Subdivision of the Jotun Nappe Complex between Aurlandsfjorden and Nærøyfjorden, South Norway

INGE BRYHNI, KJARTAN BRASTAD & VIGDIS W. JACOBSEN

Bryhni, I., Brastad, K. & Jacobsen, V. W. 1983: Subdivision of the Jotun Nappe Complex between Aurlandsfjorden and Nærøyfjorden, South Norway. *Norges geol. Unders. 380*, 23–33.

In the area between Aurlandsfjorden and Nærøyfjorden the Jotun Nappe Complex can be subdivided into a lower thrust unit of mainly gneisses with mangerites, jotunites and minor supracrustals (the Flåm unit), and an upper unit of mainly gabbroic to anorthostic rocks (the Stiganosi unit). The basal thrust of the Nappe Complex and the contact between the two internal units are blastomylonitic and characterized by retrogression of the original granulite-facies assemblages. Exrension of investigations into a larger part of the 'Faltungsgraben' indicates that the tectonic subdivision of the Jotun Nappe Complex into a lower and an upper part has regional significance.

Inge Bryhni, Kjartan Brastad, Vigdis W. Jacobsen[1]
Mineralogisk-Geologisk Museum, Sars gt. 1, Oslo 5, Norway.

[1] *Present address: Oljedirektoratet, N-4000 Stavanger*

Introduction

The area between Aurlandsfjorden and Nærøyfjorden belongs geologically to the Upper Jotun Nappe, which is shown to have a composite structure and therefore from here on will be called the *'Jotun Nappe Complex'*. It is covered in early rough maps and descriptions by Rekstad (1905), Reusch (1908) and Goldschmidt (1916), and has not been restudied since until quite recently when several informal reports have been written (Bryhni 1976, 1977, Bryhni et al., 1977, Qvale 1982).

In general, this part of the Caledonides has thick crystalline Precambrian thrust nappes resting on Cambro-Ordovician and possibly older phyllites or schists, which in turn overlie the Precambrian basement. The general relations of this 'nappe region' have been studied in adjacent areas by Hødal (1945), Landmark (1949), Skjerlie (1958), Kvale (1948, 1960), Lacour (1969, 1971), Fareth (1977), Heim et al. (1977), Roberts (1977), Bryhni et al., (1977), Henry (1977), Henry and Lacour (1978), Sigmond (1978), Corfu (1980) and others. Major problems are related to the *tectonostratigraphy, age* of the internal movement zones and the *derivation* of the thrust nappe complex: do the internal subdivisions, made in scattered areas (Skjerlie 1958, Lacour 1969, Battey & McRitchie 1973, Bryhni 1976 etc.), have any regional significance in the sense that the Jotun rocks can be subdivided into several independent thrust nappes? And if so, was the internal thrust sequence established during or prior to the Caledonian orogeny? Is the Jotun Nappe Complex rooted below the 'Faltungsgraben', as favoured in recent years by Smithson & Ramberg (1970), Battey & McRitchie (1973), Smithson et al. (1974) and Banham et al. (1979), or has it been derived from far off the coast as advocated by Holtedahl (1936), Kvale (1948, 1960), Naterstad et al. (1973) and recently by Hossack (1976), Heim et al. (1977) and Henry (1977)?

The area between Aurlandsfjorden and Nærøyfjorden is important for the solution of some of these problems, since the Jotun Nappe Complex here appears to be composed of two separate mappable, tectonic units (Fig. 1). The

