Basement gneiss doming in the Uppermost Allochthon in the Bogøy area of Steigen, Nordland, Norway

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Steigen lies geographically within the Uppermost Allochthon, which was emplaced during the Scandian phase of the Caledonian orogeny. A tectonized boundary separates a basement culmination of Precambrian granite-gneisses from younger cover metasediments. The latter comprise marbles, quartzites, amphibolites and pelitic to semipelitic schists, which have been divided informally into four groups. Caledonian metamorphism reached a peak in the almandine-amphibolite facies during the second main deformation phase (D2), with some retrograde recrystallization after D2. An early deformation phase (D1) is indicated by the preservation of discordant fabrics within porphyroblasts, while the majority of folds are contemporaneous with the formation of the penetrative schistosity (D2). D2 fabrics and fold-axes have been folded into a large D3 antiform which developed during uprise of the basement gneiss culmination late in the orogeny.
The granite-gneiss basement exhibits a foliation which is parallel to the basement's contact with the metasediments. The geochemistry of the gneisses is very similar to that of other basement gneisses in Nordland and to rapakivi granites. The gneisses are considered to be Proterozoic rapakivi granites which rose diapirically during the Caledonian orogeny, causing updoming and deformation of the metasediments.

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Introduction

The Steigen area is situated in the northwestern part of the Salten region of Nordland (Fig. 1) which lies within the north-central Scandinavian Caledonides (Gustavson 1978), formed during the closure of the Iapetus Ocean (Griffin & Taylor 1978, Griffin et al. 1978). An early description of the Salten region was given by Rekstad (1929), and more recent accounts of the complex fold nappe tectonics by Rutland & Nicholson (1965), Nicholson & Rutland (1969), Bennett (1970), Wells & Bradshaw (1970), Cooper (1978 & 1985), Cooper & Bradshaw (1980) and Tragheim (1982).

The geology of the Salten region comprises two tectonostratigraphic units: culminations of Proterozoic granite-gneiss basement forming separate 'domes' (Fig. 1), between which are depressions of cover rocks, mostly metasedimentary. The former have been dated at 1780–1730Ma by Wilson & Nicholson (1973) and 1800–1650Ma by Cribb (1981), and resemble in form and internal structure mantled gneiss domes in other orogenic belts (Rutland & Nicholson 1965, Cooper & Bradshaw 1980). The cover rocks were formerly believed to be of Lower Palaeozoic age, but Rb-Sr dates from some of these are Late Precambrian (Cribb 1981). Both the basement and cover have been deformed during the Caledonian orogeny.

The cover consists of metasediments in four major disjunctive nappe units which have been transported eastwards, and are stacked in an imbricate sequence with each nappe thinning to the west (Rutland & Nicholson 1965, Nicholson & Rutland 1969). In many places in the Salten region there is a strong lineation with a NNE-SSW trend (Cooper 1978, Tragheim 1982, R. Bradshaw pers. comm. 1988). These nappes, in ascending structural order, are the Seve-Köli, Gasak, Fauske and Beiarn Nappes (Cooper & Bradshaw 1980, Cooper 1985). The first two lie within the Upper Allochthon, while the latter two are part of the Uppermost Allochthon which occupies most of Nordland (Fig. 1), and was emplaced as an exotic terrane onto the continent Baltica during the Scandian thrusting phase of the Caledonian orogeny (Cooper 1985, Roberts & Gee 1985, Stephens et al. 1985, Stephens 1988). However, in the western coastal districts the Fauske Nappe is separated from the basement by the relatively minor Saura and Kistrand Nappes and a sequence of parautochthonous metasediments (Cooper 1978, 1985, Cooper & Bradshaw 1980). Superimposed upon this deformation of the cover rocks are later structures associated with the rise of the basement culminations.

The relationship between the granite-gneiss domes in Nordland and their cover is not fully understood, and metamorphism and folding make the distinction between parautochthonous and allochthonous crystalline units difficult (Roberts & Gee 1985). Because the penetrative foliation in the Caledonized Precambrian gneisses is parallel to concordant contacts with the cover rocks, it is also often difficult to tell if these contacts are sedimentary or tectonic (Roberts & Gee 1985). Steltenpohl & Bartley (1988) believe that the Nordland Caledonian gneiss domes are a result of interfering cross folds and back folds formed during layer-parallel shortening.

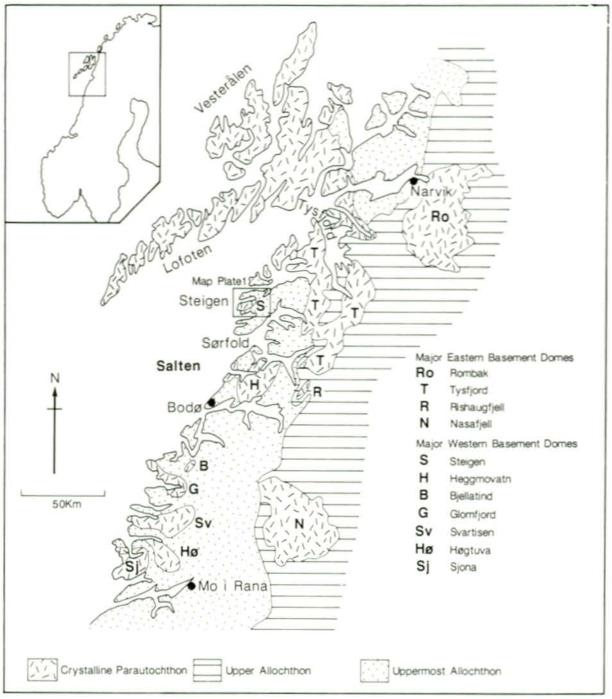


Fig. 1. Simplified tectonostratigraphic map of Nordland (after Map 1 in Gee & Sturt 1985).

