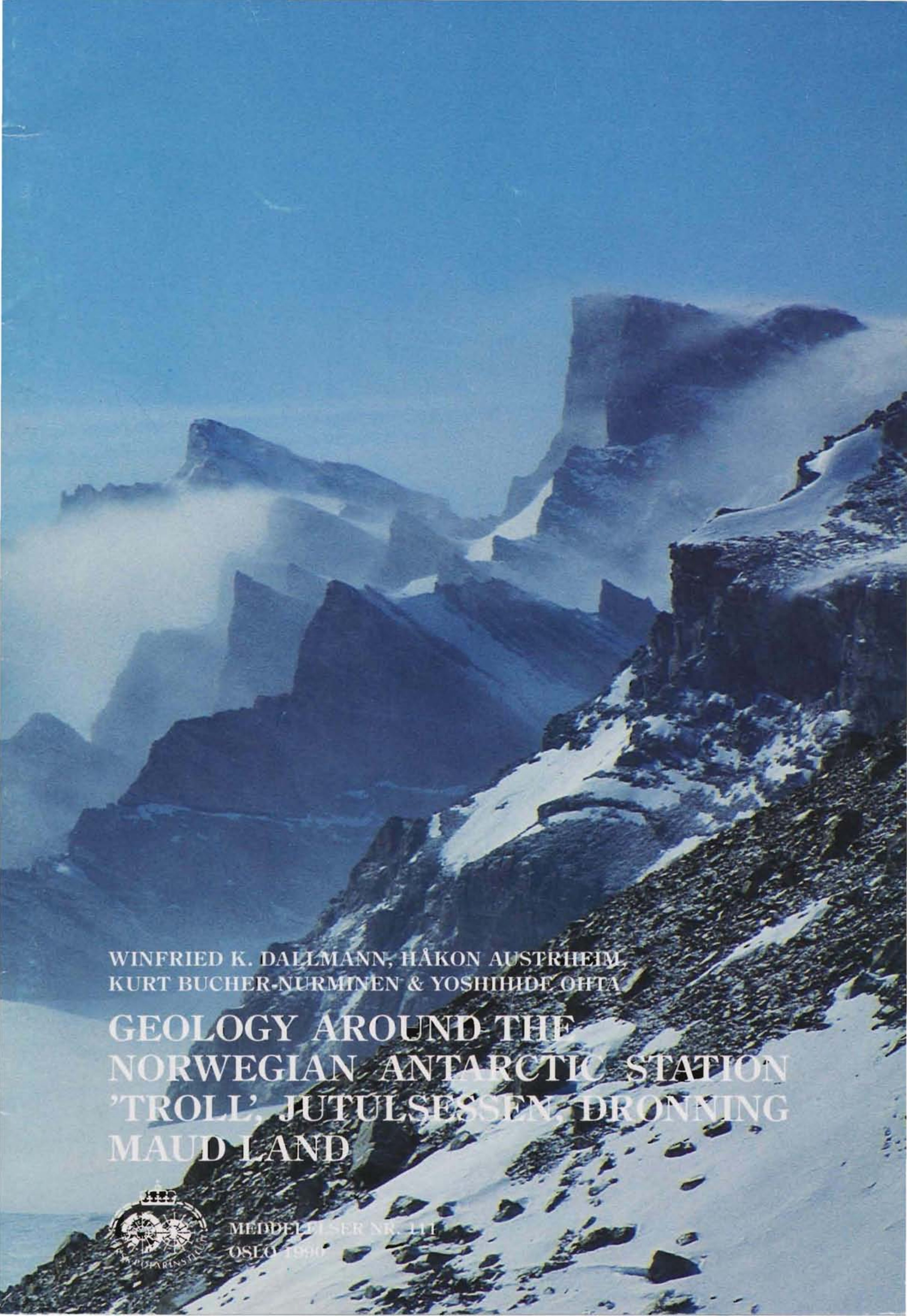

WINFRIED K. DALLMANN, HÅKON AUSTRHEIM,
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GEOLOGY AROUND THE NORWEGIAN ANTARCTIC STATION 'TROLL', JUTULSESSEN, DRONNING MAUD LAND

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NORSK POLARINSTITUTT
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Contents:

Abstract

During the Norwegian Antarctic Research Expedition 1989/90, a permanent, unmanned research station was raised in Jutulsessen, Gjelsvikfjella, western Dronning Maud Land. The present report is a description of the geology of the area accessable from the station.

Exposures of rocks in this part of Dronning Maud Land are restricted to a coastal mountain chain at c. 200-250 km distance from the ice shelf edge at elevations between 1000 and 3000 m.

Quaternary deposits are particularly restricted to the inner parts of the Jutulsessen glacier cirques. Deposits are till and talus which locally are admixing at slope angles of c. 25°. Moraines are poorly developed. Patterned ground ('stone pits') are common at slope angles below c. 15°. Recently active phenomena of special interest are ice-margin meltwater lakes with pingo-like 'blisters', the deep frost-shattering all over the mountain walls and holes in rock surfaces as a result of wind activity with grinding particles.

The bedrock belongs to the East Antarctic craton. The area under consideration (western Mühlig-Hofmannfjella and Gjelsvikfjella) consists of high-grade metamorphic rocks and forms one of the world's best exposed granulite terranes. Orthogneisses and minor metasediments have been intruded by a series of charnockites, partly altered to granulites (the 'Svarthamaren charnockite complex'), and a sequence of dyke rocks. Migmatization has affected large parts of the gneisses.

Both gneisses and granulites/charnockites show abundant evidence of transition from granulite to amphibolite facies and vice versa, and the important role of fluid-rock interactions leading to these processes can be studied.

The gneisses at Jutulsessen show a complex deformation history. They are thought to be derived from granitic intrusions, though minor amounts of high-grade metamorphic, metapelitic gneisses may represent their original host rocks. Early tectonism (c. 1000-1200 m.y.) produced gneissosity, compositional banding and a leucosome phase under high-grade metamorphic conditions. This was followed by multiple and complex intrusive activity, partial migmatization and a tectonic overprint with abundant shear deformation under amphibolite-facies conditions (c. 450-500 m.y.).