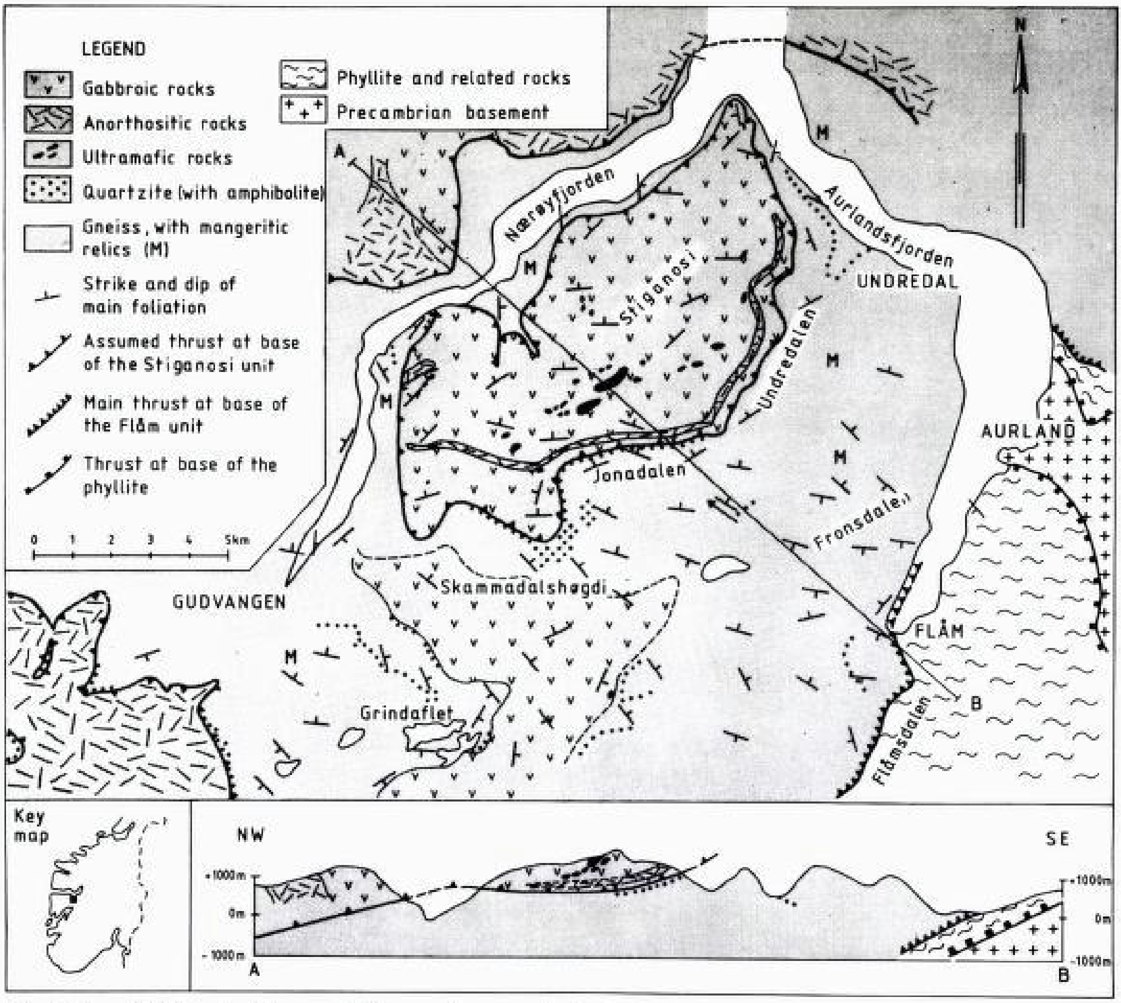

Fig. 1. Simplified geological map of the area between Aurlandsfjorden and Nærøyfjorden.

aim of the present paper is first to give a general description of these units and second to extend the tectonostratigraphy into a larger part of the 'Faltungsgraben'.

General geology

The two tectonic units between Aurlandsfjorden and Nærøyfjorden can be named after localities exposing their characteristic development:

1. *Stiganosi unit,* with gabbroic rocks, anorthosites and ultramafites.
2. *Flåm unit,* with gneisses, hornblendite, relics of mangeritic-jotunitic rocks and narrow bands of quartzite with amphibolite. Its basal thrust zone is characterized by schistose gneisses, blastomylonites and irregular intercalations of metamorphosed psammitic rocks (sparagmites?).

The Stiganosi is separated from the underlying Flåm unit by a crushed or cataclastically deformed zone, assumed to represent a major thrust fault. Minor low-angle faults are parallel to this boundary and quartzitic rocks often occur at intervals below it. Rb/Sr radiometric dating indicates that rocks within the lower unit are more than 1600 m.y. old, but that Sveconorwegian regeneration with amphibolite-facies metamorphism took place 1000–1200 m.y. ago (Bhanumathi & Bryhni, unpulished).

A few dykes of granodioritic composition have been observed, but only in the upper unit. They are related to the igneous activity so prominent in the Årdal–Kaupanger area farther to the north and where a Rb/Sr date of about 450 m.y. was recorded by Barthomier et al. (1972). Recent studies by Koestler (1982) indicate, however, that these late- or post-tectonic intrusives are actually about 900 m.y. and thus late Sveconorwegian in age.

FLÅM UNIT

The lowermost thrust unit is well exposed in the area close to Flåm railway station and in the lower part of Flåmsdalen where it overlies a more than 800 metres thick tectonic unit of phyllite (Fig. 1). The most important rocks are described below.