Stratigraphy and lithologies

Basement Gneisses

The main basement 'dome' comprises a variety of granite-gneisses which contain scattered layers and lenses of mafic schists. The gneisses vary from pink to white and grey, and are mostly leucocratic. They are medium- to coarse-grained containing pink microcline megacrysts, and there are also aplitic layers and pegmatitic pods. Lenticular concentrations of quartz and feldspar, together with diffuse mafic schlieren, produce a streaky texture.

Quartz and feldspar form an inequigranular mosaic with elongate grains which, with the preferred orientation of micas, give the rock a foliation. Biotite and muscovite crystallization post-dated the quartz and felspar, and occasional late retrogressive muscovite porphyroblasts have grown across the foliation; some biotites have altered to chlorite. Typically, nearly all the biotite is green or greenish-brown. Another characteristic mineral is olive-green to turquoise-green ferrohastingsitic amphibole, which develops poikiloblasts sieved with small rounded inclusions, mainly of quartz, indicating its late growth. Epidote is common, forming coronas of radiating grains around yellowish-brown metamict allanites, another mineral characteristic of the gneisses. Syntectonic sphene is ubiquitous, forming large grains parallel to the foliation, and accessory small red garnets, aegirine-augite and interstitial fluorite occur. In a few places euhedral to subhedral magnetites up to 5 mm across are common, particularly in quartzofeldspathic layers, and many are fringed by sphene, suggesting that they are probably titaniferous.

The granite-gneisses contain sheet-like and lenticular mafic rafts and small inclusions varying from a few centimetres to 2m in width, and up to several metres long. They lie subparallel to the foliation in the gneisses, are generally strongly schistose, and their margins range from sharp to diffuse. The schistosity is defined by greenish biotites, and poikiloblastic ferrohastingsite is a characteristic mineral, together with epidote, sphene and allanite. There is also a lenticular, fault-bounded slice of basement around Gyndelvatn. In its centre it is a grey foliated granitic rock with scattered small red garnets, and contains numerous dark lenses and mafic schlieren up to about 30cm long. Towards its margins, and particularly at either end, it becomes a strongly foliated quartz-mica schist, containing ferrohastingsite and epidote.

The presence of microcline, ferrohastingsite, and, in places, aegirine-augite in the granite-gneisses indicates that the basement rocks were highly alkaline, and this is confirmed by their chemistry.

Metasedimentary cover

The Precambrian basement culmination is surrounded by cover rocks consisting of metasediments which have undergone Caledonian metamorphism and deformation. These include marbles, quartzites, amphibolites and a variety of pelitic and semipelitic schists, which have been divided informally into four groups. There is no clear evidence of the original way-up of the succession, but those rocks nearest the basement dome are considered more likely to be older than those further away. On this basis, the succession shown in Plate 1 has been constructed.

The Holkestad Schist Group closely resembles the schists of the Kistrand Nappe in Salten 40 km to the south (Cooper 1978), and a tentative correlation is suggested. The latter is faulted against the thin Midtiskaret Group of schists, amphibolites and marbles, transitional into arkosic metasandstones, which in turn appears to be parautochthonous with respect to the basement. In Steigen the Leinesfjord, Lilandstind and Vinsnes Groups possibly occupy a position in the succession equivalent to the Midtiskaret Group.

Quartzofeldspathic semipelitic schists

These constitute most of the Leinesfjord Semipelite Group (Plate 1) at the contact with the basement gneisses north of Leinesfjord and in the core of a tight antiform to the north of Lilandsfjord. They are grey and white weathering, some units being massive psammites while others have variable amounts of mica forming a schistosity. The psammites contain microcline and plagioclase, while the schistose facies have poikiloblastic muscovite and biotite altering retrogressively to chlorite. Small red garnet poikiloblasts overgrow the schistosity, and epidote occurs sporadically.

Garnet semipelitic schists

These occupy large tracts within the Lilandstind Semipelite Group, and are typically a rusty-weathering semipelitic schist, but with some grey-weathering horizons. In places, abundant micas form a good schistosity, while other massive units are psammitic and quite feldspathic. The crystallization of biotite post-dates that of muscovite, quartz and feldspar. In places, poikiloblastic garnets reach 4cm in size and some have begun to alter retrogressively to chlorite. Garnet growth took place over an interval that spanned pre-, syn- and post-tectonic crystallization. Staurolite is rare and forms poikiloblasts overprinting the schistosity, enclosing muscovite and post-tectonic garnets. Tourmaline poikiloblasts, up to 3 cm long, have also overgrown the schistosity.

Semipelitic schists

Most of the rocks within the Vinsnes Semipelite Group, occupying the peninsulas around Bogøy, consist of semipelites which range from dark biotite-rich schists to light quartzofeldspathic mica schists. They contain little or no garnet, but syntectonic clinozoisites are aligned parallel to the schistosity. Near the shore of Holmåkfjord there is a belt containing numerous large boudins of coarse granite-pegmatite ranging up to 20 m in length. A fault runs along the valley from Holmåkfjord to Leinesfjord, and these pegmatites appear to be associated with this.

