# The geology of the northern Sulitjelma area and its relationship to the Sulitjelma Ophiolite

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The geology of the area to the north of Sulitjelma is dominated by the Skaiti Supergroup, which occurs at the top of the Upper Allochthon beneath overthrust rocks of the Uppermost Allochthon. The regional geology comprises a locally inverted, stratified ophiolite, the Sulitjelma Ophiolite, which partly intrudes the overlying rocks of the Skaiti Supergroup. These older higher grade rocks consist of a continuous 1 km thick sequence of gneisses, quartzites, semipelites, graphitic and calcareous schists, which are associated with several levels of metaigneous rocks. The most important of these are the Rupsielven Amphibolites, which are geochemically analogous to within-plate oceanic island basalts and are therefore distinct from the metabasic rocks of the Sulitjelma Ophiolite. The main period of regional deformation and metamorphism occurred during the Scandian event of the Caledonian Orogeny. Evidence is presented to show that the older metasediments and metabasites of the Supergroup retain the signature of an earlier orogenic event of possible Finnmarkian age or older. The Skaiti Supergroup therefore represents a fragment of pre-Scandian continental crust through which the ophiolitic rocks were originally intruded and onto which they were locally erupted.

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The Sulitjelma area (67°10′N, 15°21′S) is situated approximately 70 km north of the Arctic Circle straddling the international boundary between Norway and Sweden (Fig. 1). The cover rocks occur within the Upper Allochthon of the Scandinavian Caledonides (Roberts et al. 1981), and form part of the Koli Nappe (Kulling 1972). The main period of regional metamorphism and deformation in the Sulitjelma area is related to the Scandian phase of the Caledonian Orogeny (Wilson 1972; Boyle et al. 1985).

The structurally lowest rocks are a series of greenschist/lower amphibolite facies metasediments known as the Sjonsta and Furulund Groups (Table 1). The latter, which contains fossils of Middle-Upper Ordovician age (Vogt 1927), is overlain by the Sulitjelma Amphibolites. In the area to the north of Sulitjelma, the contact between these two units is extensively brecciated and chloritized and marks the level of major Cu–Fe–Zn–S ore-bearing horizons. Structurally overlying the Sulitjelma Amphibolites is a sequence of upper amphibolite facies metasediments and metabasites known as the Skaiti Supergroup. In the past these rocks have been called the Gasak Nappe (Kautsky 1953) or the Sulitjelma Schist Sequence (Wilson 1973), but have been renamed the Skaiti Supergroup after an area to the south (Boyle et al. 1985). The Supergroup is intruded by the Furulund Granite and the Sulitjelma Gabbro Complex, the largest of several major intrusions at this level. The Skaiti Supergroup also outcrops further south in Baldaoivve and Skaiti and in an isolated area to the north (Fig. 1).

The Sulitjelma area, bounded to the north and south by the Tysfjord and Nasafjell Precambrian basement culminations respectively and by the Fauske Nappe to the west and the Sjonsta Group to the east, has long been regarded as a classic area for research in the Scandinavian Caledonides. Major contributions to the understanding of the geology include:

(1) Sjögren's pioneer mapping in the late nineteenth century, culminating in the publication

*Table 1.* The tectonostratigraphy of the Upper Allochthon in the Sulitjelma area.

| Regional Tectonostratigraphy | Kautsky's Nappe Units |
|---|---|
| Skaiti Supergroup | Gasak Nappe |
| Sulitjelma Amphibolites | Vasten Nappe |
| Furulund Group | |
| Sjonsta Group | Pieske Nappe |

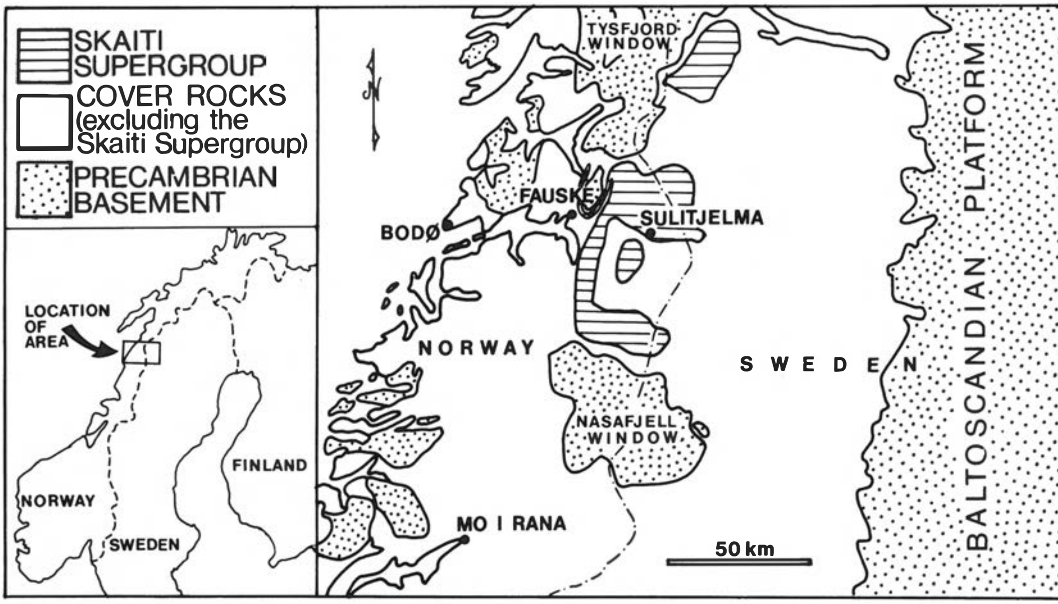


*Fig. 1.* Simplified geological map of the central Scandinavian Caledonides between 66° N and 68° N (after Nicholson & Rutland 1969).

of the first geological map of the Sulitjelma region (Sjögren 1900),

(2) the publication of a comprehensive memoir of the area between Baldaoivve to the south and Blåmannsisen to the north by Vogt (1927),

(3) Kautsky's (1953) reinterpretation of the regional geology as a series of thrust sheets, and

(4) Nicholson & Rutland's (1969) regional synthesis of the area between Bodø and Sulitjelma.