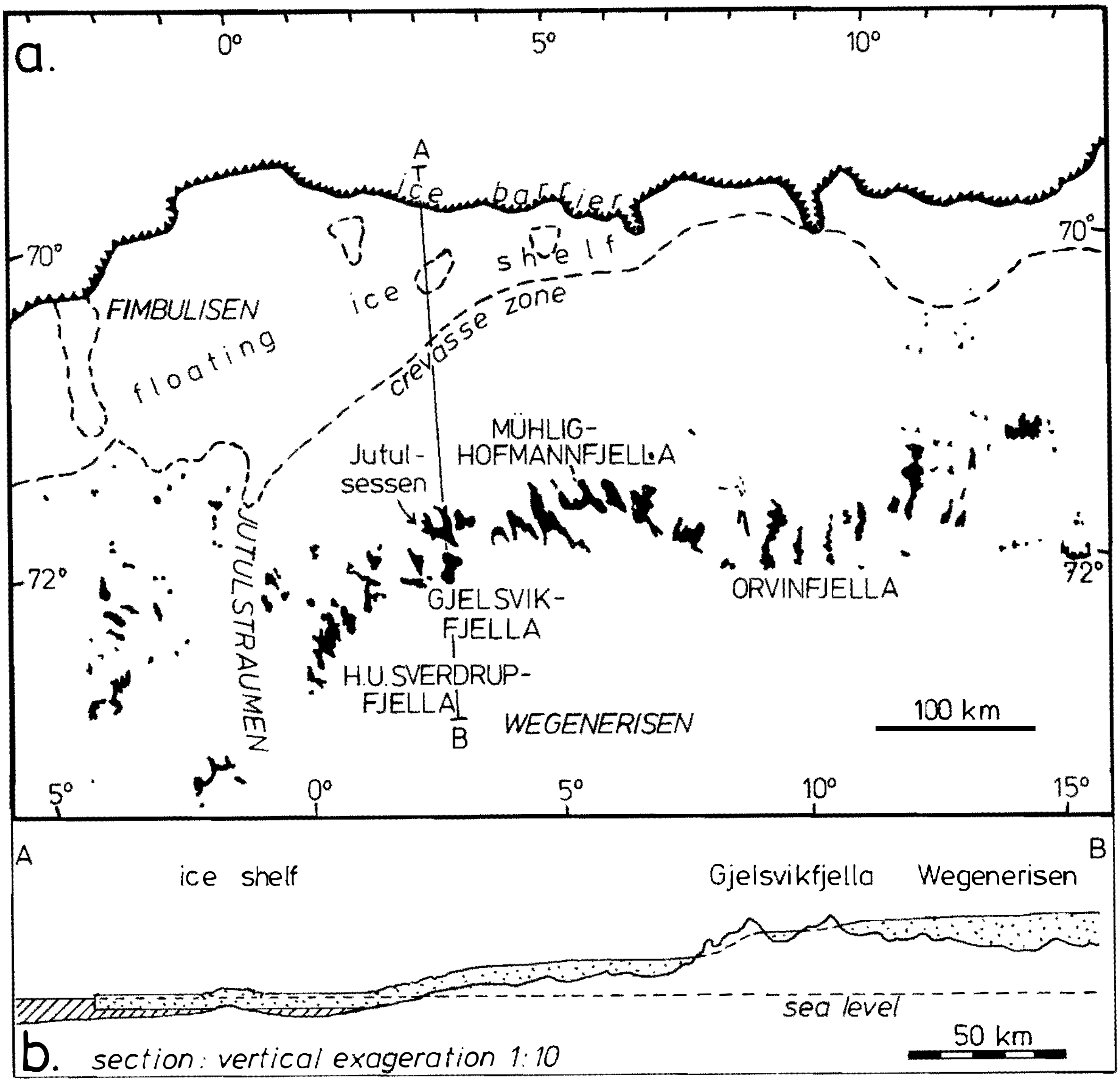


Fig. 1: a) Location map of the investigated areas, western Dronning Maud Land. b) Cross section (N-S) showing the large-scale geomorphology.

INTRODUCTION

During the Norwegian Antarctic Research Expedition (NARE) 1989/90, the permanent, unmanned research station 'Troll' was raised in the nunatak area of Jutulsessen, Gjelsvikfjella, Dronning Maud Land ('Queen Maud Land'), at 2°31'E/72°00'S (Figs. 1,2,3). Future research in Dronning Maud Land will probably have a special focus on the area around Troll for logistic reasons. We would thus like to present a description of the geology of the area with emphasis on the Jutulsessen massive, and point out possible future research topics. Since the expedition did not carry out any research project in geomorphology or Quaternary geology, there will only be given a short introduction on these items. Emphasis is put on the structural aspects of bedrock geology, as petrologic aspects will be covered to a larger extent by subsequent publications.

At the present stage, no analyses of rock samples except optical microscopy of thin sections have been carried out. Still, we consider it appropriate to give a general overview and description.

Previous geological descriptions comprising the present area have been presented by Ohta et al. (1990) from the Norwegian Antarctic Research Expedition 1984/85. From the present expedition, an overview of field activities and preliminary results is given in the expedition report (Bucher-Nurminen et al., in press).

MORPHOLOGY AND QUATERNARY GEOLOGY

General setting

The area investigated by the geology party in 1990 is situated between 2°E and 6°E, c. 200 km south of the Antarctic ice barrier. It comprises the mountain areas 'Gjelsvikfjella' and the western part of 'Mühlig-Hofmannfjella' (Fig. 1a).

A north-south trending cross section from the ice barrier to the mountain areas (Fig. 1b) shows a 60-100 km wide, mainly floating ice shelf of c. 400 m thickness (O. Orheim, pers. comm. 1989), the eastern extension of 'Fimbulisen'. From the crevassed hinge zone, where the ice sheet decouples from the solid underground, the ice surface rises to an elevation of 1100 to 1600 m at c. 200 km distance from the barrier. There, it is interrupted by a mountain range running subparallel with the Antarctic margin. The nunataks of this mountain range reach elevations of up to 3000 m above sea level. They form a barrier for the 2500 to 3000 m high inner Antarctic ice plateau to the south, which in this area is called 'Wegenerisen'. Crevassed glacier streams accommodate the ice transport from the inner to the frontal ice sheet and separate the mountain range into many groups of nunataks, some of which form rather continuous mountain complexes.

The Jutulsessen area

One of these mountain complexes is Jutulsessen (the 'seat of Jutul', a giant of the Nordic mythology; Figs. 2 and 3). It comprises two 15 to 20 km long north- and northwestward trending ridges extending from one place in the SE. Jutulsessen is situated between two glacier streams. The area between the ridges, Sætet ('the seat'), is an 8 km wide glacier cirque, which now is ice-covered only in the lower, flat part. Here, almost 1500 m change of elevation can be observed at a short distance, and a single vertical wall (Jutulhogget, the 'Stroke of Jutul') is c. 900 m high (Figs. 3,23).

Minor glacier cirques are found in many places around Jutulsessen (Figs. 2,3). Some of them are abandoned, and the ice surface is then usually curved convexly from the foreland towards the inner parts of the cirques. Others are still active and have a concave shape. In the southeastern part of Grjotlia, there is a residual ice field from a former glacier cirque. It is situated on the upper part of the mountain slope with a steep ice front towards the underlying moraine field.

All former glacier cirques, where the bottom is exposed, are covered with till. The till cover is probably mostly derived from the crests of Jutulsessen, but some boulders and blocks seem to originate from other nunataks to the south. Still today, the flat-lying and retreating ice area in front of Grjotlia provides a scattered ablation moraine with many erratic boulders, possibly derived from southern Gjelsvikfjella. Ground moraines with less than 15° slope angle usually provide patterned ground (see next section).

