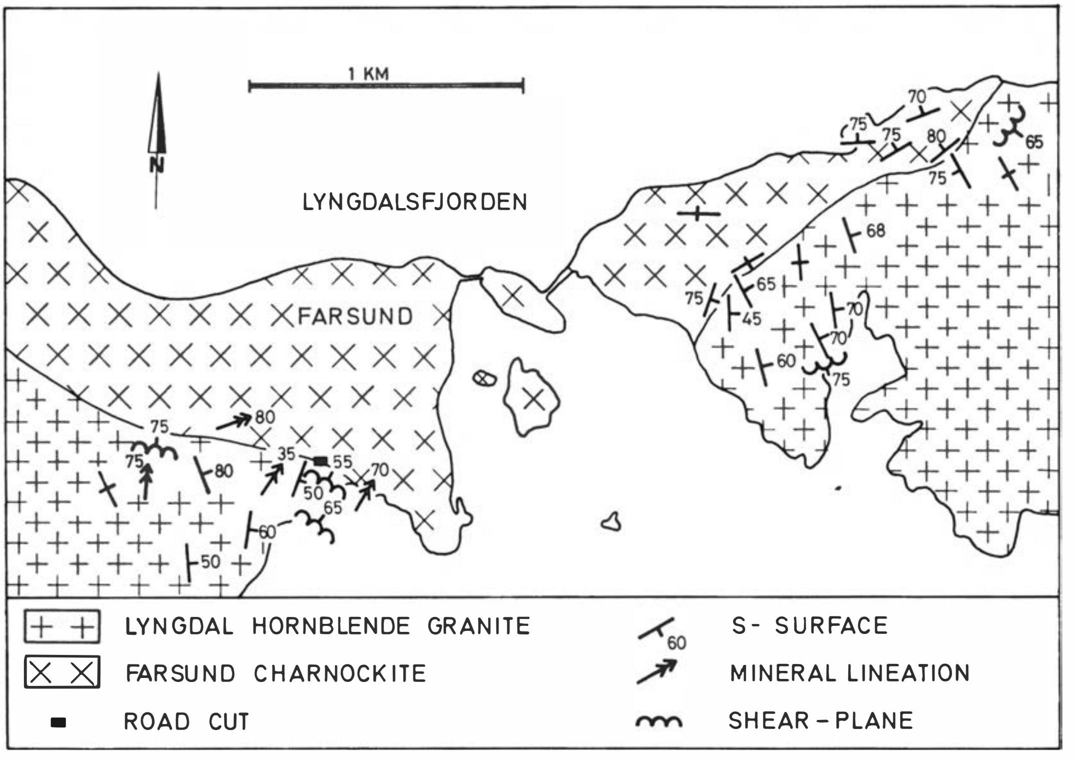

Fig. 4. Contact relations between the Farsund charnockite and the Lyngdal hornblende granite in the area around Farsund town.

clearly show that the Farsund charnockite and the Lyngdal hornblende granite are separate intrusions and the relationships around Farsund indicate that the charnockite post-dates the hornblende granite, as has been confirmed by Rb-Sr age determinations (Table 1).

North of Lyngdalsfjorden the hornblende granite has a steep s-surface essentially parallel to its margin which strikes roughly NNW. There is a zone of angular gneissic inclusions present in the hornblende granite up to a few metres away from its margin. Between the hornblende granite and the charnockite there is a strip of medium- to fine-grained pink-coloured gneiss which extends for about 4 1/2 km and is 100–200 m wide. The gneiss, which closely resembles the granitic gneisses of the country rock sequence to the north, contains some impersistent amphibolitic bands and has a variably developed foliation. The contact of the charnockite with the gneiss is sharp and generally has a clear topographic effect, frequent inclusions of gneiss occurring near the margin.