More recently Boyle (1980) and Boyle et al. (1985) have shown that the Sulitjelma Amphibolites and the Sulitjelma Gabbro Complex are a comagmatic suite of inverted ophiolitic rocks. These comprise a layered gabbro (the Sulitjelma Gabbro Complex), which is stratigraphically overlain by a sheeted dyke complex (the Mietjerpakte Sheeted Intrusive Complex), which in turn feeds and intrudes a thick sequence of pillow lavas (the Otervatn Volcanic Formation). The contact between the layered gabbros and the overlying volcanic and sub-volcanic rocks is locally marked by the development of a unit of highly deformed, coarse-grained Flaser Gabbro. The major inversion of the stratigraphy implies that the structurally highest unit in the area, the Skaiti Supergroup, may be older than the Sulitjelma Ophiolite.

The following account describes the tectonostratigraphy and structural geology of the Skaiti Supergroup in the area to the north of Sulitjelma (Fig. 2). It also highlights a number of interesting relationships between the Skaiti Supergroup and the Sulitjelma Ophiolite. In recent years several workers (Henley 1968; Wilson 1968; Nicholson & Rutland 1969; Cooper et al. 1979) have studied specific parts of the Skaiti Supergroup, in areas close to the Sulitjelma Mountains and the Sulitjelma Ore Field. This contribution represents a summary of part of a more detailed study of the Supergroup in the area to the north of Sulitjelma, and shows that it has a more complex geological history than the Sulitjelma Ophiolite, the Furulund Group and the Sjonsta Group.

## Tectonostratigraphy of the Skaiti Supergroup

The distribution of the major rock types of the Skaiti Supergroup to the north of Sulitjelma shown in Fig. 2 is based on a more detailed 1:16,400 geological map of the area (Billett 1984).

The lithological boundaries trend east–west through most of the area, and are parallel to the regional schistosity. In the north and east the contacts veer towards north–east, south–west. The outcrop pattern is largely controlled by a late, open, east–west trending fold known as the Røtind Synform which repeats much of the succession to the north and west of Stormfjellet. The structurally lowest metasediments are a series of gneisses and quartzites which are well-developed in the north–east and the north–west of the area. They are overlain by a group of rusty and calcareous schists, which in turn give way to aluminous pelites and semi-pelites at the top of the succession. Although the Skaiti Supergroup is primarily a sequence of metasediments, there are a number of important developments of meta-igneous rocks. The most significant are the Rupsielven Amphibolites, which occur near the top of the succession between the Rusty Schists and the Røtind Schist.

A stratigraphy of the Skaiti Supergroup has been set up using both well-established names, such as Røtind Schist (Sjögren 1900), Lapphelleren Schist (Wilson 1968) and new descriptive terms such as garnet-hornblende gneiss. The tectonostratigraphy presented in this paper (Table 2) is a simplified version of that used in Billett (1984).

## Metasedimentary rocks

### *Gneiss*

The structurally lowest unit in the Skaiti Supergroup is a series of foliated, coarse-grained gneisses comprising both leucocratic augen gneiss and garnet-hornblende gneiss. The former outcrops extensively to the west of the study area, where it forms typical rounded outcrops in the low-lying ground towards Skoffedalfjellet (Kollung 1980). The dominant lithology is a medium- to coarse-grained quartzo-feldspathic orthogneiss containing segregations of biotite and muscovite with or without garnet. Petrographically it comprises quartz–plagioclase–biotite–muscovite–clinozoisite ± garnet–apatite. Texturally it is dominated by large recrystallized (5 mm) plagioclase augen, which forms up to 50% of the mode. The leucocratic gneiss is overlain by the Calcareous Amphibolite, the latter being intensely cross-cut by quartzo-feldspathic pegmatite veins. At the contact veining is so intense that the amphibolite becomes volumetrically insignificant, forming rare screens amongst the pegmatites. Veining decreases in frequency away from the contact, and at a distance of 100 m it virtually ceases. The distribution of pegmatite veining shows that it originated from the leucocratic gneiss, which is considered to have undergone partial melting and remobilization.

The second group of gneisses, the garnet–hornblende gneiss, comprises 1–4 mm clots of garnet and quartz in a medium- to coarse-grained light green matrix rich in amphibole, quartz, biotite and muscovite. It frequently develops a strong banding consisting of alternating leucocratic and darker hornblende–biotite rich bands. Kyanite and staurolite are common porphyroblast phases. These paragneisses have sharp contacts with the units above.

*Table 2.* Tectonostratigraphy of the Skaiti Supergroup to the north of Sulitjelma, showing the main levels at which meta-igneous rocks occur.

| Metasedimentary rocks | Metaigneous rocks |
|---|---|
| Lapphelleren Schist | Furulund Granite |
| Røtind Schist | |
| Rusty Schists (rusty pelite and semi-pelite, graphitic schist and calcareous schist) | Rupsielven Amphibolites<br>Sorjus 2 Metagabbro |
| Rusty Micaceous Quartzite and Metaconglomerate | Foliated Metagabbro |
| Gneisses (garnet-hornblende gneiss and leucocratic gneiss) | Calcareous Amphibolite |

### *Quartzite-metaconglomerate unit*

A sequence of micaceous quartzite and metaconglomerate, which overlie the basal gneisses and are easily recognizable in the field by their white, saccaroidal and often rusty appearance, occurs at a number of levels in the Skaiti Supergroup (Fig. 2). The rusty colouration is due to the weathering of up to 10% disseminated or banded pyrite. Metaconglomerate horizons are a characteristic feature of the unit, consisting of elongate, flattened, grey quartzite and white quartz clasts in a muscovite-rich matrix. Individual metaconglomerate bands contain a wide distribution of clast sizes, ranging from 3 to 150 cm in length. The larger fragments are enclosed in a deformed matrix consisting of small quartz clasts and mica.