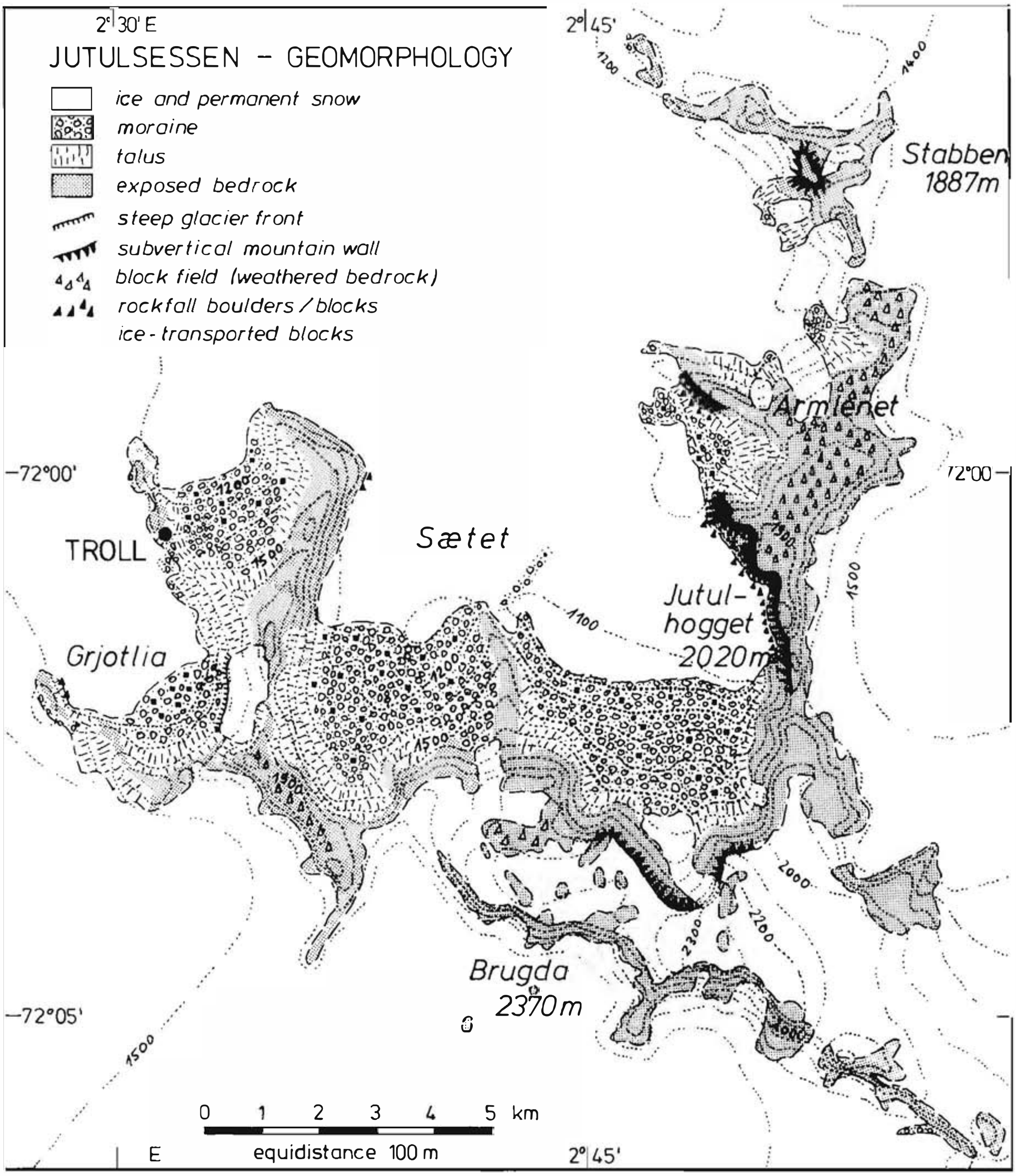


Fig. 2: Geomorphological map of Jutulsessen (the 'Seat of Jutul'), Gjelsvikfjella.

The mountain shapes are related to the bedrock geology. Ridges and notches tend to be subparallel with the strike directions of gneissosity and rock boundaries. Homogenous, resistent lithologies form almost vertical mountain walls (e.g. Jutulhogget, Stabben) or sharp edges, whereas lithologies rich in mafic minerals form moderate slopes of lower mountains, where denudation has progressed further (e.g. northern continuations of Armlenet and Stabben). Block fields occur on flat-topped ridges as a result of deep weathering.

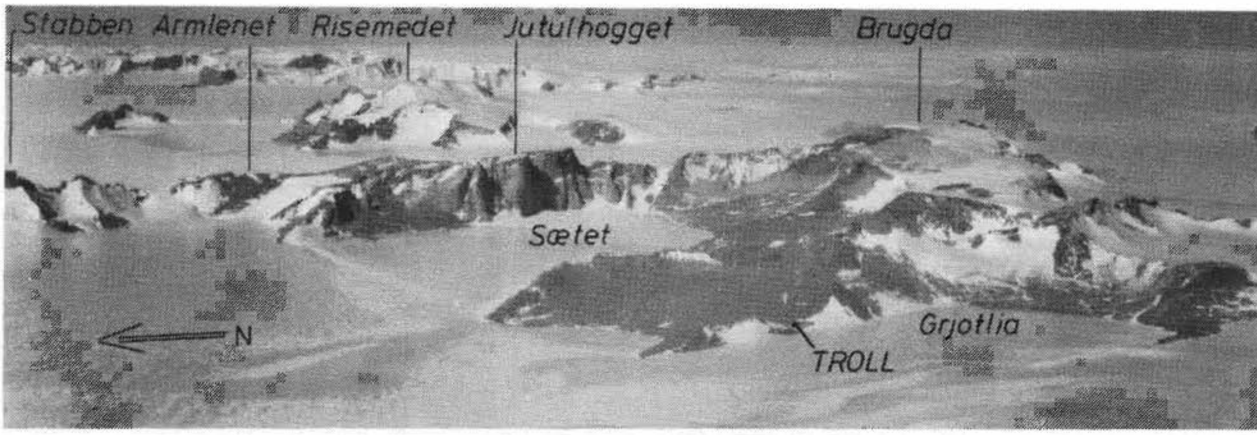


Fig. 3: Aerial photography (DML 1958/59, no. 1302) of Jutulsessen (Gjelsvikfjella). Risemedet is seen in the background, while Mühlig-Hofmannfjella are visible far behind.

The 'Troll' station area

The station is situated in the northern part of Grjotlia, on the western side of a minor, SW-NE trending pass between two glacier cirques (Figs. 2,3), at an altitude of c. 1290 m. The station is built on a ground of frozen moraine at an average slope angle of c. 5°, into which the poles are lowered and attached by permafrost.

The outer part of the glacier cirques is covered with flat ice free of crevasses. From the southwestern ice flat, the terrain rises with c. 15 m to the pass (Fig. 4), while it is c. 100 m down to the northeastern ice flat. To the NNW from the pass, there are to small mountain tops at c. 1390 m (Fig. 3), while to the SSE, the Grjotlia ridge reaches almost 2000 m.

Bedrock is exposed only in the upper parts of the ridges, while the lower parts are covered with thin talus at a slope angle of c. 30°. The talus, consisting of particles up to boulder size, covers the till fields of the abundoned cirques. The talus may be admixed with the till along the former ice margin, where the slope angle is c. 25°. The till, indicated by less sorting of the material and the presence of exotic boulders, has usually a slope angle of less than 20° (Fig. 4). Below c. 15°, the ground is patterned (mainly 'stone pits', Fig. 5).

The stone pits are subcircular to subpolygonal patterns. The individual circles have diametres between 5 and 10 m and are up to 1 m high. Sorting is poor, but the depressed rings around the circles lack the largest boulder sizes and are slightly enriched in sandy material.

Approximately 100 m S of the station buildings, a minor SW-NE trending, only a few m high lateral moraine is situated along the northern elongation of the ridge to the SSW. It is probably preserved from the time when there was a continuous ice cover from Grjotlia across the pass to the northwestern glacier cirque. There is still a firn field from the rim of the moraine to the Grjotlia ice flat. The photograph (Fig. 4a) is taken from the crest of this moraine.

Still c. 200 m further south, there is an other topographic elevation (c. 10 m) consisting of talus material attached to the end of the mountain ridge. Its front has a convex shape, while its transition to the mountain slope is concave. This indicates that the rock mass is moving by creep. It is an open question if this phenomenon should be called a rock glacier due to its small size, though the exact definition would fit. It might be of interest to men-