Garnet-mica schists

These constitute a large proportion of the Holkestad Schist Group, occupying the northern part of the peninsula between Flagsund and Skotsfjord. They are distinctive fine-grained, silvery-grey, lustrous schists very rich in micas, especially muscovite, which form a good schistosity. Quartz and plagioclase grains are generally slightly elongate, and have recrystallized before the micas. Small red garnets, usually 2-3 mm across, are ubiquitous and may reach 1 cm in diameter. They are generally euhedral to subhedral, and crystallized before the formation of the present schistosity, which is strongly flattened around them. These garnet porphyroblasts contain inclusion trails of quartz oblique to the present schistosity, and occasional sigmoidal trails indicate that garnet growth was syntectonic with an early deformation. Broken and deformed staurolites up to 5 cm in length are poikiloblastic, with inclusion trails of quartz strongly discordant to the matrix schistosity. Kyanites are rare, although they are found up to 3 cm in length; these too are deformed and broken, being pre- or syntectonic.

Marbles

Each of the schist and semipelite groups contains marbles, which have long narrow outcrops, varying in width from a few metres up to tens of metres, and in places have been thickened up to 600 m by intra-unit folding. Colours range from creamy-white to bluish-grey, sometimes with brown-weathering. Lithologies vary from fairly pure, coarse calcite-marble with variable amounts of muscovite and quartz, to marbles with numerous thin siliceous layers containing phlogopite and tremolite in addition to quartz and calcite; locally there are layers and pods of actinolite concentrations.

Quartzites

The only quartzites in the area occur on Alpøen and at Holkestad. At the former locality, massive banded white micaceous quartzites are interbedded with marbles within the Leinesfjord Semipelite Group, while the quartzite at Holkestad forms a unit 150 m wide within the Holkestad Schist Group. Quartz, together with a little muscovite and plagioclase, forms an inequigranular mosaic with grains elongated parallel to the alignment of small micas. There are also thin quartzite units within both the Lilandstind Semipelite Group and the Vinsnes Semipelite Group.

Amphibolites

All the stratigraphic groups contain thin amphibolite sheets ranging up to 50 cm in thickness, which are too small to be shown on the map, Plate 1. They are particularly common in the Holkestad Schist Group, generally within or along the margins of marbles.

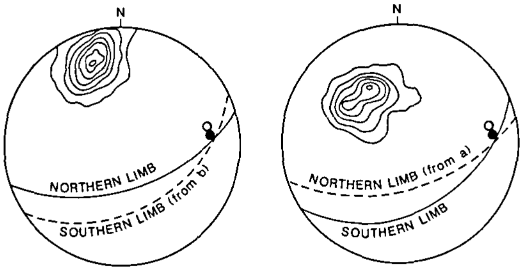
Five types of amphibolite can be recognized:

1. Fine-grained hornblende schists, which are the most abundant.
2. Schistose augen garnet-amphibolites.
3. Actinolitic amphibolites, which are associated with marbles and in places cut across the former two types. They contain sheaf-like aggregates of poikiloblastic actinolites with interstitial calcite, some also with clinozoisite, phlogopite and garnet, or with sphene and scapolite. In a few amphibolites, relict poikiloblastic diopsides have retrogressed to actinolite or epidote.
4. Quartz-cummingtonite rock within biotite-cummingtonite schists, in which the quartz-amphibolite has been folded and broken into small isolated blocks within the schist. Porphyroblasts of garnet up to 2 cm across and tourmaline up to 3 cm long cut across and post-date the schistosity.
5. Creamy-white tremolite schist, which occurs as a lenticular outcrop 50 m long on the west side of Lilandstind. It consists of a mass of tremolite (commonly asbestiform), talc, carbonate and phlogopite, with relics of olivine and rarely enstatite indicating that the rock was originally a peridotite. This rock-type has affinities with sagvandite (carbonate-orthopyroxenite) such as that occurring in Troms (Schreyer et al. 1972, Ohnmacht 1974), at Misvær (Farrow 1974), Nordmøre (Moore 1977), Straumen (Tragheim 1982) and Sørfinset (R. Bradshaw pers. comm. 1988), and also near Ørnes (Cribb 1982) where the sagvandite lies along a major tectonic boundary. All these authors suggest that sagvandites form by H_2O and CO_2 metasomatism of ultramafic igneous rocks, and they describe how the sagvandites have undergone further variable alteration with the formation of later tremolite and talc. The Steigen rocks may thus represent an extreme development of this alteration.

Structure

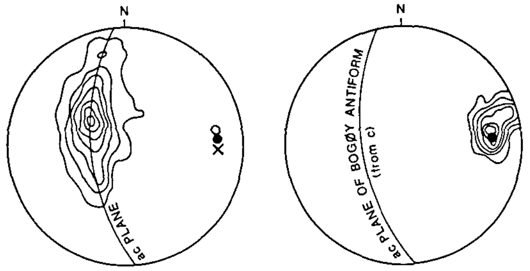
There are two major structural units: a large basement granite-gneiss culmination occupying the central part of the area, and the metasedimentary cover rocks. The gneisses also form a small subsidiary lenticular tectonic inlier within the cover around Gyndelvatn. Structures within the cover rocks will be discussed first.