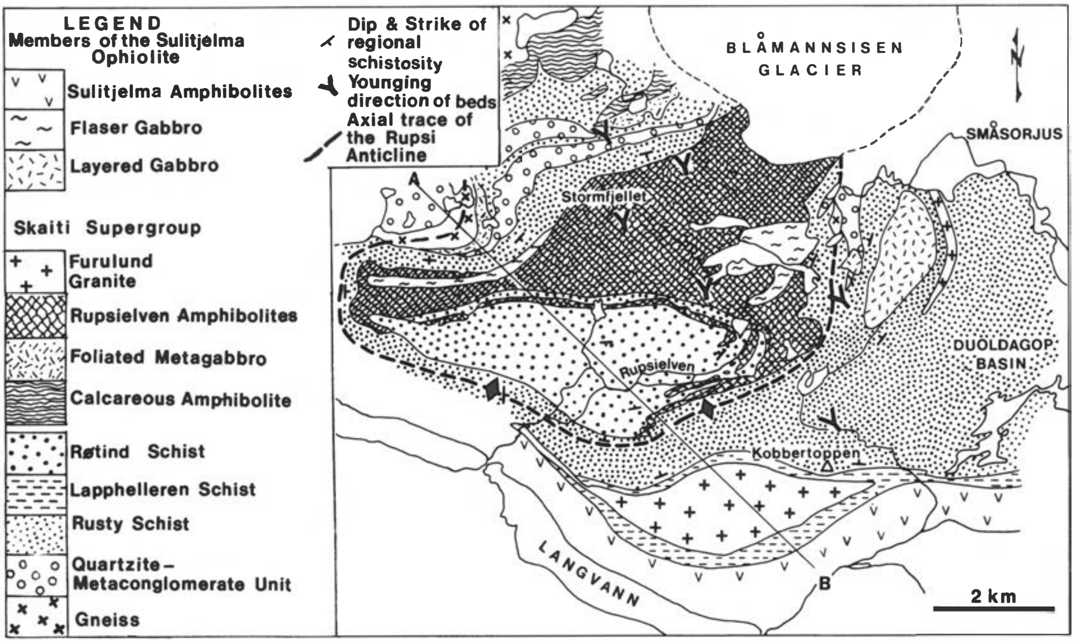


*Fig. 2.* Simplified geological map of the area to the north of Sulitjelma, showing the distribution of the major units.

Petrographically the quartzite is a fine- to coarse-grained rock with a poor schistosity and consists of quartz–muscovite–green biotite ± kyanite – staurolite – plagioclase – pyrite – clinozoisite–tourmaline–chlorite. Porphyroblasts are common, particularly in the more aluminous horizons, where kyanite and occasionally staurolite are present.

## *Rusty Schists*

Rusty weathering pelites and semi-pelites are not only the most extensive and characteristic unit of the Skaiti Supergroup, but as Sjögren (1900) pointed out, the most widespread and important unit in northern Sulitjelma (Fig. 2). The term Rusty Schists (Billett 1984) groups together a large number of lithologies which include pelites, semi-pelites, calcareous and graphitic schists (Table 2).

The Rusty Schist *sensu stricto* comprises fine- to medium-grained, well-banded, semi-pelites containing the assemblage quartz–muscovite–biotite–pyrite ± plagioclase–clinozoisite. The rusty colouration, which is ubiquitous throughout the unit, is attributed to the oxidation of drusy pyrite along cleavage planes.

The calcareous schist forms a 300 m thick unit to the north of Kobbertoppen. It has a grey, irregular weathering appearance, related to the presence of quartz- and amphibole-rich lenses in a soft fine-grained schistose matrix. In thin-section the calcareous schist comprises quartz–clinozoisite–biotite–muscovite–calcite–sphene ± garnet–plagioclase–hornblende-opaques. Porphyroblasts are common, particularly of garnet, muscovite and hornblende.

The structurally highest member of the Rusty Schist Unit is a 150 m thick horizon of graphitic schist. In the field it appears as a fissile, rusty-purple weathering, well-foliated, fine-grained phyllite containing 1–2 mm clasts of quartz. Petrographically the graphitic schist comprises quartz–muscovite–graphite ± biotite–garnet–chlorite–clinozoisite. A unit of fragmental graphitic schist, which outcrops to the north of Stormfjellet, comprises a 50 m thick graphitic phyllite containing numerous folded and broken fragments of pure graphite. Nicholson & Rutland (1969) have described a similar unit of graphitic schist containing clasts of graphite to the north-east of Sorjusvann.

### Lapphelleren Schist

The Rusty Schists are stratigraphically overlain by a diverse group of pelitic, garnet–mica–quartz schists, which Wilson (1968) termed the Lapphelleren Schist after a locality to the north of Sulitjelma. The Lapphelleren Schist dips at 10–45° to the north and north–east and attains a maximum thickness of 270 m. The Furulund Granite also occurs at this level in the succession, where it is enclosed in an envelope of Lapphelleren Schist.

Under the general umbrella term pelitic, the Lapphelleren Schist comprises a diverse sequence of phyllites, semi-pelites and quartz–biotite–amphibole schists (Billett 1984). Detailed investigations of the lithological variation within the unit show that it represents a continuous stratigraphic sequence (Billett 1984).

The most common lithology of the Lapphelleren Schist comprises bands or lenses of quartz in a pink-red matrix of garnet, muscovite and biotite. Porphyroblasts of kyanite and staurolite are common, in addition to calc-silicate knots and minor amphibolite bands.

### Røtind Schist

The Røtind Schist, the structurally highest unit in the area, occurs in the core of the Røtind Synform, where it lies above the Rupsielven Amphibolites. It is well-exposed over an area of 7 $km^2$ and has a vertical thickness in excess of 200 m.

In the field it appears as a strongly foliated aluminous schist containing visible porphyroblasts of garnet, staurolite and kyanite in a banded fine-grained matrix, consisting of 1 mm bands of quartz, biotite and muscovite. Petrographically it is similar to the more common aluminous assemblages in the Lapphelleren Schist. Two of the most striking features of the Røtind Schist, however, are its overall lithological uniformity and the occurrence of abundant quartz lenses and boudins. This often gives it a gneissose appearance.

## Metaigneous rocks

The Skaiti Supergroup contains a large number of basic and acidic metaigneous rocks, which are intruded by dykes, Flaser Gabbros and layered gabbros. These later intrusions, which are analogous to the stratigraphically lower members of the Sulitjelma Ophiolite, are discussed in a later section.