The contact between the charnockite and the hornblende granite around Farsund is illustrated in Fig. 4. Here the hornblende granite has a steep s-surface which strikes generally north–south, or a lineation which plunges north, consisting of parallel oriented or rod-like alkali feldspars sometimes together with streaked out patches of mafic minerals. On the regional scale this s-surface is normally developed essentially parallel to the country rock contact. In the area around Farsund this s-surface is clearly oblique to the contact with the charnockite and is occasionally cut by later shear planes parallel to the charnockite contact. The earlier s-surface becomes deflected over a distance up to 0.5 m into a well-defined shear zone up to 1 m wide. The shear zones are enriched in biotite and possess a strong planar fabric in which the mafic minerals, hornblende, and biotite are streaked out, quartz aggregates are strongly sheared, while pink feldspar grains are cracked and broken and may develop an augen form with the other minerals flowing around them. These shear zones in the hornblende granite occur up to 500 m away from the contact with the charnockite, always dip steeply, and are parallel to the charnockite contact.

Internal variation within the plutons

Division of the separate plutons was achieved by field mapping of the contacts. There exist major differences in appearance between the main rock types, while there is also considerable variation within the individual plutons.

The most striking contrast between the two major plutons is their difference in colour, the feldspars in the Lyngdal hornblende granite being light in colour while those in the Farsund charnockite are dark, often greenish, especially in fresh exposures. The Kleivan granite shows a continuous variation from a dark charnockitic facies in the north, through a hornblende granite in its central part, to a light biotite granite in the south. A detailed description of the highly differentiated Kleivan granite is presented elsewhere (Petersen 1973) and it will not be discussed further here.

The Farsund charnockite is normally coarse grained without pronounced phenocrysts except along the eastern and northern borders where sporadic large plagioclases occur. A porphyritic texture with pink alkali feldspar megacrysts is normal in the Lyngdal hornblende granite, except in the central part of the northern limb. An s-surface, which is often a planar arrangement of shear planes, or partly caused by a planar arrangement of elongate minerals, is normally developed roughly parallel to the contact of the Lyngdal hornblende granite. An east–west s-surface occurs in the Lyngdal hornblende granite to the south of the eastern part of Lyngdalsfjorden. North of this fjord the granite appears to be slightly more felsic than to the south, and the fjord may possibly represent a contact zone between two facies of the Lyngdal hornblende granite.

Many inclusions have been found in all plutons, particularly near the contacts. Most of them are rather small, ranging from 1 m to a few cm. These inclusions represent more or less sharp-edged xenoliths of gneissic country rocks. When inclusions are found farther away from the margins they often appear to be thoroughly recrystallized.

The Farsund charnockite contains many small inclusions near the margins, especially along the SW contact. An area in NW Lista has abundant felsic inclusions, and the rock here is more fine-grained and lighter in colour than normally observed further to the east and south. Middlemost (1968a) termed the rock in this area 'B-type Farsundite', describing it as a mixture of normal charnockite and a later microgranite. A N–S lake dissects the central part of Lista, and many large felsic inclusions occur along its southernmost shores (Fig. 1A). The area between this lake and the eastern contact contains several felsic and mafic inclusions.

As noted by Middlemost (1968a), there is a small area of dark coloured charnockite at Drange to the north of Drangsfjorden, a branch of Lyngdalsfjorden (Fig. 1A). This roughly circular patch measures some 500 m in diameter and is entirely enclosed by hornblende granite. As in the area south and east of Farsund the hornblende granite is sheared parallel to the contact, and this 'Drange charnockite' may be a large inclusion or could possibly represent a small plug.

Aeromagnetic map

The geological map (Fig. 1) allows interpretation of the aerial magnetic maps of the Farsund and Lyngdal areas (N.G.U.; map series 1:50,000, nos. 1311 II and 1411 III). The gneisses in general are weakly magnetic and there is only occasionally any correlation between lithology and anomaly trends. The Lyngdal hornblende granite, particularly its northern limb, presents a strong positive anomaly and the pluton is for the most part neatly outlined on the magnetic map. Only the central, hornblende-bearing part of the Kleivan granite gives rise to a positive anomaly, and the 'magnetic boundary' of the Lyngdal hornblende granite adjacent to the Kleivan granite clearly separates the two bodies. The Tranevåg granite and the 'red granite' both have positive anomalies, the former being separated from the Lyngdal hornblende granite by a wedge of poorly magnetic granitic gneiss. The Farsund charnockite is very weakly magnetic, and the contact between the charnockite and the Lyngdal hornblende granite is a most striking feature on the aeromagnetic map. Positive anomalies in the western part of the Farsund charnockite correspond to the inclusion-rich areas shown in Fig. 1A.