The cover rocks surround the northeastern end of the basement culmination, around which they are folded. Uprise of the gneiss dome has apparently caused the formation of a large ENE-plunging fold, the Bogøy Antiform, which folds both the lithological boundaries and the penetrative foliation within the cover (Plate 1). Discordant fabrics within porphyroblasts show that the present penetrative schis-



a.Contours: 1,5,10,15,20,25,30%
540 poles

b.Contours: 2,6,10,14,18,24%
150 poles



c.Contours: 1,3,5,7,9,11,13%
300 poles

d.Contours: 5,10,15,20,25,30%
30 axes

Fig. 2. Stereographic projections (equal area net, lower hemisphere) of schistosity in the cover, defining the D3 Bogøy antiform: (a) Poles to S2 schistosity on northern limb. (b) Poles to S2 schistosity on southern limb. (c) Poles to S2 schistosity around fold-closure. (d) Axes of D3 minor folds.
● — fold axis of Bogøy Antiform (from c), o — maximum of D3 minor fold axes (from d), x — fold axis of Bogøy Antiform as determined from basement foliation (from Fig. 3).

tosity was not the earliest to have formed, so this is designated S2; therefore the Bogøy Antiform and the uprise of the basement is at least D3. This is analogous to the emplacement of the syn-D3 Rishaugfjell basement gneiss dome 60 km to the south, with the synchronous formation of the Rishaugfjell Anticline (Cooper & Bradshaw 1980). The majority of folds in the area are contemporaneous with the penetrative schistosity, and are thus of D2 age, and are mainly responsible for the present distribution of lithologies. They are now isoclinal, having been strongly flattened against the basement gneisses during the formation of the Bogøy Antiform, around which the D2 fold axes have been folded (Plate 1). The Bogøy Antiform has both its limbs dipping to the southeast; for clarity, its two limbs and fold-closure are plotted on separate diagrams (Fig. 2a-c). Thus, on the northern side of the basement culmination the granite-gneisses overlie the metasediments. The axes of D3 minor folds, which fold the schistosity, have a fairly constant orientation, with their stereographic maximum lying very close to the axis of the Bogøy Antiform (Fig. 2c&d).

In the area of the Bogøy Antiform fold-closure the metasediments exhibit complex accomodation folds, and outcrops of the lithological units have been widened by intraformational folding. By contrast, on the limbs of the Bogøy Antiform the cover rocks have been strongly flattened, and lithological units are greatly attenuated, with very few minor folds being preserved. The flattening has been particularly strong in the belt between Skotsfjord and Gyndelvatn, where rocks have been compressed between the basement culmination and the subsidiary tectonic lens of basement gneisses. Here, the D2 fold axial traces converge and have been brought into close juxtaposition, while some folds with marble cores have been sheared out completely. This compression of pre-existing folds is similar to that in Connemara, Ireland, where fold axial traces in the steep belt of the Connemara Schists converge as they are flattened against the massive Bennabeola Quartzites (Evans & Leake 1970, Tanner & Shackleton 1979).

The southern contact of the Holkestad Schist Group is transgressive to the other metasedimentary units and the lens of granite-gneiss, and is a tectonic boundary. There are numerous faults parallel to this trend within the Holkestad Schist Group, particularly near its southern margin, and the metasediments are strongly sheared. The whole area is bounded to the southeast by a fault running the length of Knedal, beyond which is a continuous unit of marble transgressing various units of semipelite.

The contact between the basement and the cover is not exposed, but is likely to be a tectonic one since it transgresses units in the cover and there is usually strong shearing within both the basement and the adjacent cover rocks. Syn-D2 garnets in the schists have been broken down and cracked, the fractures being perpendicular to the contact with the basement, implying that the basement culmination may have been faulted into place during its uprise, after the main D2 movements.

An alternative possibility for the nature of this boundary is that it is a thrust, which has been folded subsequently into an antiform. According to Ramberg (1981), in some of the Caledonian basement domes it is not easy to decide whether the shear strains are due to the movement of the nappes or to the rise of the domes, but he stated that the symmetry of the resulting strains should be distinctive. In the Bogøy area it is difficult to be sure which explanation is more likely, but there is a similar situation in the Sørfold area of Salten, 40 km to the south, where cover rocks occupy a tectonic depression between the two granite-gneiss culminations of Heggmovatn and Rishaugfjell (see Fig. 1). There, minor folds in the metasedimentary cover verge away from each dome, suggesting that the cover sequences collapsed into the depression during uplift of the domes (Cooper & Bradshaw 1980, Cooper 1985, R. Bradshaw pers. comm. 1988). If the boundary was a folded thrust, tectonic movement aasociated with the thrusting would have been essentially unidirectional, while any minor folds formed during anticlinal folding would have verged towards the domes instead of away from them.

The foliation in the marginal parts of the basement granite-gneisses is parallel to the contact with the cover rocks, having been folded by the post-D2 Bogøy antiform. The axis of this fold in the gneisses is very close to the axis of the Bogøy Antiform as determined from the folding of the cover schists (Fig. 3).

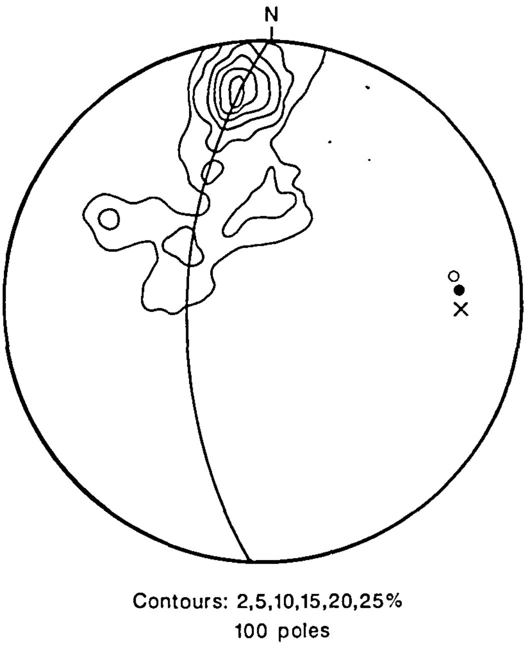


Fig. 3. Stereographic projection (equal area net, lower hemisphere) of poles to foliation in the basement, defining the D3 Bogøy Antiform: x — fold axis of Bogøy Antiform as determined from basement foliation, ● — fold axis of Bogøy Antiform as determined from cover S2 schistosity (from Fig. 2c), o — maximum of D3 minor fold axes in cover (from Fig. 2d).