A. *Cataclastic Rocks*

The cataclastically deformed, often schistose zone at the base of the Flåm unit varies in thickness from a few metres to a few hundred metres. The effect of flattening within this thrust zone is demonstrated locally by the presence of boudins and by the realignment of originally cross-cutting pegmatite dykes into parallelism with the main foliation.

The rocks closest to the phyllite (0–100 m above the contact north of Aurland) are developed as compositionally layered blastomylonitic gneiss with a planar foliation parallel to the contact. There is no distinct lineation within the closely spaced foliation surfaces and the banding is often transected by dykes of black, flinty ultramylonite and cataclasite. A sample of such an ultramylonite dyke from only a few metres above the phyllite contact has a distinct fluxion structure defined by alignment of flat, irregular domains with different coloration formed by diminuation of individual minerals of an original medium-grained rock. Few mineral fragments in this rock exceed 0.2 mm in their longest dimension and most of the grains in the matrix are too small to be resolved under the microscope. Another sample, collected along the road below Skjerdal about 100 m from the contact, is massive and with only a faintly visible fluxion structure. Grain outlines indicative of a pre-existing medium-grained fabric can be seen in plane-polarized light, while inspection with crossed polarisers reveals that the average grain-size is less than 0.1 mm. Chlorite and calcite have formed in the matrix and quartz occurs in minor veins cutting through the rock fabric.

It is difficult to evaluate the exact extent of recrystallization in cataclastically deformed rocks, but the lack of easily visible strain effects in the matrix grains indicates that most of the investigated samples were strongly recrystallized. A rock from the thrust sole at Fronsdalen apparently consists of 70% recrystallized grains less than 1 mm in size and 30% of porphyroclasts about 0.2 mm across. It is a typical blastomylonite derived from similar feldspathic rocks as those occurring higher up in the nappe, possibly with some addition of new sericitic mica during cataclasis. Some have a laminated or finely layered structure falsely reminicent of supracrustal rocks, which may occur locally, however. Thus, a quartzose, grey-black, quartz net-veined blastomylonite in the contact zone along the west side of the fiord north of Flåm railway station represents a severely altered psammitic rock. It is composed mainly of quartz (c. 60%) and sericite (c. 40%), and makes up a layer only a few metres thick above black phyllite. Feldspathic sandstones with primary flood structures like coarse graded bedding, cross-bedding and cross-lamination have been recorded by Bryhni et al. (1977) in a similar tectonic position just outside our map-area (Ljosberget, southeast of Flåm). On the basis of our evidence, it is likely that also the sericite-quartz blastomylonite at Flåm is, in fact, a remnant of Valdres Sparagmite-type psammites which have become overridden by the Jotun Nappe Complex and are only preserved in places within the thrust zone.

B. *Gneisses and deformed plutonic rocks*

The Flåm unit consists mainly of gneisses which sometimes appear to have formed by cataclastic deformation, recrystallization and neomineralization from original plutonic rocks. The rocks have various mixtures of feldspar (microperthite, microcline, plagioclase), quartz, orthopyroxene, clinopyroxene, biotite, amphibole and garnet as essential minerals. Quartz rarely makes up more than 20% of the modes. Thus they classify in the field between syenite and gabbro, and can often be termed mangeritic or jotunitic. It is difficult to distinguish the different types in the field because the extent of secondary alteration is so variable. – Relatively unaltered mangeritic rocks are massive, medium- or coarse-grained with pale-brown, pink or grey feldspar. The feldspar is string microperthite or mesoperthite broken down in gneissic varieties to a more fine-grained mosaic of microline and acid plagioclase. This transformation is accompanied by complete alteration of original pyroxenes to amphibole, biotite and epidote.

C. *Quartzite with amphibolite*

A rock composed essentially of quartz (c. 70–90%) occurs in intimate association with amphibolites as regionally distributed layers, up to a few hundred metres thick. Apart from quartz the rock contain potash feldspar (including microperthite), plagioclase, biotite and minor white mica, sphene and epidote. Grain-size varies from medium-grained to very fine-grained, but the rock is mesoscopically often a 'glassy' white and grey orthoquartzitic rock. Hødal (1945) described corresponding rocks as 'silexites' of inferred magmatic origin, but we would rather interpret them as originally supracrustal rocks, either older than the associated gneissified mangerites-jotunites or tectonically interlayered with them. Fareth (1977) has described similar quartz rocks from his 'Klovafjell Group', and we must conclude that metasedimentary rocks have a much wider occurrence in the Jotun Nappe Complex than hitherto recognized.