Petrography of the plutons

Comparative petrography of Farsund charnockite and Lyngdal hornblende granite.

In thin section the Farsund charnockite is a hypidiomorphic equigranular rock, while the Lyngdal hornblende granite is hypidiomorphic inequigranular, containing alkali feldspar megacrysts up to 1 cm long. Modally both rocks fall in field 3b in the QAP classification triangle of Streckeisen. The charnockite has a Q:A:P mean ratio of about 24:40:36 and the Lyngdal hornblende granite's mean ratio averages 26:31:43; they contain about 13% and 18% mafic minerals respectively. According to the system of Streckeisen (1974) the Farsund charnockite should be called a hypersthene granite, or the alternative special name of farsundite (see Wilson (1977) for a discussion of the term farsundite). In both rocks quartz, plagioclase, and alkali feldspar dominate greatly over the mafic minerals which tend to occur in aggregates, especially in the Lyngdal hornblende granite where the aggregates often form elongate zones. A major mineralogical difference is in the dark minerals, with orthopyroxene, hornblende, and subordinate biotite and clinopyroxene in the charnockite, and only hornblende and biotite in the granite. Apatite, zircon, and allanite occur as accessory minerals in both. A major contrast is that sphene is markedly absent in the charnockite while it is often a notable accessory in the granite. The opaque phase in the charnockite appears to be dominantly ilmenite, while in the granite magnetite seems to predominate.

Quartz occurs as irregular grains in both plutons and usually has an undulatory or mosaic extinction pattern. Minute 'dusty' inclusions are abundant and the frequent fluid inclusions often contain bubbles which are believed to be CO_2-dominated in the charnockite and H_2O-dominated in the granite (J. K. Madsen, pers. comm. 1976). Quartz/quartz boundaries are normally globular in outline, especially in the charnockite, indicating at least marginal recrystallization.

In both bodies, plagioclase shows subhedral outlines, and zoning is often developed. In the charnockite antiperthite is very common and occurs as blebs of alkali-rich feldspar in the plagioclase, often transgressive to the plagioclase twinning and probably having nucleated on the twin planes. Plagioclase crystals are occasionally bent, as indicated by curved albite twin planes, in both plutons. Very fine needle-like inclusions are abundant in the charnockite plagioclases and are often oriented in two or more directions. Alteration of plagioclase to sericite or epidote occurs patchily in both bodies. Plagioclase compositions lie between An_{22} and An_{32}, averaging about An_{25} in both plutons.

Alkali feldspar is normally microperthitic in both plutons. Microcline cross-hatch twinning is extensively developed in the Lyngdal hornblende granite, and rather less so in the Farsund charnockite. Alkali feldspar in the latter sometimes has well developed mesoperthitic textures. Larger grains of alkali feldspar are often undulatory in both plutons, and small blebs of quartz are frequently present, especially in the charnockite.

In both plutons, but especially in the Farsund charnockite, feldspar grain boundaries show a series of textural features: myrmekitic intergrowths are developed at plagioclase-plagioclase, plagioclase-alkali feldspar, and alkali feldspar-alkali feldspar boundaries; plagioclase has albitic rims where in contact with alkali feldspar; a tendency towards grain boundaries approaching 120° is shown by plagioclase and alkali feldspar when they are in contact with each other or themselves; alkali feldspar grain boundaries are highly irregular and interfingering is frequent, with double rows of 'saw teeth' sometimes developed, particularly in the charnockite.

Orthopyroxene is present in most samples from the charnockite and occurs as prismatic grains which are normally colourless but may have a weak pale brown pleochroism. Anomalous blue birefringence is sometimes present. Clear exsolution lamellae of clinopyroxene are often developed and orthopyroxene and clinopyroxene (often with pale greenish pleochroism) also occur together as discrete grains in aggregates, frequently surrounded by hornblende. Along cracks and cleavage planes in the pyroxene an orange-brown or rust-coloured alteration product, possibly iddingsite, is frequently developed.