Metamorphism

Recrystallization of the metasediments began during D1, with the formation of a schistosity. Garnet started to grow during D1 as indicated by sigmoidal inclusion trails within porphyroblasts. These early garnets were often fractured and augened during D2 deformation. Some of the staurolites and tourmalines are also pre-D2 as they contain inclusions delineating a pre-D2 schistosity discordant to the D2 schistosity which is flattened around them.

The present penetrative schistosity developed during D2, and is orientated subperpendicular to fine-grained syn-D1 inclusion trails in some of the porphyroblasts. Garnet growth continued during D2 as shown by inclusion trails in some porphyroblasts being orientated parallel to the schistosity and having a grainsize similar to that of the matrix; sometimes this growth was an overgrowth to the early pre-D2 garnets, which acted as nuclei. Rare post-D2 garnets, overgrowing the schistosity, are post-dated by staurolites. Biotite, and sometimes garnet, are partially retrogressed to post-D2 chlorite, and the D2 schistosity in places has been deformed by D3 crenulation folds associated with the development of the Bogøy Antiform.

Much of the present fabric of the Precambrian granite-gneisses is a product of the Caledonian D2 deformation. Syntectonic biotites form a foliation, and epidote, ferrohastingsite, actinolite and some of the sphenes are also commonly aligned within this fabric, indicating syntectonic growth. The epidotes and amphiboles are usually fractured, showing that their crystallization pre-dated the latest phases of deformation. Biotites, however, had a long period of growth, since while they are overprinted in places by epidote they usually postdate the latter. Similarly, poikiloblastic ferrohastingsites, which post-date quartz and feldspar, locally also enclose biotite, whereas they usually pre-date the biotite. Furthermore, in a few cases two phases of biotite are seen in one rock, where early biotite forms the foliation and is overgrown by later poikiloblastic biotites. Many of the muscovites are also late, forming poikiloblastic crystals growing perpendicular to the schistosity. Retrograde recrystallization is shown by the alteration of some biotites to chlorite. Another late event is the formation of rare, interstitial fluorite, which sometimes nucleates on biotite.

The overall picture of the Caledonian metamorphism is one of prograde regional metamorphism beginning during D1, and reaching a peak in the almandine-amphibolite facies during D2. This was followed by some post-D2 retrograde recrystallization and the formation of a D3 crenulation cleavage.

Geochemistry of the basement granite-gneisses

Chemical analyses of the basement granite-gneisses are presented in Table 1. Shaw (1972) developed a geochemical discriminant function to distinguish between orthogneisses and paragneisses. Positive discriminant function values ranging from 1.96 to 7.68 for the Steigen basement gneisses (Table 1) indicate that they are likely to be orthogneisses. This is in agreement with Cooper & Bradshaw (1980) who concluded that the basement gneisses in the Sørfold area of Salten, 40 km to the south, are mainly orthogneisses. An igneous parentage for the Steigen gneisses is supported by their extremely low Ni and Cr content (Van de Kamp et al. 1976).

In Fig. 4 the geochemistry of the Steigen granite-gneisses is compared with that of the granite-gneisses occurring in domes in the Sørfold area, based on data in Table 2; each element is normalized with respect to the average value for granite (Taylor 1964). The patterns for the two areas are very similar, and greatly different from the average granite. This is also shown clearly in Fig. 5 which emphasizes the high K and low Ca in the Steigen gneisses compared with average granite values, which is reflected by the high microcline/plagioclase ratio in the former. The low Sr is correlatable with low Ca. The Sørfold and Steigen gneisses are enriched in the incompatible trace elements compared with average granite values (Fig. 4), suggesting that they may be more fractionated or may have been generated by a lower degree of partial melting.

Petrogenesis of the basement granite-gneisses

Cooper & Bradshaw (1980) pointed out that the Sørfold basement gneisses are geochemically similar to the Precambrian rapakivi granites of Finland. Fig. 4 shows a close correspondence between rapakivi granites and the Nordland gneisses from Steigen and Sørfold. The slightly higher Na content of the Nordland granites (see also Fig. 5) is believed by Cooper & Bradshaw to be due to the effects of Caledonian metamorphism. They consider that the Nordland gneisses are Precambrian rapakivi granites which have been reactivated and tectonized at their margins during the Caledonian orogeny.

Rapakivi granites in Finland were emplaced during the Svecokarelian orogeny (2200—1800Ma). Their magmas are believed by Vorma (1976) to have been generated synorogenically as a partial melt by ultrametamorphism under conditions of intermediate- to high-pressure granulite facies, with their diapiric uprise taking place during a post-orogenic tensional regime. Support for this is given by geochemistry. K/Rb ratios for common continental igneous rocks usually fall within the range of 160-300, the average being about 230 (Heier & Billings 1969), but according to Heier & Billings (op. cit.) and Griffin et al. (1974, 1978), Rb is depleted in medium- to high-pressure granulites, giving high K/Rb ratios. K/Rb ratios for Finnish rapakivi granites are as low as 119, and Vorma (1976) concluded that these granites formed from anatectic melts complementary to refractory granulites, since they would be enriched in Rb, giving them low ratios. The K/Rb ratios in the Nordland gneisses are also lower than those of normal granites (Table 2). This, together with the enrichment of other incompatible elements in the Norwegian rocks, could be attributable to the process of partial anatexis, producing a rapakivi granite melt and a refractory granulite restite.