### Calcareous Amphibolite

The Calcareous Amphibolite interdigitates with the metasediments occurring close to the structural base of the Skaiti Supergroup, and rests on the basal gneisses. It reaches a maximum thickness of 240 m to the west of the Blåmannsisen Glacier and is characterized by the occurrence of orange weathering carbonate (up to 10%) in veinlets, cavities or as a matrix mineral. In the field it outcrops as a homogeneous, poorly-foliated, fine-grained amphibolite containing common relict vesicles and rare pseudomorphs after plagioclase phenocrysts.

Petrographically it comprises the assemblage hornblende – plagioclase – calcite – sphene ± clinozoisite–muscovite–quartz–chlorite–opaques. Rare hornblende porphyroblasts retain a relict inclusion fabric, which is oblique to the regional mineral lineation defined by the preferred orientation of idiomorphic hornblende.

### Foliated Metagabbro

The Calcareous Amphibolite is overlain to the north of Stormfjellet (Fig. 2) by a 50 m thick, homogeneous, coarse-grained, moderately- to well-foliated metagabbro consisting of visible, 5–15 mm, dark-green hornblende prisms in a fine-grained feldspar-rich matrix. A smaller body of Foliated Metagabbro also crops out to the west of Stormfjellet. Although both metagabbros have been extensively deformed and folded, the northern intrusion still contains features such as xenoliths of highly deformed semi-pelitic country rocks and cross-cutting metabasic dykes.

Both metagabbros develop a podiform structure in the field, characterized by 40–50 cm lenses of coarse-grained metagabbro in a fine-grained deformed or mylonitic hornblende-rich matrix. They contain the assemblage hornblende–plagioclase–sphene ± various minor phases. The main textural feature is the presence of large (1.5 cm) randomly orientated poikiloblastic hornblende.

### *Rupsielven Amphibolites*

The most extensive development of metabasic rocks in the Skaiti Supergroup occurs close to the top of the succession, between the Rusty Schists and the overlying Røtind Schist. The Rupsielven Amphibolites reach a maximum thickness of 700 m in the Stormfjellet area and thin progressively and die out eventually towards the south-west, where they are in contact with the Røtind Schist (Fig. 2). Although this outcrop pattern appears to suggest a tectonic contact, there is no field evidence to support this and it appears that it represents an original thinning of the volcanic succession.

The Rupsielven Amphibolites consist of schistose coarse-grained and porphyritic metabasites, in which pillowed and massive lavas, pillow breccias, volcano-clastic rocks and dykes are commonly preserved and exposed over an area of 13 sq km. In their field relationships and petrography they show some similarities to the Sulitjelma Amphibolites. A more detailed comparison of both groups of metaigneous rocks will be made later (p. 23).

The most common rock type (approx. 70%) of the Rupsielven Amphibolites are porphyritic metabasites. These contain between 30 and 40% (rarely up to 80%) pseudomorphs after plagioclase phenocrysts. At several levels an original volcanic stratigraphy can be recognized in which individual 0.5–2 m thick pillowed flows are intercalated with pillow breccia horizons. A similar stratigraphy has been described from modern pillow lava sequences whose formation has been observed in Iceland and Hawaii (Wells et al. 1979; Moore et al. 1973). The Rupsielven Amphibolites also contain intercalated pelite, semi-pelite, dolomite-magnetite and garnet-rich bands.

The petrography of the Rupsielven Amphibolites is characteristic of middle- to upper amphibolite facies conditions. They comprise the assemblage hornblende–plagioclase–clinozoisite–sphene ± muscovite–garnet–opaques. Garnet porphyroblasts occur throughout the succession and commonly form porphyroblasts up to 3-4 mm in size. Clinopyroxene bearing assemblages have not been observed in the Rupsielven Amphibolites.

### *Furulund Granite*

Granitic intrusions, which are generally absent from the structurally lower units in the Sulitjelma area, such as the Furulund Group and the Sulitjelma Amphibolites, are relatively common in the Skaiti Supergroup. The Furulund Granite, described in detail by Vogt (1927) and Wilson (1968), is the most important of these intrusions. It is a homogeneous, coarse-grained, granite-gneiss which is characterized by the presence of approximately 1 cm diameter K-feldspar augen in a foliated matrix of quartz, plagioclase, muscovite and biotite. A L–S fabric, which is particularly well-developed at the margins of the intrusion, is defined by the preferred orientation of muscovite and biotite.

The metasediments surrounding the Furulund Granite contain numerous granitic apophyses up to 8 m in width, which have been affected by F2 folding. This implies that the intrusion pre-dates or is penecontemporaneous with the regional (Scandian) deformation. Wilson (1968, 1981) obtained a Rb–Sr wholerock isochron of 424 ± 11 Ma for the Furulund Granite; this age suggests that the intrusion was emplaced during the Scandian Orogeny.

## Geological history of the Skaiti Supergroup

The Caledonides in Norway involve two principal orogenic events; an early Upper Cambrian–Lower Ordovician (490–530 Ma) event known as the Finnmarkian, and a later Middle–Upper Silurian (400–425 Ma) event known as the Scandian (Roberts & Sturt 1980). The Finnmarkian event is best developed in the Finnmark region of northern Norway (Sturt et al. 1978), whereas the Scandian event is well developed throughout Norway and Sweden and represents the major tectonic event throughout the Sulitjelma area. Using K–Ar radiometric dating, Wilson (1972) indicates that the argon blocking temperatures of hornblende and biotite occurred around 420 Ma; this concurs well with the date of the Scandian event elsewhere in the Scandinavian Caledonides (Roberts & Sturt 1980). One of the most important features of the Scandian event in the Sulitjelma region is the development of a regional penetrative schistosity, defined by the planar growth of hornblende and biotite in the metabasites and muscovite and biotite in the metasediments. The Scandian event is also responsible for Barrovian type regional metamorphism, which reaches kyanite and sillimanite grade in the Skaiti Supergroup. Boyle et al. (1985) also suggest that the Sulitjelma Fold Nappe Complex was formed during the Scandian event. This deformation event will be referred to henceforth as D2. In addition, the Skaiti Supergroup also retains the imprint of an earlier orogenic event (D1).