In the Farsund charnockite hornblende may be more or less abundant than pyroxene, while in the Lyngdal hornblende granite hornblende normally dominates over biotite. In both bodies hornblende grains are usually subhedral and have a pleochroism from green-brown to green to straw; sometimes a slight blue-green colour occurs towards the margin. Biotite occurs only in subordinate amounts in the charnockite where it often grows parallel to and appears sometimes to replace hornblende, while in the granite biotite is often abundant, sometimes dominating over hornblende. In both plutons the biotite has a reddish-brown to straw pleochroism and may show inclusions of vermicular quartz.

In the charnockite, the opaque phases are ilmenite and ilmenomagnetite, this being linked with the marked absence of sphene. In the Lyngdal hornblende granite the dominant opaque phase is magnetite and sphene is often notably abundant, sometimes forming a rim to the opaque phase.

In both bodies, frequent euhedral apatites occur enclosed in all other minerals, but mostly together with the mafic minerals. The frequent zircons are relatively large, usually euhedral and zoned. Rusty allanite, usually at least partly metamict, is a sporadic accessory. Calcite locally occurs as a secondary product in cracks and interstices in the charnockite.

Kleivan granite

In the Kleivan granite, the northernmost, charnockitic part displays identical petrographic properties to those previously described for the Farsund charnockite. The body exhibits strong compositional variation and the central part of the pluton is dominated by hornblende as the major mafic phase, pyroxene being absent. A transition zone with progressively altered pyroxenes marks the boundary between the two types. Further south in the pluton biotite becomes progressively more important, until hornblende completely disappears. From this point a further compositional variation towards the south is marked by a change in pleochroism of biotite, the maximum absorption colour progressing from dark reddish brown to dark green. In the biotite granite, apatite is absent, but occasionally fluorite is found, appearing as drop-shaped inclusions in quartz and biotite. Along the southernmost boundary a fine-grained granite variety is found, containing a reddish garnet (presumably Mn-rich) as the only essential mafic mineral. In the pluton as a whole plagioclase is found in decreasing amounts from north, about 30%, to less than 15% in the southernmost types, and the composition varies between andesine (An_{32}) in north to oligoclase (An_{18}) in south. A detailed account of the Kleivan granite will be given by Petersen.

Tranevåg and 'red' granite

The Tranevåg granite is rather similar in mineralogy and texture to the eastern part of the Lyngdal hornblende granite. It has a hypidiomorphic inequigranular texture with alkali feldspar megacrysts in a medium-grained matrix. This consists of microcline microperthite, undulose quartz, oligoclase with hornblende, biotite, sphene, zircon, apatite, and opaques often gathered in aggregates. The main mineralogical difference between the Lyngdal hornblende granite and the Tranevåg granite is that the ratio of hornblende to biotite is larger for the Tranevåg granite.

The 'red granite' can vary widely in grain size and has a xenomorphic inequigranular texture which consists dominantly of microcline microperthite often with irregular cross-hatching, undulose quartz, sericitised oligoclase, and less than about 5% mafic minerals. The latter are mostly opaques and biotite which frequently alters to chlorite and epidote, with very minor zircon and apatite. Secondary calcite occurs sporadically, and myrmekite and replacement textures between the felsic minerals are abundant.

Discussion

The Farsund area was the site for multiple magmatic activity during the closing stages of the Sveconorwegian orogeny. The granitic and augen gneisses which make up much of the country rocks may represent extensively deformed and metamorphosed granites. The 'early granites' in Fig. 1 are evidence of intrusive activity after the formation of the gneisses and prior to the emplacement of the major plutons. It has been established in the field that the Farsund charnockite and the Lyngdal hornblende granite are two entirely separate plutons, and they differ in mineralogy and texture, have significantly different ages and initial ratios and contrasting chemical compositions (Table 3 and Falkum et al. (1972), Killeen & Heier (1975a, b), Smithson & Heier (1971)). The Kleivan granite is also an independent body which shows a marked systematic variation in mineralogy and texture from north to south. The largest pluton, the Lyngdal hornblende granite, is divided into two main parts by Lyngdalsfjorden. The east–west limb south of this fjord is generally more mafic

Table 3. Average FeO (total)/MgO, K, Th and U data for the granites of the Farsund area.