Deep-seated Precambrian granulites underlie the Lofoten Islands 50 km to the northwest (Griffin & Heier 1969, Heier & Compston 1969, Devaraju & Heier 1974, Griffin et al.

Table 1 Chemical analyses of basement granite-gneisses

Major elements	S49	S51	S53	S54	B56	B66	SA1	SA2	SA3	SA6
SiO_2	72.23	73.13	76.52	74.71	73.17	75.61	76.97	74.67	74.99	73.55
Al_2O_3	13.77	13.19	11.72	12.37	12.92	12.50	12.25	13.39	13.12	12.43
TiO_2	0.24	0.30	0.14	0.18	0.27	0.22	0.22	0.36	0.37	0.34
Fe_2O_3	1.02	0.92	0.60	0.60	1.21	0.53	0.77	1.08	0.51	2.56
FeO	1.44	1.37	1.10	1.30	1.28	0.60	0.40	0.43	0.86	0.11
MnO	0.04	0.03	0.02	0.02	0.05	0.02	0.02	0.02	0.01	0.07
MgO	0.17	0.43	0.11	0.32	0.27	0.09	0.22	0.54	0.43	0.29
CaO	0.65	0.53	0.48	0.58	0.44	0.38	0.50	0.54	0.41	0.50
Na_2O	4.24	4.17	3.61	3.50	4.13	4.02	3.96	4.05	3.76	4.03
K_2O	5.29	5.12	5.01	5.16	5.29	5.17	5.10	5.69	5.81	5.30
P_2O_5	0.01	0.04	0.00	0.03	0.02	0.04	0.02	0.08	0.09	0.05
H_2O	0.38	0.33	0.19	0.24	0.36	0.37	0.23	0.06	0.48	0.14
	99.48	**99.56**	**99.50**	**99.01**	**99.41**	**99.55**	**100.66**	**100.93**	**100.84**	**99.37**

Trace elements	S49	S51	S53	S54	B56	B66	SA1	SA2	SA3	SA6
Nb	31	30	33	26	10	26	23	27	28	26
Zr	320	331	169	183	332	175	163	272	273	461
Y	53	42	49	49	24	26	31	38	19	51
Sr	47	63	29	43	56	42	38	71	66	64
U	6	5	4	3	2	12	9	4	17	10
Rb	244	193	239	225	127	280	289	283	229	171
Th	29	34	52	44	13	40	44	43	26	23
Pb	21	22	12	19	20	22	31	20	21	32
Ga	21	20	22	21	19	23	n.d.	n.d.	n.d.	n.d.
Zn	49	45	24	39	67	14	15	32	24	70
Cu	n.d.	3	4	8	7	3	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	3	3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ni	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6	7	5	6
Co	44	64	53	58	61	55	131	120	79	73
Nd	80	33	80	89	89	38	39	53	31	98
Sm	15	n.d.	n.d.	21	15	n.d.	2	18	2	12
Ce	155	69	189	262	192	123	117	144	61	212
Ba	269	315	150	194	199	159	191	387	497	319
La	80	26	93	128	107	23	66	66	32	106
D.F.	3.72	3.07	1.96	7.68	3.14	2.98	2.50	3.03	2.69	2.88

D.F. = discriminant function (Shaw 1972)
n.d. = not determined

Table 2 Comparative geochemistry of granites

	1	2	3	4
SiO_2	74.55	72.40	72.58	69.10
Al_2O_3	12.77	13.10	13.32	14.55
TiO_2	0.26	0.32	0.34	0.38
Fe_2O_3	0.98	0.22	0.76	3.85*
FeO	0.89	2.13	2.14	
MnO	0.03	0.05	0.04	0.05
MgO	0.29	0.51	0.25	0.27
CaO	0.50	0.89	1.17	2.21
Na_2O	3.95	3.92	2.65	3.73
K_2O	5.29	5.71	5.63	4.02
P_2O_5	0.04	0.07	0.07	0.16
Rb	228	257	393	150
Sr	52	69	71	285
Zr	268	468	266	180
Ba	268	408	644	600
La	73	109	100	40
Th	36	28	39	17
U	7	9	6	5
K/Rb	193	184	119	222

1. Average of 10 granite-gneisses from Steigen (this study)
2. Average of 14 granite-gneisses from Salta (Cooper & Bradshaw 1980)
3. Average of 52 rapakivi granites from Laitila (Vorma 1952)
4. Average values for granites (Taylor 1964)

* Total Fe as FeO

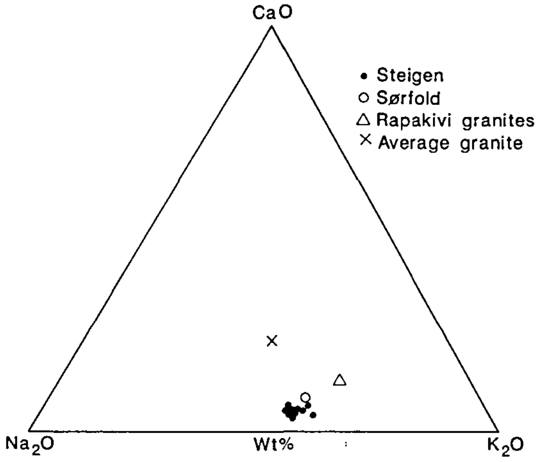


Fig. 5. Plots of granites from Steigen (10 analyses — this study) and Sørfold (average of 14 analyses — Cooper & Bradshaw (1980)), compared with rapakivi granites (average of 52 analyses from Laitila — Vorma (1976) and average values for granites (Taylor 1964).