CONTACT BETWEEN FLÅM AND STIGANOSI UNITS

The contact between the two units is distinct on the western side of Nærøyfjorden where it is a cataclastic zone, a few metres thick, which also cuts obliquely into the overlying Stiganosi unit. It is less conspicuous to the east of the fiord where it often is merely a cataclastically deformed contact zone between lithologically different rocks. To the southwest of Gudvangen it has also been mapped over extensive areas outside the present map-area. There the contact is a strongly deformed zone that appears to be affected by regional folding along an ESE-axis. Gabbroic rocks near the base of the Stiganosi unit above Jonadalen are strongly flattened and gneissified towards this cataclastic zone, which here follows closely a zone of quartzite with amphibolite. Quartzite also occurs in the strongly tectonized marginal zone of anorthositic rocks southwest of Gudvangen where also dykes of granodiorite are involved in the deformation (Ottesen, pers. comm. 1978). Schistose meta-anorthosites in the contact zone have retrograde mineral assemblages (sodic plagioclase down to An_{11}, epidote, chlorite and white mica).

STIGANOSI UNIT

The uppermost thrust unit is typically developed in the high ground west of Undredalen–Jonadalen where it underlies the mountain Stiganosi and the plateaux southwestwards toward Skammadalshøgdi (Fig. 1). The body of essentially gabbroic rocks at Stiganosi can be correlated with bodies of mainly anorthositic rocks northwest of Nærøyfjorden and southwest of Gudvangen. A large body of gabbro-norite at Grindaflet–Skammedalshøgdi bounded by blastomylonitic rocks with local quartzite can possibly be related to the same unit. The most important rocks are described below.

A. *Anorthostic rocks*

The largest anorthostic body, southwest of Gudvangen, is exposed in 1,200 metres high, almost vertical cliffs, above a sole of amphibolite, schistose gabbro, quartzite and blastomylonites. Another occurrence, a layer 100 m thick in gabbroic rocks between Undredalen and Gudvangen, has a blastomylonitic base and grades upwards into the gabbroic rocks or their amphibolitized derivatives. Small anorthostic bodies or layers less than 1 m thick also occur within the gabbro-norites, especially in the Grindaflet area. Primary igneous layering is locally preserved, but the rocks have more often a foliation parallel to the axial planes of tight folds. It would therefore appear that the more than 1,200 metres thickness of the Gudvangen anorthositic body is due to tectonic repetition of thinner layers.

The relative contents of dark minerals vary, so that there is a gradual transition from true anorthosite to anorthositic gabbro. The main minerals of such anorthositic rocks are plagioclase An_{60-75} (with inverse zoning up to An_{81}), olivine, clinopyroxene, garnet, amphibole, corundum and spinel.

The first foliation with flattened coronas of pyroxenes and garnet around original olivine (Griffin 1971 a) is cut by gabbroic dykes with marginal enrichment of garnet. Such dykes are locally strongly flattened in the foliation surface and altered to conformable amphibolitic layers. Schistose zones in the anorthositic rocks have fine-grained retrograde mineral assemblages, and contain a penetrative ESE–WNW trending lineation which is not found in the associated massive rocks. Thus, there are probably various sets of foliations formed under different metamorphic conditions spanning from the granulite to the greenschist facies.

B. *Gabbroic rocks*

The gabbroic rocks comprise banded as well as massive gabbro-norites or basic granulites with their amphibolitized derivatives. Plagioclase, orthopyroxene, clinopyroxene, amphibole and garnet are the main minerals.

A regular alternation of light and dark layers is characteristic for large parts of the gabbroic massif between Undredal and Nærøyfjorden, where the rocks often have a gneissose aspect. The light bands are relatively enriched in plagioclase, and locally contain dark red garnets in crystals up to several centimetres across. The dark layers are relatively enriched in amphibole. Other varieties are massive or display igneous graded layering, as is typically developed in the Grindaflet–Skammadalshøgdi body.

Blastomylonitic zones, up to 50 metres thick, transect the gabbroic rocks and locally include varieties that can be termed plagioclase augen gneisses.

C. *Ultramafite*

About 25 isolated occurrences of ultramafite have been mapped as inclusions in the gabbroic rocks. To this can be added many minor disrupted layers or ultramafic basal parts of graded beds in gabbro-norite. Post-crystalline tectonic movements within the main rock body led to disruption of the layers into fragments which become enclosed within the gabbroic rocks.

The main minerals of the ultramafite are olivine, orthopyroxene, clinopyroxene, amphibole, spinel and plagioclase. Orthopyroxene is always present in the contact zone between plagioclase and olivine, and the whole ultramafite body is usually bounded by an amphibolized reaction rim of enstatite, clinopyroxene and spinel towards the surrounding rocks, as described by Griffin (1971 b) from Jotunheimen. Garnet may be concentrated in the outer part of the reaction rim.