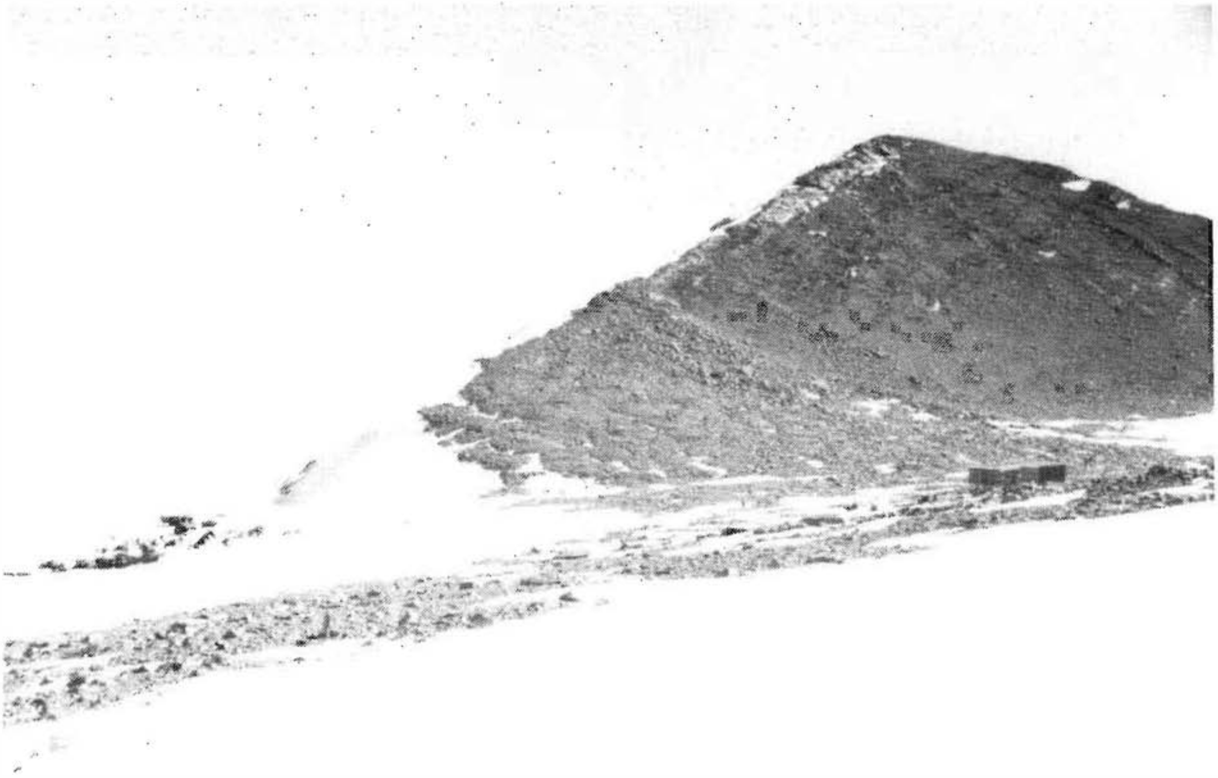


Fig. 4a: The Norwegian Antarctic station 'Troll' (to the right) and the main camp of the Norwegian expedition, January 1990. The photo shows the Quaternary sediment cover around the station. The Jutulsessen area is the only place within the investigated area where significant cover sediments occur.

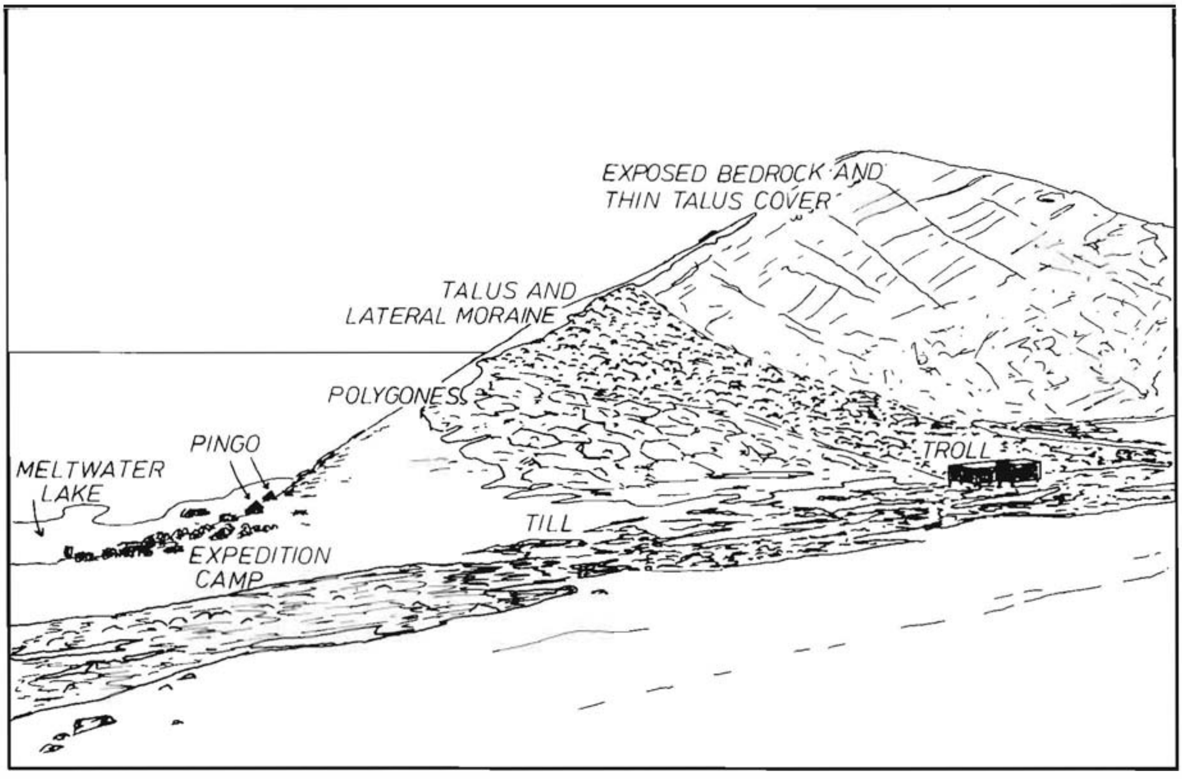


Fig. 4b: Line drawing to explain the Quaternary sediments seen on the photo above.

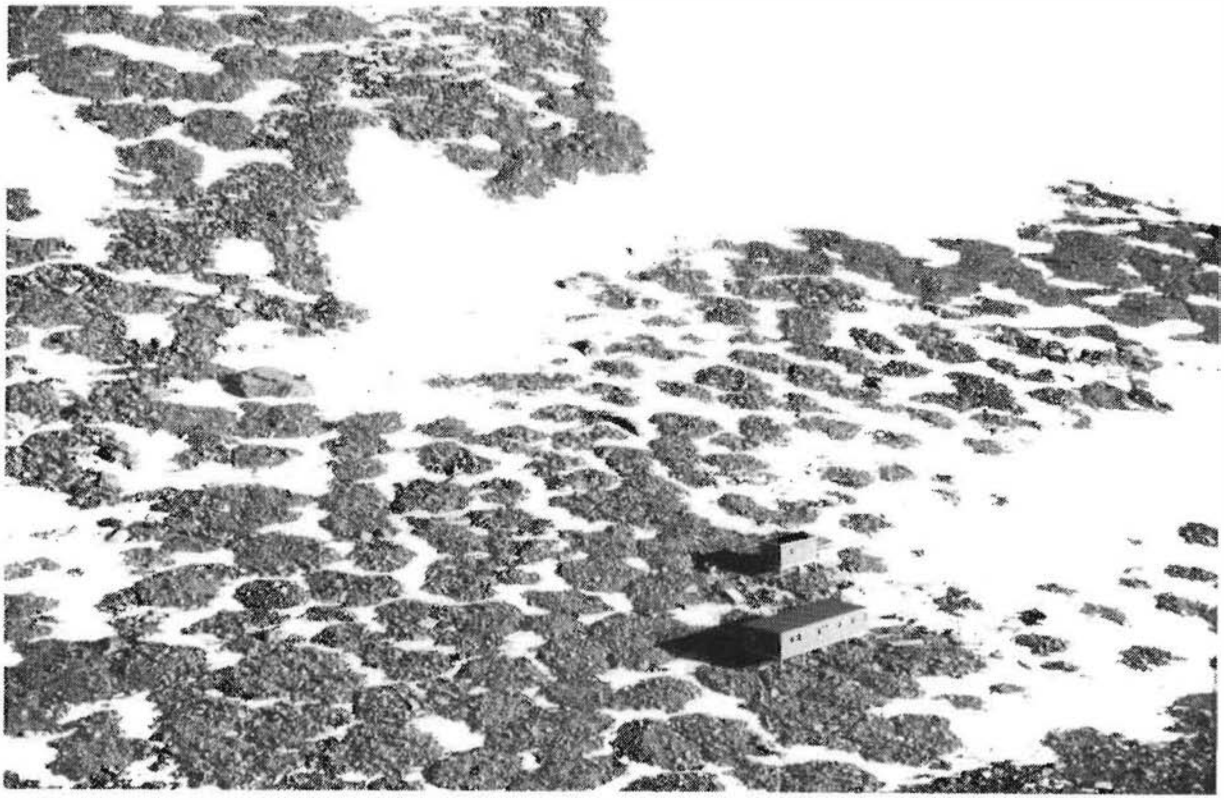


Fig. 5: Patterned ground ('stone pits') in till deposits around the station buildings.