## Pre-Scandian deformation and metamorphism

Fig. 3 shows the development of two fabrics in the Rupsielven Amphibolites. The field relationships suggest that the intrusion of the dykes took place after the deformation event that produced a D1 fabric in the volcanic and volcano-clastic horizons.

Although rare and difficult to recognize in the field, the Skaiti Supergroup preserves evidence of a pre-Scandian folding event. These tight to isoclinal folds are best preserved at the contact of the Foliated Metagabbro, which itself has been deformed and metamorphosed during the regional Scandian event. The contacts of the metagabbro cross-cut folds in the surrounding country rocks, implying that intrusion and subsequent deformation and metamorphism took place after development of the F1 folds.

Tight to isoclinal folds occur elsewhere in the Skaiti Supergroup and, although comparable to many Scandian structures, the axial planes of the pre-Scandian folds still retain angular discordances with lithological contacts. The F1 fold axes are cross-cut and deformed by the regional fabric, the latter being axial planar to the F2 Scandian structures. The axial planes of Scandian structures are always parallel to the regional foliation and major lithological contacts.

Evidence for a D1 orogenic event is augmented by petrographic evidence from the metabasites. Large relict hornblende prisms containing a pre-existing fabric, form 2–4 mm, partially recrystallized, altered poikiloblasts with a patchy

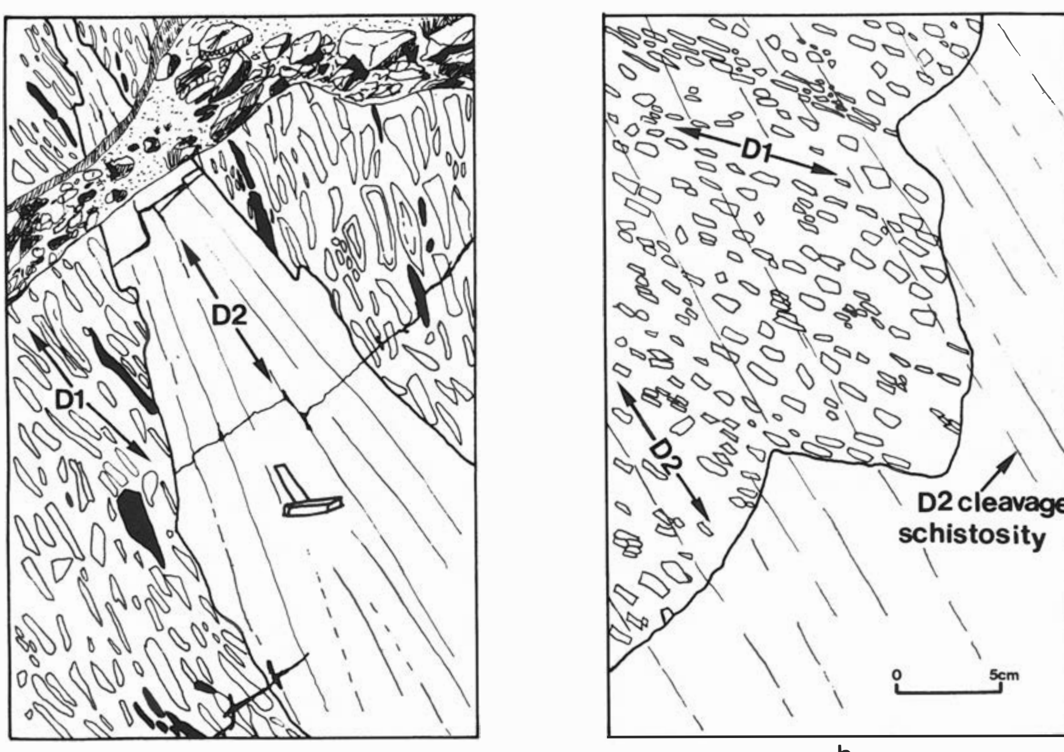


*Fig. 3.* Fabrics in the Rupsielven Amphibolites. a. D2 fabric in a metabasic dyke truncating a pre-existing D1 fabric in a fragmental volcano-clastic horizon. b. D1 deformation event preserved in a porphyritic amphibolite cross-cut by a later metabasic dyke. Both rock types are overprinted by the later D2 regional deformation.