Igneous layering is sometimes developed in the ultramafite, grading upwards from olivine-rich to pyroxene-spinel-rich layers. The thickness of such graded layers is usually several metres, and locally there may be continuous gradation from the upper pyroxene-rich part of the layer into gabbronorite.

Linear structures

The primary igneous layering in the original Jotun plutonites has been obliterated in most places by strong transposition and isoclinal folding along axes trending between E–W and ESE–WNW. Stereograms of poles to the foliation and compositional layering show diffuse girdles around the same ESE–WNW axis, which is transverse to the axial trend direction of the Caledonian 'Faltungsgraben'. Pegmatite dykes sometimes cut foliated rocks with transverse linear structures, and limbs of major folds with this orientation are cut at the contact to the underlying phyllite. Such evidence – seen in conjunction with the limited radiometric data – suggests that the transverse axial structure in most cases pre-date the Caledonian emplacement of the Nappe Complex. There is, however, also evidence that transverse linear structures have been formed subsequent to emplacement. For example, the basal thrust zone south of Flåm is folded along an ESE–WNW axis, and similar trending lineations can be found in the phyllites and in the uppermost, 'Caledonized' part of the basement. We conclude, therefore, that the transverse linear structures have a composite origin both pre-dating and post-dating the Caledonian thrusting in the area.

A later deformation is recognizable as regional folds along the NE–SW Caledonian trend. It has affected the trust zone and is also visible as open, upright folds in schistose zones in the interior of the Nappe Complex. Structure-contour maps show that the basement/phyllite contact forms a series of regional elongated domes and basins with a similar Caledonian trend (Fareth 1977), and the 'Faltungsgraben' itself could be related to this phase of deformation.

In the area to the southeast of Aurland, Fareth (1977) found either calcareous schist or a zone of cataclasis and retrograde-metamorphosed rocks between groups which we correlate with our Flåm and Stiganosi units. Reconnaissance geological mapping by us in the area between Nærøyfjorden and Sognefjorden has indicated that the two major tectonostratigraphic units are developed over a large area (Fig. 2, and Bryhni et al. 1977, Qvale 1982). At