Fig. 6: A 'blister', a pingo-like ice upwelling, with frozen radial cracks. A part of the expedition camp is seen in the background.

tion that the flow direction of this ice-cemented rock mass is headed towards the station, although its velocity is probably so low that it will not do any harm to the buildings within several decades.

The last noteworthy phenomenon is the action of melting water from the Grjotlia glacier flat. Just beside the expedition camp (Fig. 4), a meltwater lake has formed between the ice margin and the moraine. It was (january/february 1990) covered with a c. 75 cm thick ice layer and was used for drinking water.

Two c. 50 cm high, circular, pingo-like elevations ('blisters') with frozen, radial cracks (Fig. 6) witness pressure changes within the lake and indicate that melting of ice is a non-neglectible process in spite of the low temperatures, where one normally expects that sublimation should be the main process. Several similar blisters occur scattered across the lower part of the moraine field in the southeastern part of Grjotlia, there in connection with frozen water ponds between minor elevations within the moraine fields.

Wind erosion and frost-shattering

The fact that weathering of nunataks in the Antarctic is defined to very few, but strongly active processes, results in a characteristic texture of bedrock and block surfaces. These processes are frost-shattering, temperature expansion and wind-blowing. Temperatures vary between c. -60° and +5°, but micro-conditions close to rough surfaces may reach much higher summer temperatures. Strong winds are common during a large part of the year, and the air may be loaded with sand and ice particles.

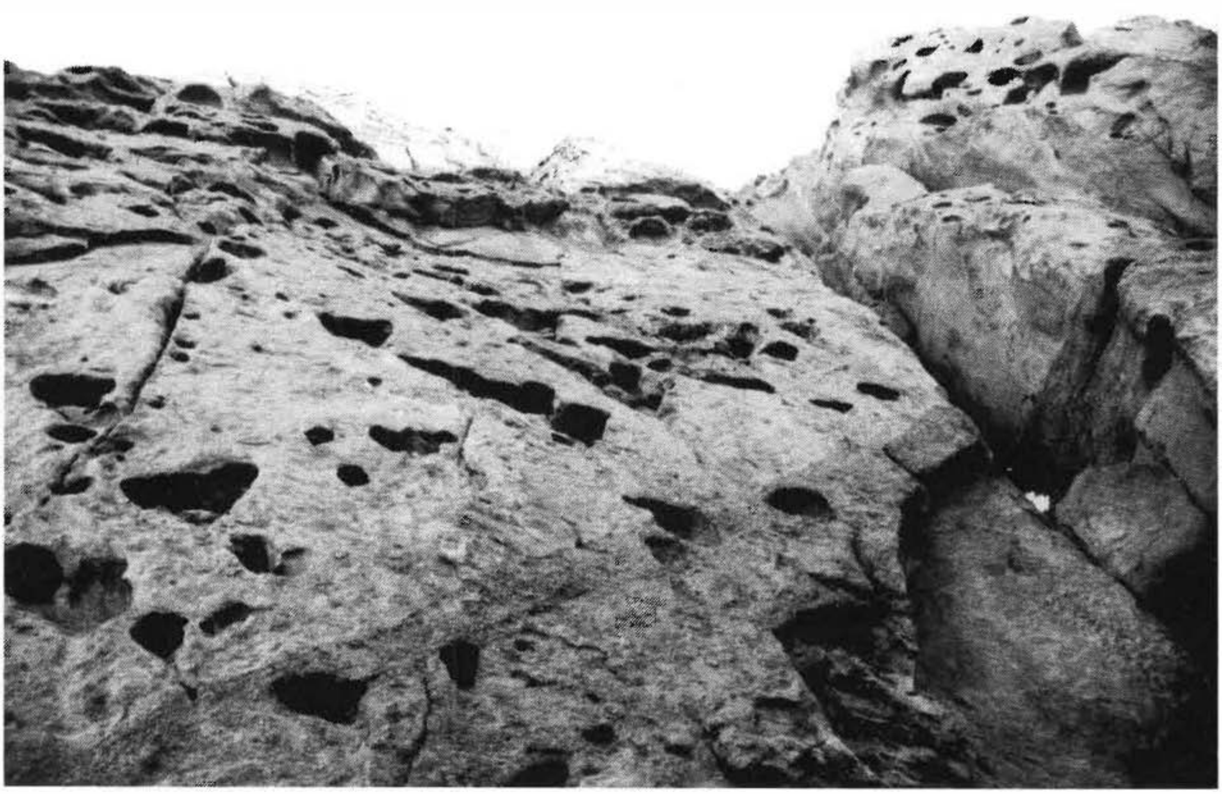


Fig. 7: Holes in a subvertical mountain wall. They have initially been formed by wind erosion, which preferentially affected parts of the wall deeply weathered by temperature changes and frost. Later, whirling-around particles (remains from erosion) were grinding the hole deeper and deeper.

The effects of temperature changes and frost often penetrate several decimetres into the bedrock and result in a mouldering consistence. The effect is largest in coarse-grained rocks with a fairly high amount of mafic minerals, especially the granulites and charnockites that appear widely in the eastern part of the investigated area (Fig. 8), but it is also considerable in inhomogeneous gneisses and mafic lithologies forming parts of the Jutulsessen massive.

The wind effect is not only that of denudation of the mouldering surface material, but also that of 'digging holes' in bedrock slopes. Weaker parts of the rocks weather more deeply by differential frost-shattering and exposes these parts to preferential wind erosion. Once started, the wind-blow process may almost become a self-perpetulating mechanism, as surface depressions act as traps for whirling-around particles. Supported by the grinding effect of small stones (remains from weathering), holes of more than a meter across with an almost equivalent depth have developed in many places, even in vertical moutain walls (Fig. 7).

Some of these holes found in subvertical mountain walls high above the present glacier surface contain exotic stones and can probably be used to determine the maximum ice level.

BEDROCK GEOLOGY

General setting

The area investigated by the expedition, Gjelsvikfjella and western Mühlig-Hofmannfjella, lies within the northwestern part of the East Antarctic craton to the east of a suggested Proterozoic rift zone, the Jutulstraumen-Pencksøkket rift zone (Neethling 1972).

While non-metamorphic, Mid-Proterozoic platform cover rocks (Ritscherflya Supergroup) are exposed to the west of this rift zone (Borgmassivet / Ahlmannryggen mountains; Wolmarans & Kent 1982), high-grade metamorphic and igneous rocks lie to the east of it (Roots 1953, Ravich & Krylov 1964, Ravich & Solov'ev 1966, Hjelle 1974, Grantham et al. 1988, Allen 1988). Radiometric ages concentrate around two tectonothermal events, one at 1200 to 1000 m.y., the other at 450 to 500 m.y. (Moyes 1989) which is coeval with the Ross Orogeny.

A similar pattern is found in the Rhodesian Craton and the Pan African-Kibaran tectonothermal province in Mozambique, which according to plate tectonic reconstructions of the Gondwana continent formed the northern continuation of Dronning Maud Land. There, however, the high-grade terrane is thrust westward onto the Mid-Proterozoic platform rocks. Similar evidence is not known from Dronning Maud Land (Grantham et al. 1988), though it may be hidden beneath the extensive ice cover.

Ravich & Krylov (1964) proposed that western Mühlig-Hofmannfjella represent an acid intrusive complex (granite-granosyenite) which was emplaced in a high-grade metamorphic meta-supracrustal environment. Ohta et al. (1990) reported that the intrusive complex mainly consists of c. 500 m.y. old charnockites. The host rocks are of intermediate pressure type, subjected to upper amphibolite to granulite facies metamor-phism (c. 1000-1200 m.y. from age determinations in northern H.U. Sverdrupfjella and Kirwanveggen, Wolmarans & Kent 1982), and later high-temperature-type metamorphism due to the emplacement of the charnockites.