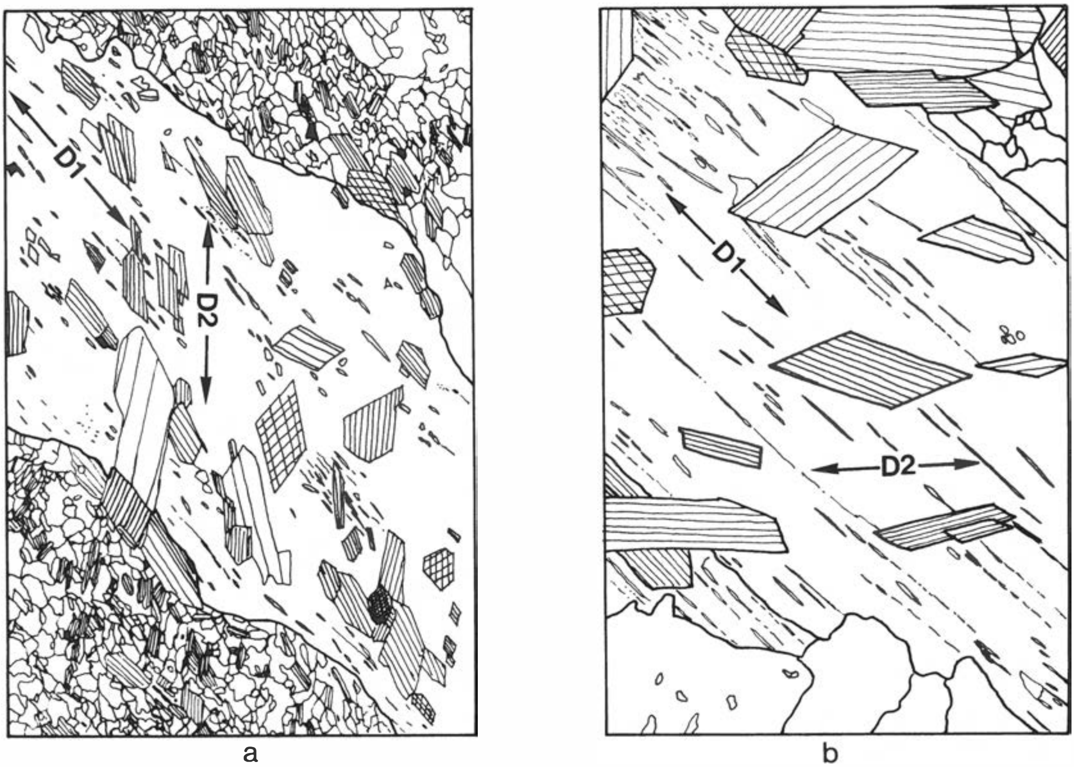


*Fig. 4.* Petrographic evidence for an early pre-Scandian period of deformation and metamorphism. a. Early D1 fabric preserved in quartz and sphene inclusion trails in a relict hornblende poikiloblast. The inclusion trails are overgrown by euhedral hornblende crystals exhibiting a D2 deformation fabric (×30). b. Euhedral hornblende prisms overprinting a large poikiloblast (×50).

extinction (Figs. 4a and 4b). Many are clearly orientated at an angle to the regional (S2) schistosity and are overgrown by finer grained (1–2 mm), fresh euhedral hornblende prisms which define a good regional lineation.

The evidence outlined above, therefore, suggests that the Skaiti Supergroup has been affected by a pre-Scandian metamorphic and tectonic event which has not been recognized in the Sulitejelma Ophiolite or the younger Furulund and Sjonsta Groups. The pre-Scandian structures and metamorphic minerals observed in the Skaiti Supergroup may be comparable with those preserved in xenoliths and in the contact aureole of the Sulitjelma Gabbro Complex (Mason 1971).

## The Rupsi Anticline

Way-up criteria have been used to unravel the structural geology of the Skaiti Supergroup and to identify a major fold in the area. Younging directions from pillow lavas have already been successfully used to define a major isoclinal fold in the Sulitjelma Amphibolites, which has an inverted upper limb and a normal lower limb (Boyle et al. 1979). The inverted upper limb of the so-called Vaknahelleren Syncline includes the layered gabbros, sheeted dykes and pillow lavas of the Sulitjelma Ophiolite. Recognition of a stratigraphic inversion at this level and within the Furulund Group (Kirk & Mason 1984; Kekwick in press) suggests that the Furulund and Sjonsta Groups, which lie structurally beneath the ophiolite, represent the youngest units in the area. The inversion of the stratigraphy also suggests that the Skaiti Supergroup, occurring structurally above the ophiolite, may in fact be older than the ophiolite. The older age of the Skaiti Supergroup is clearly indicated by the intrusive nature of the Sulitjelma Ophiolite (Mason 1980).

Pillow lavas in the Rupsielven Amphibolites have been used in the same way to unravel the structural geology of the Skaiti Supergroup. They

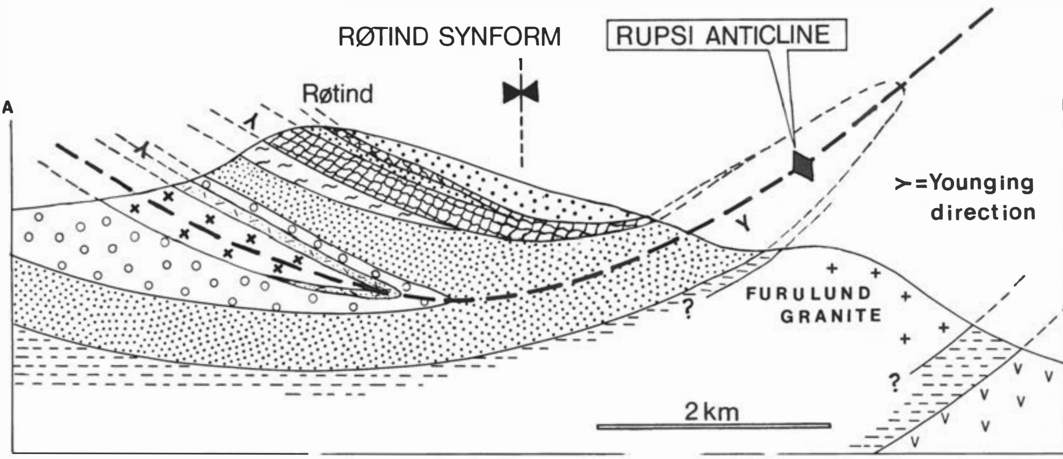


*Fig. 5.* Northwest-southeast cross-section of the area to the north of Sulitjelma (refer to Fig. 2).

show that a major part of the Supergroup is right way-up, as the lavas dip and young in the same direction (Figs. 2 and 5). This implies that the stratigraphically lowest and oldest unit in the Skaiti Supergroup are the gneisses, and the youngest and highest unit the Røtind Schist. The recognition of right way up strata in the Supergroup also implies that, since the Rupsielven Amphibolites and the Sulitjelma Amphibolites young in opposite directions, there must be a structural inversion, possibly a major isoclinal fold, with an axial surface that lies between the two units in the upper part of the Skaiti Supergroup.

Younging directions from graded bedding and cross-bedding are also summarized in Fig. 2. They show that the upper members of the Supergroup are inverted in the region to the north and north-east of Kobbertoppen, as the beds dip and young in opposite directions. The presence of overturned strata close to the contact with the Sulitjelma Amphibolites suggests that the upper members of the Supergroup form part of the inverted limb of the Vaknahelleren Syncline (Boyle et al. 1985). These inverted units also help to delineate the axial trace of the major isoclinal fold structure in the Skaiti Supergroup (Figs. 2 and 5). This fold, which is formally named the Rupsi Anticline, has a similar stature and amplitude to the Vaknahelleren Syncline. A feature of this model is that it regards the Lapphelleren Schist as a structural repetition of the Røtind Schist (Fig. 5). Although there are close lithological similarities between the two units, the Lapphelleren Schist does contain a number of minor rock types not seen in the Røtind Schist. The most likely reason for their absence is large-scale facies variation. The model also implies that the Furulund Granite and the Sulitjelma Amphibolites and their associated ore bearing horizons may outcrop to the north-west of the study area on the western side of Blåmannsisen.