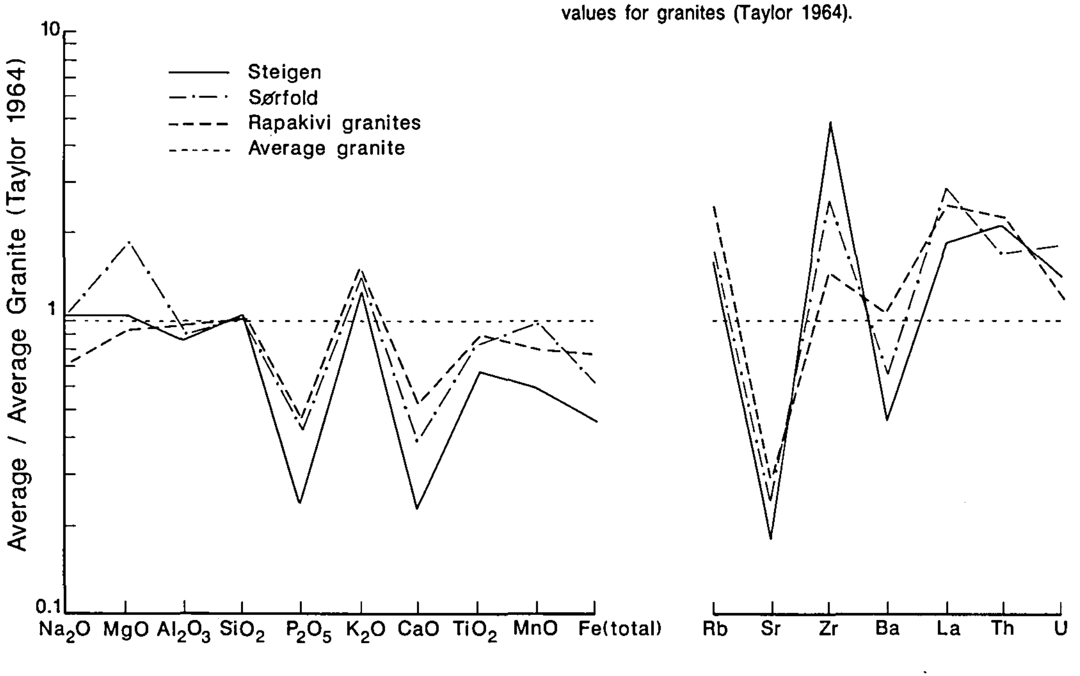


Fig. 4. Major and trace elements in granites, normalized with respect to average values for granites (Taylor 1964), from Steigen (average of 10 analyses — this study) and Sørfold (average of 14 analyses — Cooper & Bradshaw 1980), compared with rapakivi granites (average of 52 analyses from Laitila — Vorma 1976). Data are given in Table 2.

1974, 1978, Griffin & Taylor 1978). The granulite metamorphism reached its peak at about 1830Ma and was followed by intrusion of mangerites and charnockites at around 1800—1700Ma (Griffin et al. 1978). The Tysfjord granitic gneiss basement dome, 50 km to the northeast of the Steigen culmination, is of similar age to the Lofoten—Vesterålen mangerites, and underlies and is infolded with Caledonian cover (Malm & Ormaasen 1978). At its western margin, the Tysfjord gneisses have transitional intermingling contacts with mangerites, and are considered by Malm & Ormaasen to be either retrograded acid mangerites and charnockites, or a hydrous magma derived late in the evolution of the mangeritic series and emplaced at higher crustal levels than the mangerites. Cooper & Bradshaw (1980) envisaged a Svecokarelian intrusive zone exending from southern Finland through Nordland to Lofoten, with the Salten basement gneisses having a rapakivi origin, developed from the evolution of mangeritic anatectic melts. They consider that petrogenetically related rocks, similar to the mangerites of Lofoten, may still be present at depth beneath Nordland.

The tectonostratigraphic status of Precambrian granite-gneiss domes in western Nordland and their relationship to the cover are uncertain (Stephens et al. 1985, Lindqvist 1988). These gneisses are either westerly extensions of the Baltoscandian craton (Wilson & Nicholson 1973, Lindqvist 1988), and form part of the autochthon/parautochthon, or are integral parts of the Upper Allochthon, having become completely detached from the underlying Precambrian crystalline rocks of the autochthon/parautochthon (Stephens et al. 1985). In the absence of geophysical data, it is not possible to be certain about the extent of the sole thrust westwards beneath the Caledonides (Gorbatschev 1985). In the former case the granite-gneisses would have been derived from Baltoscandian crust, while in the latter their source must have been some distance to the west.

Gorbatschev (1985) has pointed out that the Caledonides of Nordland are underlain by the Proterozoic Transscandinavian Granite-Porphyry Belt of alkaline granites, syenites and monzonites which were intruded into cratonic Svecokarelian crust contemporaneously with the emplacement of rapakivi granites. He considered that the chemical variations and N-S trend of the Transscadinavian Belt militate against a correlation between Nordland basement granite-gneisses and Finnish rapakivi granites. However, Lindqvist (1988) uses the geochemical similarities between these two groups of rocks in support of the deduction that the Nordland basement windows form a westerly continuation of the Baltic craton.