After the 1989/90 expedition, we prefer to interprete the high-grade rocks intruded by the charnockites as mainly orthogneisses with only minor enclosures of metasediments and consider the entire working area as a major, high-grade igneous province with 1000 -1200 m.y. regional metamorphic, and 450-500 m.y. intrusive ages.

Fig. 8: Geological overview map showing the major lithologic domains within the investigated area (Gjelsvikfjella and western Mühlig-Hofmannfjella). ⟹

The main petrographic regimes

Within the investigated area, four largely exposed petrographic regimes can be distinguished (Fig. 8):

1. A granitic gneiss regime, comprising southern and western Gjelsvikfjella - here called the 'Jutulsessen granitic gneisses';

2. a granitic migmatite regime, covering eastern Gjelsvikfjella and Festninga - here called the 'Risemedet migmatites';

Most of Mühlig-Hofmannfjella belongs to a major igneous complex, the 'Svarthamaren charnockite complex'. This complex is here divided into:

3. a partly granitized complex of granulites and charnockites - the 'granulite/charnockite A complex';

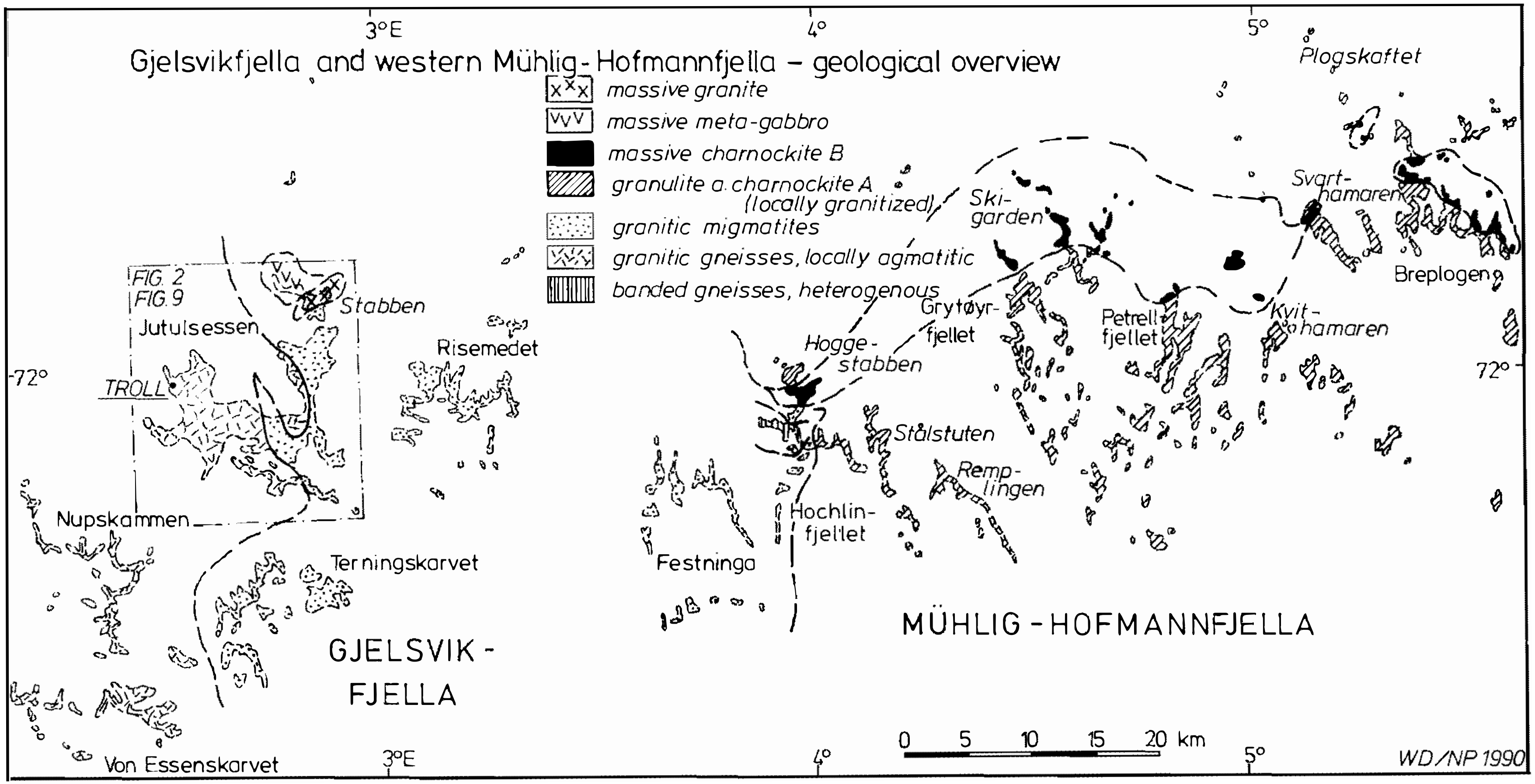
4. a younger charnockitic complex exposed along the northern rim of Mühlig-Hofmannfjella - the 'charnockite B'.

Some minor lithologic units do not fit into this scheme; these are bimodal igneous rocks in the Stabben massif (northeastern Jutulsessen), described later on in the Jutulsessen section, some Mesozoic dolerite dykes observed locally in Gjelsvikfjella, and a heterogeneous, high-grade metamorphic banded gneiss sequence exposed between Hochlinfjellet and Hoggestabben near the contact between the granulite/charnockite and migmatite regimes. These gneisses are metapelitic with cordierite-garnet-spinel parageneses and are at the present stage of study the only certain metasediments within the investigated area.

The Jutulsessen granitic gneisses

Gneisses of granitic bulk composition in upper amphibolite facies (locally granulite facies) form the western and southern part of Gjelsvikfjella. In spite of their generally homogeneous mineralogy, they can be divided into a variety of gneiss types on the basis of structural and textural parameters.

Basically, one has to distinguish between older, transposed and interfingering gneiss lithologies with a well-developed gneissosity, and a sequence of younger cross-cutting aplitic and pegmatitic (and occasionally mafic) veins, dykes and networks. The latter may in places accommodate more than half of the rock volume (e.g. S end of Nupskammen) and give the rock an agmatitic structure. Dyke intrusions have often been accompanied by partial melting of the gneisses and formation of neosomes, so that transitions to truly migmatitic lithologies are common. This is particularly the case in eastern areas, and the boundary with the migmatite regime (Fig. 8) seems to be transitional, with a very low gradient.



Gjelsvikfjella and western Mühlig-Hofmannfjella – geological overview
massive granite
massive meta-gabbro
massive charnockite B
granulite a. charnockite A (locally granitized)
granitic migmatites
granitic gneisses, locally agmatitic
banded gneisses, heterogenous
3°E
4°
5°
-72°
72°
FIG. 2
FIG. 9
Jutulsessen
TROLL
Stabben
Risemedet
Nupskammen
Terningskarvet
Von Essenskarvet
GJELSVIK-FJELLA
Festninga
Hochlin-fjellet
Hogge-stabben
Stålstuten
Remp-lingen
Grytøyr-fjellet
Ski-garden
Petrell-fjellet
Kvit-hamaren
Svart-hamaren
Plogskaftet
Breplogen
MÜHLIG-HOFMANNFJELLA
0 5 10 15 20 km
WD/NP 1990

However, some of the granitic lithologies occupy a transitional state between transposed and cross-cutting relations; e.g. an augen gneiss body exposed at SW Nupskammen and NW Von Essenskarvet. In the northwesternmost tip of Von Essenskarvet, the rocks show transitions towards an unfoliated, porphyritic granite, which has a sharp boundary - though not cross-cutting - towards completely planar-structured, aplitic gneisses. The same augen gneiss has a transposed, interfingering contact with aplittic gneisses at the southwestern slope of Nupskammen (Fig. 9).