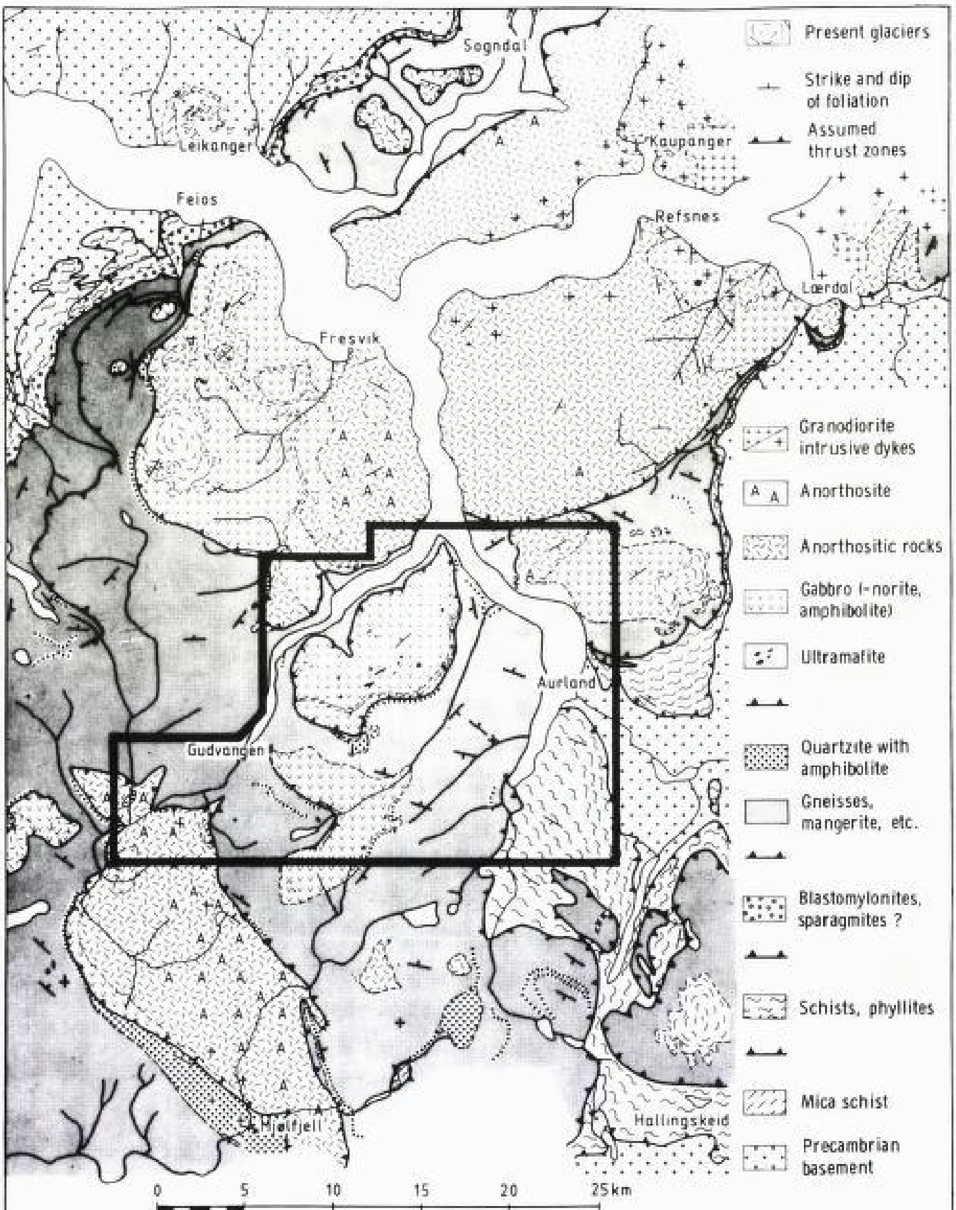

Fig. 2. Geological map of the 'Faltungsgraben' in Sogn. Area of Fig. 1. is outlined. (Mainly after Bryhni et al. 1977).

Sogndal the contact can be tied up with the boundary described by Skjerlie (1958) and Lacour (1969) between lower groups of essentially alkalifeldspar-bearing rocks and upper groups of rocks with abundant plagioclase. The Flåm unit is, however, in these western parts of the 'Faltungsgraben' probably underlain by one or possibly two thrusts which are not found in the Aurlandsfjorden–Nærøyfjorden area. The lower of these units has even recently been considered (Roberts 1977) to represent psammitic rocks ('Valdres Sparagmite') but is more likely to represent cataclastically deformed gneisses with only minor and locally distributed sediments. Its position at the base of the Jotun Nappe Complex probably indicates that it represents an analogue to the Valdres Nappes east of the 'Faltungsgraben', albeit in a very cataclastic state and with more basement than cover sediments represented.

A summary of the tectonostratigraphy is given here as Fig. 3. The apparent continuation of at least some of the tectonic units across the 'Faltungsgraben' indicates that the contacts are thrusts of regional significance. Movements along the contact between the two major units of the Jotun Nappe Complex have probably been extensive in this part of the 'Faltungsgraben' since dykes of granodiorite here appear to be present only in the upper unit (Bryhni et al. 1977, Henry 1977). The dykes are usually undeformed, but tend to become strongly deformed in the contact zone between the two units (Ottesen, pers. comm. 1978). Thus, at least some of the movement along the contact zone post-dates the intrusive date of about 900 m.y. recorded by Koestler (1982) and must then be either late Sveconorwegian or Caledonian in age. The contact south of Gudvangen shows local inversions which indicate a stronger folding than can reasonably be expected in the Jotun Nappe Complex during