The recognition of a major isoclinal fold structure in the Skaiti Supergroup suggests that a repetition of units should occur across the axial plane of the Rupsi Anticline. Fig. 2 shows that many of the units do occur on both limbs of the Røtind Synform, an open, late Scandian structure, which formed after the Rupsi Anticline. The Quartzite–Metaconglomerate unit, for example, outcrops above and below the gneisses on both limbs of the Røtind Synform. This suggests that the outcrop pattern is caused by a structural repetition across a major axis, with gneisses outcropping in the core. The Rusty Schists overlie the Quartzite–Metaconglomerate unit to the west of Stormfjellet and Sjögren (1900) and Kollung (1980) have mapped large areas of Rusty Schists to the north and west of the study area. This suggests that they may underlie as well as overlie the Quartzite–Metaconglomerate unit (Fig. 5). The outcrop pattern produced by the folding of the Rupsi Anticline by the Røtind Synform is similar to Ramsay's 'Type 3' fold interference pattern, produced when recumbent folds are refolded by later structures with upright axial surfaces (Ramsay 1967).

The repetition of major lithological units across the axis of the Rupsi Anticline suggests that the gneisses represent the oldest exposed rocks in the Skaiti Supergroup, with younger rocks outcropping structurally above and below. The outcrop pattern of the major units also implies that the fold closes to the south–west, as the gneisses and the Quartzite–Metaconglomerate unit pinch-out progressively in that direction.

In summary, the structure of the Skaiti Supergroup to the north of Sulitjelma is dominated by a major isoclinal fold which is related to the formation of the Vaknahelleren Syncline. The Rupsi Anticline may therefore represent the structurally highest part of the 'Sulitjelma Fold Nappe Complex', which Boyle et al. (1985) regard as a single large allochthonous nappe unit. In the author's view this structural model provides a good working hypothesis for the geology of the Sulitjelma area. It also has the merit of explaining the way-up criteria and stratigraphical anomalies in the area to the north of Sulitjelma.

## Relationship between the Skaiti Supergroup and the Sulitjelma Ophiolite

Flaser Gabbros, sheeted dykes and layered gabbros, which are an integral part of the Sulitjelma Ophiolite (Boyle 1980), outcrop and intrude rocks of the Skaiti Supergroup.

The best documented exposures of Flaser Gabbro occur in the Sulitjelma Mountains and consist of coarse-grained, lineated, amphibolite containing large (0.5–1 cm) porphyroblasts of hornblende in a plagioclase-rich matrix. Mason (1966) originally considered the Flaser Gabbro with its tectonic fabric to mark the boundary between the Gasak Nappe and the Pieske Nappe (Table 1). In a recent reinterpretation of the Flaser Gabbro, Boyle (1980) recognizes within it lenses of trondhjemite, layered gabbro and cross-cutting dykes, and therefore regards it as the tectonized equivalent of the intrusive zone between the Mietjerpakte Sheeted Intrusive Complex and the Sulitjelma Gabbro Complex.

Recent mapping (Billett 1984) has shown that the Flaser Gabbro outcrops at a lower stratigraphical level within the Skaiti Supergroup. It occurs as linear 300 m thick bodies extending for as much as 3 km along strike (Fig. 2). The Flaser Gabbros incorporate a number of different lithologies, namely layered gabbros, trondhjemites, gabbro breccias and undeformed dykes which cross-cut the flaser texture. The contacts of the Flaser Gabbros with the rocks of the Skaiti Supergroup are associated with 100 m thick porphyritic sheeted dyke complexes. These are analogous to the porphyritic metabasaltic dykes of the Mietjerpakte Sheeted Intrusive Complex (Boyle 1980). The contact with the Rupsielven Amphibolites is well exposed 2 km to the south of the Blåmannsisen Glacier. Both lithologies show an increase in deformation, producing widespread shearing, and lenses of Flaser Gabbro occur in the amphibolites.

The Skaiti Supergroup is also intruded by several gabbro bodies which resemble the Sulitjelma Gabbro Complex, both in terms of their field relationships and petrochemistry (Billett 1984). The largest of these satellite intrusions, the Sorjus 2 Metagabbro, occurs immediately to the SSW of the lake of Småsorjus (Fig. 2). It comprises a medium- to coarse-grained, poorly foliated metabasite consisting of amphiboles and plagioclase with minor amounts of clinozoisite, biotite and opaques. Texturally the Sorjus 2 Metagabbro is a massive, isotropic intrusion associated with layered gabbros, gabbros breccias, gabbro pegmatites and trondhjemites. Contact metamorphism of the country rocks by the gabbros has produced orthopyroxene, scapolite, sillimanite and cummingtonite bearing assemblages.

The Skaiti Supergroup has thus been intruded by gabbro bodies, Flaser Gabbros and porphyritic dyke swarms, which can be directly related in time to the emplacement of the Sulitjelma Ophiolite. Both the Flaser Gabbros and the *en echelon* dyke swarms appear to represent zones of shearing and extension within the Skaiti Supergroup, through which the ophiolitic rocks may have been intruded and erupted.

The Flaser Gabbros described above are analogous to some of the highly sheared zones of metabasic rocks described from the Chennaillet Ophiolite in the Western Alps (Mevel et al. 1978). The Flaser Gabbros, which occur in 50 m wide zones, are cross-cut by unfoliated dykes. These presumably post-date the shearing and metamorphism, which Mevel et al. believe to have occurred *in situ* within the oceanic crust. Strongly foliated and sheared gabbros have also been found in the Dun Mountain Ophiolite Belt in New Zealand (Kidd, pers. comm.).