Augen gneisses (often with Rapakivi-type feldspar augen up to 10 cm across) and aplitic gneisses are characteristic for the southwesternmost part of Gjelsvikfjella, while the remaining areas are dominated by medium-grained gneisses, rich in a variety of leucosomes, rods and boudins of leucocratic material. In Jutulsessen, several gneiss lithologies occur and are described in more detail in the corresponding section (p. 25 ff.).

Most of the granitic lithologies contain layers, where mafic minerals (mainly biotite, or biotite and hornblende) are concentated. Some layers may be purely mafic or even monomineralic (biotite). In many places, these layers can be traced to construct fold patterns in the gneisses indicating regional flattening.

Garnets are common minerals in many lithologies, and samples for thermo-barometry have been collected.

Less common minerals have been observed in a few places in western Von Essenskarvet:

1. Beryl (a few crystals) in a pegmatite;
2. Cordierite within biotite- and hornblende-rich zones;
3. Various skarn minerals in loose blocks.

Megascopic folds which refold the transpositional structures with steeply to moderately dipping limbs and SE to E dipping fold axes, are superimposed across the whole area. An E-W trending antiform is situated between Von Essenskarvet and Nupskammen, an ESE-WNW trending synform passes through Nupskammen and Terningskarvet, and a SE-NW trending antiform runs through Jutulsessen (Ohta et al. 1990).

The Risemedet migmatites

Although agmatitic structures occur throughout the granitic gneisses, there is an increasing degree of migmatization by partial melting of the rock mass from W to E. The boundary between these two regimes (Fig. 8) is somewhat artificial, as the transition happens very smoothly.

The pre-migmatization lithologies of both regimes have obviously been continuous, although it is difficult to distinguish between them in the east. Formation of neosomes and irregular flow-folding in addition to the agmatitic network have destroyed many of the structural and textural parametres critical for their discrimination (Fig. 10).

Also, the migmatites contain bands where mafic (biotite ± hornblende) horizons are concentrated. Garnet occurs in many places in both mafic and granitic lithologies.

The slope of northwestern Risemedet shows a megascopic, recumbent, isoclinal fold (Fig. 11) with a NE-SW axial trend in the migmatites. It refolds the gneissosity of the rocks. Due to the poor exposure of the entire region, it can be suggested that there are many lithologic repetitions within both migmatites and gneisses, although fold hinges are not exposed.

The megascopic regional folding observed in the granitic gneisses affects also the migmatites and is younger than the recumbent isocline.

Fig. 9: Interfingering of a transposed contact between augen gneisses and aplitic gneisses, Nupskammen.

Fig. 10: Granitic migmatite, Risemedet.

Fig. 11: Megascopic isoclinal fold, northwestern slope of Risemedet.

The Svarthamaren charnockite complex

The granulite/charnockite A complex

Most of Mühlig-Hofmannfjella to the east of Festninga consists of an intrusive, granitic complex in granulite to upper amphibolite facies. It provides mostly igneous textures in northern areas, but becomes increasingly foliated and gneissose to the south. It contains abundant xenoliths in many areas, and is cut by a bimodal sequence of dykes.

It is at the present state of knowledge not possible to decide if this complex mainly represents one intrusive event, or is a composite one. However, one later intrusive body can clearly be distinguished and is here called 'charnockite B' (see next section), while 'charnockite A' is used for the charnockitic parts of the older complex.

It is also not clear, how the migmatites to the west are related to the deformed parts of the igneous complex. Although the migmatites probably are altered orthogneisses themselves, they may have been the host rocks for the intrusive complex, owing their migmatization to the heat from the intrusions. This interpretation is preferred here.

Alternatively, they may - together with the gneisses of Gjelsvikfjella - form parts of the same intrusive complex that later have been subjected to more intensive deformation. This, however, would not explain the occurrence of gneiss and migmatite xenoliths similar to the Jutulsessen and Risemedet lithologies within the charnockite A intrusions.

Many portions of the complex are dominated by a massive, unfoliated or weakly foliated, medium-grained granitic rock. These rocks display at some places a granulite facies mineralogy (charnockite; with hyperstene and mesoperthitic feldspar), characterized

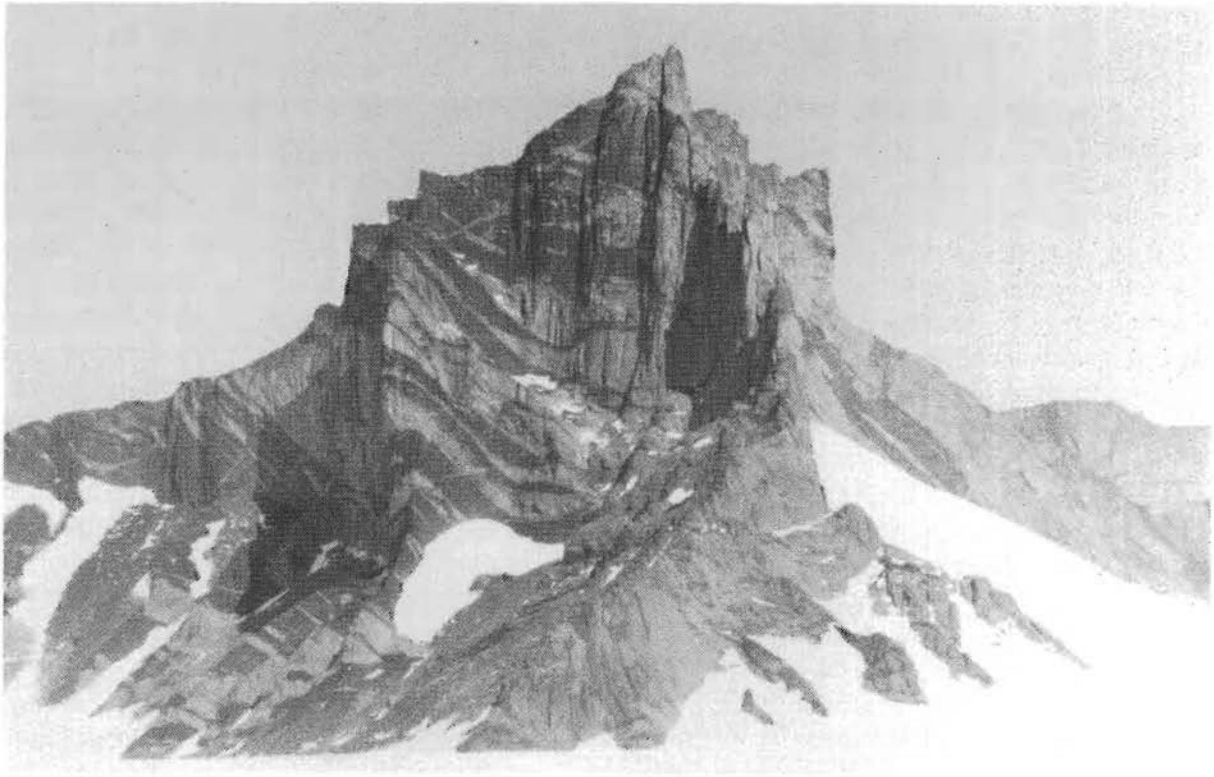


Fig. 12: Charnockite A (dark) with granitized bands (light), Stålstuten (the 'Steel Bull').