The present work indicates that the granite-gneisses of the Steigen Dome are closely related geochemically to those of the Sørfold area, and probably represent rapakivi granites originally emplaced during the Svecokarelian orogeny. During the Caledonian orogeny the Precambrian sialic basement was passive in the eastern part, but became progressively Caledonized by metamorphism towards the west (Gorbatschev 1985), where the basement became quite ductile with a tendency to rise in the form of anticlinal cores, domes and diapirs (Ramberg 1981). Diapiric rise of the basement after initial nappe translation is one possible mechanism for the uplift of the Precambrian basement domes (Dyrelius 1985).

In Nordland, the basement granites were covered by a relatively dense metasedimentary sequence during D1, creating a gravitationally metastable system which started to become stabilized during D2 by the increasing grade of regional metamorphism (cf. Cooper & Bradshaw 1980). The metamorphic thermal energy may have caused the low-density rapakivi granites to rise diapirically to form basement granite-gneiss domes, in the manner described by Eskola (1949) and Grocott et al. (1987), modelled by Fletcher (1972) and Ramberg (1981), and studied experimentally by Talbot (1974). This late updoming could have caused the D3 folding of the metasedimentary cover rocks, which were transported away from the rising basement culminations towards the depressions that now occur between the granite domes of Nordland.

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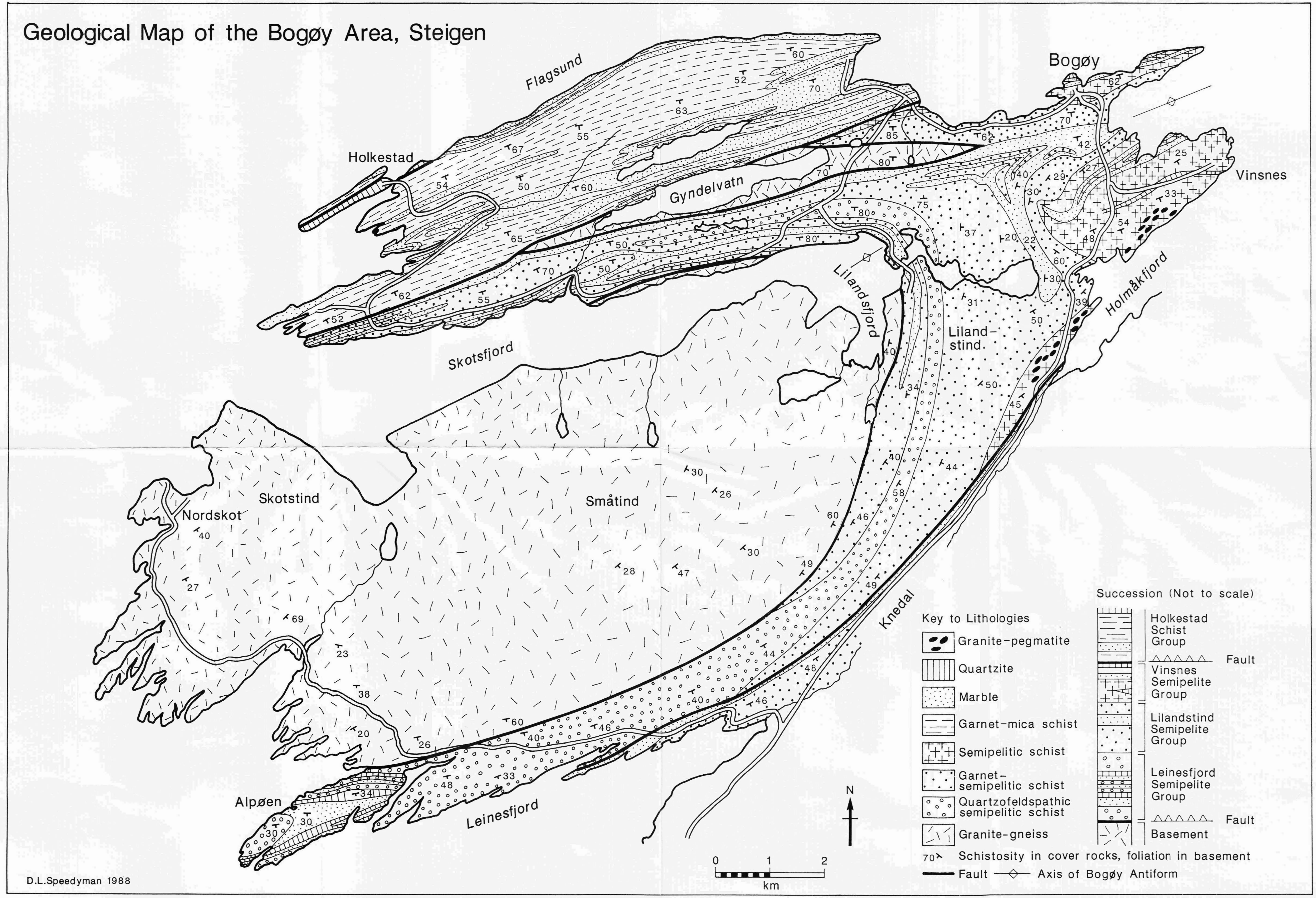
Geological Map of the Bogøy Area, Steigen



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