Metabasalts and metagabbros exhibiting strongly foliated and mylonitic fabrics have been dredged from modern fracture zones on the Mid-

Atlantic Ridge and from the FAMOUS area (Bonatti et al. 1975). Flaser Gabbros have recently been observed *in situ* on the Gorringe Bank seamount off the Moroccan Coast (Honnorez et al. 1984). They are developed along shear zones in coarse-grained gabbroic rocks, which are cross-cut by late undeformed dykes.

These examples show that *in situ* metamorphism and deformation is common in parts of the oceanic crust. The shear zones contain undeformed late cross-cutting dykes and are therefore similar to the Flaser Gabbros from the Rupsielven area. However, the occurrence of quartzitic sedimentary rocks within the Flaser Gabbros and the contact relationships between Flaser Gabbros and metasedimentary rocks, suggest that these shear zones may relate to marginal oceanic crust.

## The Rupsielven and Sulitjelma amphibolites: a comparison

Although both groups of amphibolites contain pillow lavas, fragmental volcanic rocks, dykes and Flaser Gabbros, Table 3 shows that there are a number of fundamental differences between the individual rock types. In addition, there are marked differences in the abundance of keratophyres and trondhjemites in the two groups of amphibolites.

Both groups of amphibolites are associated with contact mineralization, the Sulitjelma Amphibolites with economic ore bodies which occur along its boundary with the younger Furulund Group, and the Rupsielven Amphibolites with a thinner mineralized horizon along its contact with the Røtind Schist. Table 3 shows that the metasediments which lie above and below both units are also fundamentally different.

In terms of metamorphic history the Rupsielven Amphibolites differ in two significant ways from the Sulitjelma Ophiolite. Firstly they preserve the imprint of a pre-Scandian phase of deformation and metamorphism and secondly they have been overprinted by a higher grade of regional (Scandian) metamorphism.

These differences are also brought out in the geochemistry of the amphibolites (Billett 1984). The Rupsielven Amphibolites are incompatible element enriched alkali to transitional tholeiitic

*Table 3.* A comparison of the Rupsielven and Sulitjelma Amphibolites.

| | Rupsielven Amphibolites | Sulitjelma Amphibolites |
|---|---|---|
| *Field Relationships* | | |
| Pillow Lavas | Strongly Porphyritic | Aphyric or Sparsely Porphyritic |
| Fragmental Rocks | Pillow Breccias | Hyaloclastites |
| Dykes | Fine-grained, aphyric | Porphyritic |
| Flaser Gabbro | Present | Present |
| Trondhjemite | Rare | Widespread |
| Keratophyre | One occurrence | Widespread |
| *Contact Relationships* | | |
| Mineralization | Thin disseminated sulphide band | Economic Cu–Fe–Zn–S bodies |
| Associated Units | Stratigraphically overlain by the Røtind Schist and underlain by the Rusty Schists | Stratigraphically overlain by the Furulund Group and underlain by the Lapphelleren Schist |
| *Metamorphism* | | |
| Grade | Amphibolite and Garnet-Amphibolite Facies | Greenschist and Lower Amphibolite Facies |
| Pre-Scandian Event | Present | Absent |
| *Geochemistry* | | |
| Chemistry | Alkali to transitional basalts | Tholeiitic basalts |
| Tectonic Setting | Within plate oceanic island | Mid-Ocean Ridge |

basalts with within plate oceanic island magmatic affinities. In contrast, the volcanic and sub-volcanic rocks of the ophiolite are characteristic of ocean floor tholeiites (Boyle et al. 1985). The Rupsielven Amphibolites therefore represent an early, pre-ophiolite, pre-Scandian phase of intraplate magmatic activity.

## Summary and discussion

The Skaiti Supergroup represents a 0.3–1 km thick volcano-sedimentary sequence dominated by rusty weathering, pyritiferous phyllites and semi-pelites associated with a variety of basic volcanic rocks. The occurrence of marbles, calcareous schists and highly aluminous schists suggests a marine, predominantly non-clastic environment of deposition for the metasediments.

The oldest rocks in the Supergroup comprise a series of gneisses overlain by quartzites and metaconglomerates. It could be argued that this lower sequence is comparable to the basement-cover relationships observed in many parts of the Scandinavian Caledonides, in particular the sparagmite-gneiss association described from southern Norway (Barth 1938).

The Skaiti Supergroup retains the signature of a pre-Scandian tectonic and amphibolite facies metamorphic event. This early episode of deformation and metamorphism has not been observed in the stratigraphically younger, overlying formations. The Sulitjelma Ophiolite and the Furulund and Sjonsta Groups were therefore emplaced and deposited onto an existing deformed and metamorphosed substratum.

It is now well established that parts of the Seve-Koli Nappe Complex, which includes the Skaiti Supergroup, contain the signature of both Precambrian and Finnmarkian orogenic events (Binns 1978; Reymer et al. 1980; Dallmeyer et al. 1985; Dallmeyer & Gee 1986). The age of the pre-Scandian metamorphic and tectonic event in the Skaiti Supergroup could therefore be equivalent to the Finnmarkian event (Sturt et al. 1978), or could be considerably older. Precambrian ages have been recorded from the Beiarn Nappe, which overlies the Seve-Koli Nappe Complex to the west of Sulitjelma (Styles 1978) and from the Seve Nappe of central Scandinavia (Reymer et al. 1980).

The geochemistry and field relationships of the Rupsielven Amphibolites show that they represent within plate oceanic island volcanic and sub-volcanic rocks. These pre-date the ocean-floor magmatism which characterizes the Sulitjelma Ophiolite. The Skaiti Supergroup is intruded by members of the Sulitjelma Ophiolite, namely Flaser Gabbros, isotropic and layered gabbros and sheeted dykes. The structural model developed for the area to the north of Sulitjelma suggests that the Sulitjelma Ophiolite and their associated base metal deposits may outcrop to the north-west in the area to the west of Blåmannsisen.

In conclusion, the Skaiti Supergroup represents a continuous sequence of supracrustal rocks through which the Sulitjelma Ophiolite Complex was originally intruded and erupted. The sites of crustal extension are related to the development of Flaser Gabbros and the intrusion of small sheeted dyke complexes.

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