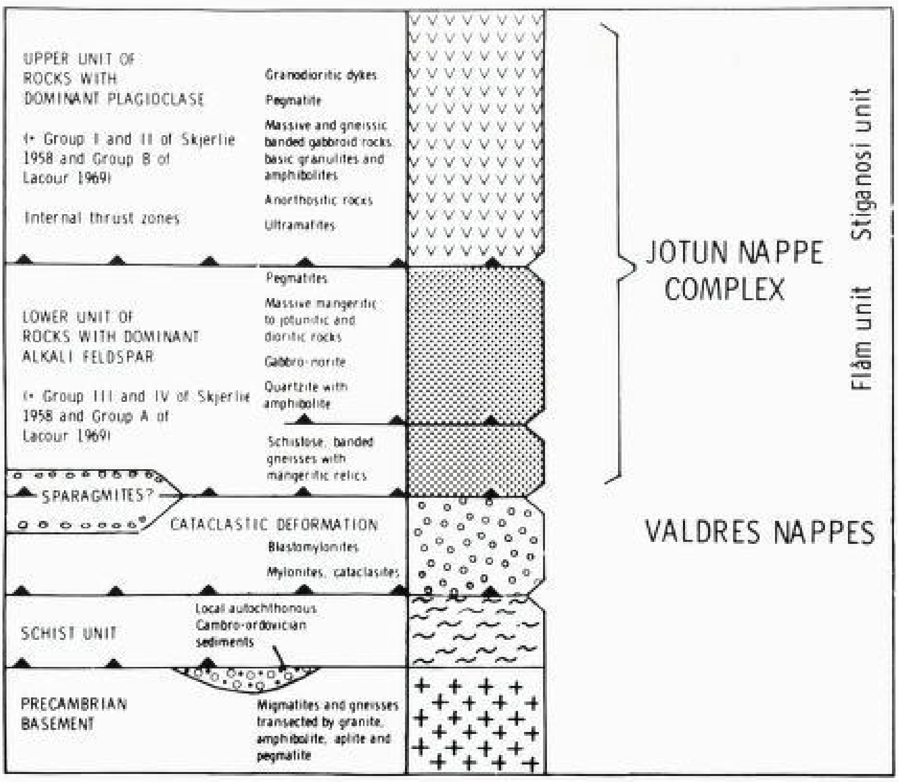

Fig. 3. Tectonostratigraphic subdivision of the Jotun Nappe Complex in Sogn.

any of the Caledonian events, and the emplacement of the Stiganosi unit upon the Flåm unit thus most likely pre-dates the Caledonian orogeny.

At Fillefjell, Corfu (1980) has subdivided the Jotun Nappe Complex into three subunits which were emplaced as nappes in a tectonic sequence and later metamorphosed *prior* to the movement of the whole pile as a Caledonian nappe with negligible internal deformation. The story in the area around Sognefjorden may turn out to be similar to that at Fillefjell although there is as yet no radiometric evidence.

The geometry of the internal thrust in the Jotun Nappe Complex and the presence also of supracrustals leads us to believe that the units are relatively shallow sheets which have been derived by horizontal thrusting rather than upthrusted from a root below the 'Faltungsgraben'.

Acknowledgements. We thank A. Grønhaug and E. Øvstedal for valuable help. Mike Howe kindly improved the English text of an early draft of the paper, and we have profited from critical comments by E. Fareth, A. Krill, D. Roberts and T. Torske.
International Geological Correlation Programme, Norwegian Contribution No. 60 to Project Caledonide Orogen.

REFERENCES

Banham, P. H., Gibbs, A. D. & Hopper, F. W. M. 1979: Geological evidence in favour of a Jotunheimen Caledonian suture. *Nature 277,* 289–291.

Battey, M. H. & McRitchie, W. D. 1973: A geological traverse across the pyroxene-granulites of Jotunheimen in the Norwegian Caledonides. *Norsk geol. Tidsskr. 53,* 237–265.

Berthomier, C., Lacour, A., Leutwein, F., Maillot, J. & Sonet, J. 1972: Sur quelques trondhjemites de Norvège: étude géochronologique et géoshemique. *Sciences de la Terre 18,* 341–351.

Bryhni, I. 1976: Geologisk undersøkelse av tunnelprosjekter på stamveg Bergen–Oslo mellom Flåm og Styvi (Flåm-Gudvangen). *Rapport til Statens Vegvesen, Sogn og Fjordane* (Unpubl. report) 29 pp.

Bryhni, I. 1977: Geologisk undersøkelse av tunnelprosjekter på stamveg Bergen–Oslo mellom Flåm og Gudvangen. *Rapport til Statens Vegvesen, Sogn og Fjordane* (Unpubl. report), 20 pp.

Bryhni, I., Brastad, K. & Jacobsen, V. W. 1977: Jotundekket og dets underlag i Sogn. *Norges geol. Unders.,* Rapport 1560/28, 73 pp.

Corfu, G. N. 1980: Geologie der Jotun-decke sowie U/Pb und Rb/Sr Geochronologie des darunterliegenden Precambrischen Schieldes, Filefjeld, Suednorwegen. *Eidgenossischen Techn. Hochschule Zürich, Doktorabhandlung,* 137 pp.

Fareth, E. 1977: Petrography and structure of the Aurlandsdalen area, western Norway – a portion of the Caledonian margin. *Norges geol. Unders. 334,* 59–81.

Goldschmidt, V. M. 1916: Geologisch-petrographische Studien im Hochgebirge des südlichen Norwegens. IV. Übersicht der Eruptivgesteine im Kaledonischen Gebirge zwischen Stavanger und Trondhjem. *Skr. Norske Vidensk.-Akad. i Oslo, Mat.-Naturv. Kl., 1916, No. 2,* 140 pp.