		FeO (total) /MgO	K	n_1	Th	U	n_2
Farsund charnockite		16.2	3.88	99	2.9	0.7	22
Kleivan granite	charnockite	18.2	3.65	11	2.7	0.6	7
	hornblende-	20.7	4.20	18	15.1	1.0	6
	biotite-	65.8	4.16	14	31.3	3.4	3
Lyngdal hornblende granite	overall	4.7	3.25	235	8.0	1.5	68
	north limb	5.6	3.34	73	7.8	1.1	14
	east limb	4.4	3.19	150	8.1	1.6	54
Tranevåg granite		3.8	3.53	18	9.3	1.8	6
Red granite		4.6	4.46	9	-	-	0
Holum granite		4.8	3.31	36	12.0	2.0	36

Data for the Kleivan granite are presented for the three facies, (from north to south) charnockite, hornblende-, and biotite-bearing. The Lyngdal hornblende granite is subdivided into the two main northern and eastern limbs. Th and U data (except Kleivan granite) recalculated after Killeen & Heier (1975b). Th, U and K Holum granite data recalculated by Wilson et al. (1977) after Killeen & Heier (1975b). The Holum granite is situated just to the east of Fig. 1b. n_1-number of samples for FeO (total)/MgO and K. n_2-number of samples for Th and U.

with a lower FeO (total)/MgO ratio, and slightly less K (Table 3) than the northern limb; these two limbs may represent two facies of the pluton, though samples from the two limbs lie on a single Rb-Sr isochron (Pedersen & Falkum 1975).

The contact relations of the two minor granites outcropping south of the Lyngdal hornblende granite, the Tranevåg granite and the 'red granite', are not clear. The Tranevåg granite is similar in mineralogy and texture to the Lyngdal hornblende granite, with a slightly lower FeO/MgO ratio and slightly more K, and may be a related body, while the 'red granite' is distinctly felsic. These 'normal' granites, and also the Holum granite which lies to the east, all have FeO/MgO ratios of between 3.8 and 5.6 (Table 3), and are markedly different from the two charnockitic intrusions which have values more than three times as high.

Killeen & Heier (1975a, b) presented Th, U, and K data for the intrusive rocks of the Farsund area, and some of their data have been recalculated here (Table 3). Average values of Th for the two limbs of the Lyngdal hornblende granite, the Tranevåg granite, and the Holum granite lie between 7.8 and 12 ppm while U is from 1.1 to 2.0 ppm. Mean values for the three subdivisions of the Kleivan granite show an increase from north to south of about 6-fold for U and almost 12-fold for Th, again reflecting its extreme differentiation.

The mineralogical and textural similarity between the Farsund charnockite and the northern, charnockitic, part of the Kleivan granite is striking, and in addition (Table 3) both have extremely low values of U and particularly Th, very high FeO/MgO ratios, fairly high K/Rb ratios (about 300 and 400 respectively), and relatively anhydrous mineralogy. These are all features characteristic of rocks belonging to anorthositic suites (Emslie 1973, Carmichael et al. 1974, Duchesne et al. 1974).

There has been a tendency in the past for the 'Rogaland anorthosite complex' and the 'Farsundite complex' to be considered separately. The subdivision of the 'Farsundite complex' into normal granites and intrusives of charnockitic affinity and the anorthositic characters of the latter suggest a genetic relationship to the adjacent Rogaland anorthosite complex. In this context it is interesting to note that the post-kinematic Precambrian rocks of this part of southern Norway generally have low (<0.707) initial Sr-ratios, both the granitic plutons (Pedersen & Falkum 1976) and the anorthosite kindred rocks (Demaiffe et al. 1974). The only plutonic rocks so far reported to have considerably higher initial Sr-ratios are the Farsund charnockite (0.7128) and the quartz mangerite of the Bjerkrem–Sogndal massif (0.713) (Demaiffe et al. 1974) in the Rogaland anorthosite province. The Farsund charnockite and this quartz mangerite unit may have similar genetic relationships to the anorthosite complex.

The normally low initial Sr-ratios indicate that the late intrusions were generated at considerable depths during the Sveconorwegian orogeny and can be considered as granitic material added to a Precambrian basement during continental growth.

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