Griffin, W. L. 1971a: Genesis of coronas in anorthosites of Upper Jotun Nappe, indre Sogn, Norway. *J. petrol. 12,* 219–243.

Griffin, W. L. 1971b: Mineral reactions at a peridotite-gneiss contact, Jotunheimen, Norway. *Min. Mag. 38,* 435–445.

Heim, M., Schärer, U. & Milnes, A. G. 1977: The nappe complex in the Tyin–Bygdin–Vang region, central southern Norway. *Norsk geol. Tidsskr. 57,* 171–178.

Henry, A. 1977: La nappe du Jotun et les nappes de socle connexes. *Revue de geogr. phys. et geol. dynamique XIX,* 433–442.

Henry, A. & Laccour, A, 1978: Les grand traits structuraux de la region de Sogndal, Caledonides de Norvège centro-méridionale. *Bull. Soc. géol. France XX,* 71–79.

Holtedahl, O. 1936: Trekk av det skandinaviske fjellkjedestrøks historie. *Skand. Naturforsk. Möte 19, Helsingfors,* 129–145.

Hossack, J. R. 1976: Geology and structure of the Beito Window, Valdres. *Norges geol. Unders. 327,* 1–33.

Hødal, J. 1945: Rocks of the anorthosite kindred in Vossestrand, Norway. *Norsk geol. Tidsskr. 24,* 129–243.

Koestler, A. G. 1982: A Precambrian age for the Ofredal granodiorite intrusion, Central Jotun Nappe, Sogn, Norway. *Norsk geol. Tidsskr. 62,* 225–228.

Kvale, A. 1948: Petrologic and structural studies in the Bergsdalen quadrangle, Western Norway. Part II, structural geology. *Bergens Museum Årbok 1946–1947. Naturv. rekke no. 1,* 155 pp.

Kvale, A. 1960: The nappe area of the Caledonides in western Norway. *Int. geol. Congress Norden 1960, Guide to excursions no. A7 and no. C4,* 43 pp.

Lacour, A. 1969: Données pétrologiques sur la nappe de Sogn–Jotun et son substratum dans la region de Sogndal (District de Sogn, Norvège centro–meridionale). *Bull. Soc. geol. France 7, XI,* 354–366.

Lacour, A. 1971: Observations sur la mylonization des roches de la nappe du Jotun dans la région de Sogndal, Norvège centro–meridionale. *Extrait du C. R. Sommaire des séances de la Soc. Geol. de Grance 1971. Fascicule 3,* 150–151.

Landmark, K. 1949: geologiske undersøkelser Luster–Bøverdalen. *Univ. i Bergen Årbok 1948, Naturv. rekke no. 1,* 57 pp.

Naterstad, J., Andresen, A. & Jorde, K. 1973: Tectonic succession of the Caledonian nappe front in the Haukelisæter–Røldal area, Southwest Norway. *Norges geol. Unders. 292,* 1–20.

Qvale, H. 1982: Jotundekkets anorthositter: geologi, mineralogi og geokjemi. *Norges geol. Unders.,* Rapport 1560/32, 98 pp.

Rekstad, J. 1905: Fra indre Sogn. *Norges geol. Unders. 43, no. 7,* 53 pp.

Reusch, H. 1908: Tekst til Geologisk kart over fjeldstrøkene mellom Jostedalsbreen og Ringerike. *Norges geol. Unders. 47,* 40 pp.

Roberts, J. L. 1977: Allochthonous origin of the Jotunheim Massif in southern Norway: a reconnaissance study along its northwestern margin. *Geol. Soc. London* 351–362.

Sigmond, E. M. O. 1978: Beskrivelse til det berggrunnsgeologiske kartbladet Sauda 1:250 000. *Norgs geol. Unders. 341,* 94 pp.

Skjerlie, F. S. 1958: Geological investigations between Fjærlandsfjord and Sogndalsdalen, Western Norway. *Univ. i Bergen Årbok 1957. Naturv. rekke no. 5,* 67 pp.

Smithson, S. B. & Ramberg, I. B. 1970: Geophysical profile bearing on the origin of the Jotun Nappe in the Norwegian Caledonides. *Geol. Soc. Amer. Bull. 81,* 1571–1576.

Smithson, S. B., Ramberg, I. B. & Grønlie, G. 1974: Gravity interpretation of the Jotun Nappe of the Norwegian Caledonides. *Tectonophysics 22,* 205–222.