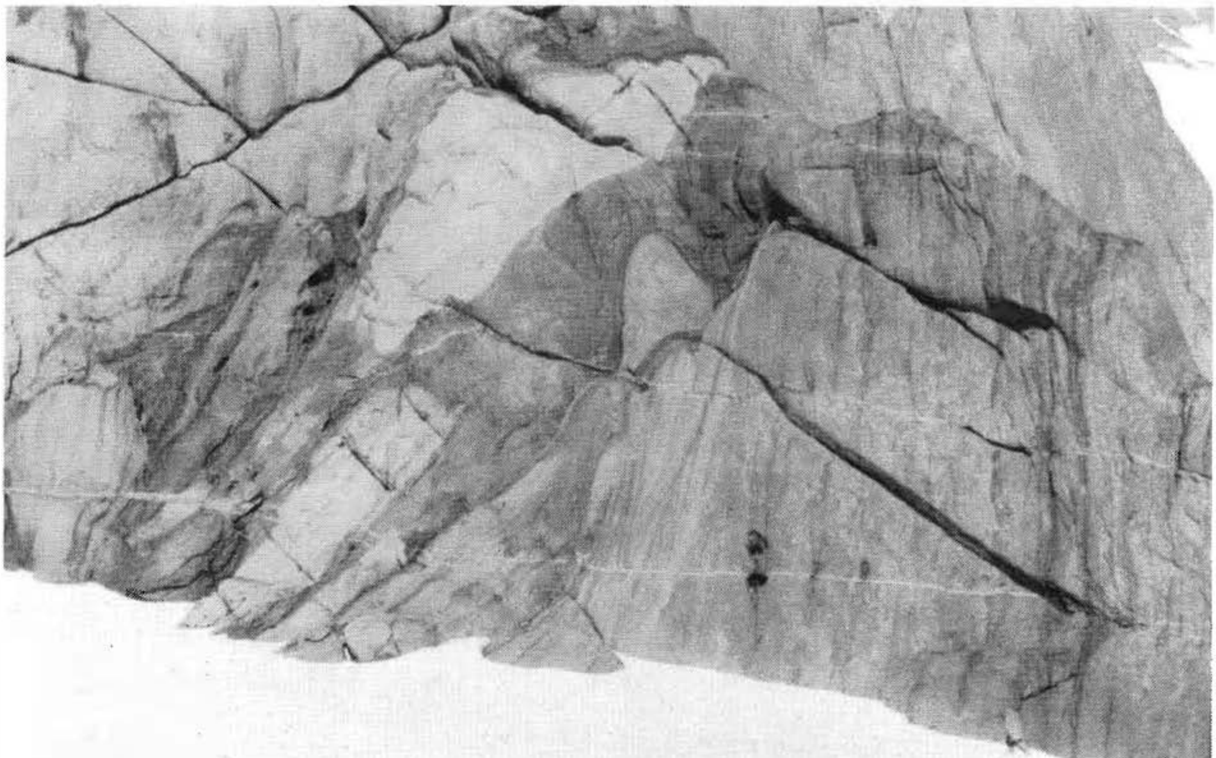


Fig. 13: Granitic xenoliths and flow banding in charnockite A, Tjuvholene (the 'Dens of Thieves')/Grytøyrfjellet.

by a distinct reddish-brown weathering colour. At other places it contains a typical amphibolite facies mineralogy (biotite-hornblende granite) with a light grey weathering colour.

The boundary between the two varieties is normally sharp, but geometrically very complex. Mountain slopes may have a patchy appearance, with either granulite patches in a granitic ground mass, or vice versa. In other places, the distribution may be banded, with or without indication of tectonic shear along the boundaries. The best exposed example for the latter is the mountain Stålstuten, where alternate bands of charnockite and granite give the impression of a zebra pattern across the entire, 800 m high mountain walls (Fig. 12). Occasionally observed deformation patterns (e.g. gneissosity) are continuous across the banding and thus clearly reflect deformation older than the facies transitions.

To explain this phenomenon, one must take into consideration that the granulite-amphibolite facies transition is not only dependant on the temperature. At a given pressure (or crustal depth), the equilibrium temperature of all reactions needed to perform the amphibolite-granulite facies transition is strongly dependent on the composition of the fluid phases. Small-scale variations in fluid parametres may thus result in an extremely complex granulite-amphibolite facies interface.

The areas with a patchy facies interface are often penetrated by a system of granitizing veins, through which reacting fluids could migrate and 'white-wash' the granulite/charnockite (Fig. 16).

Xenoliths are common within the intrusive complex, but are concentrated in - though not restricted to - certain areas (e.g. Plogskaftet, Remplingen, etc.; Fig. 13). Both granitic, granitic gneiss and mafic xenolith lithologies are common. They often influence the granulite-amphibolite facies transitions in different ways. A good exposure of a mega-breccia-like assemblage of granitic xenoliths in a granulitic matrix can be seen on the north slope of Remplingen, where it comprises the entire, 600 m high mountain wall.

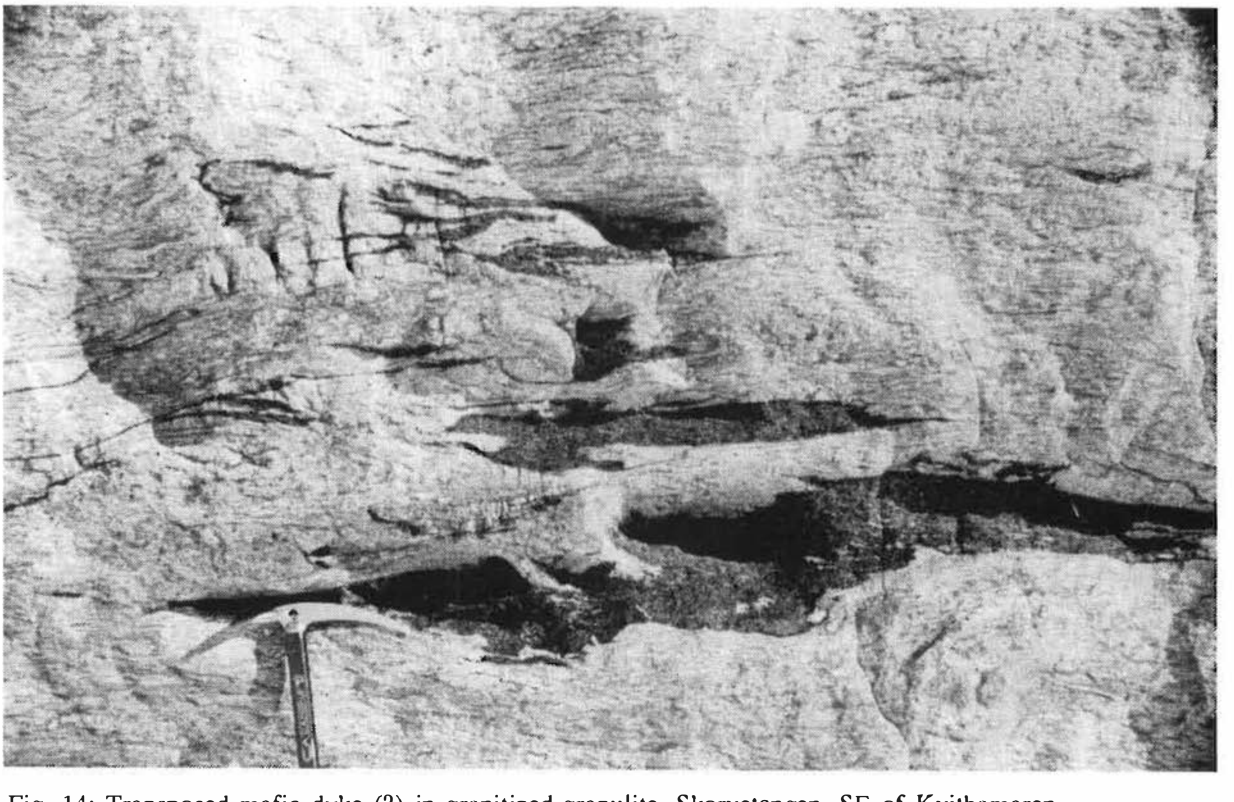


Fig. 14: Transposed mafic dyke (?) in granitized granulite, Skorvetangen, SE of Kvithamaren.

Mafic xenoliths have mostly an amphibolitic composition. They appear often in clusters, initially larger xenoliths, that were 'brecciated' by the intruding granitic melt.

Strongly foliated or gneissose lithologies related to the granulite/charnockite A complex have been observed in southern areas, between the southern and central part of Remplingen, and in the southern nunataks of Kvithamaren. The composition of these gneisses corresponds usually to the less foliated rocks to the north; locally - like at Remplingen - there is a transition zone via sheared and stretched xenoliths indicating that these gneisses are deformed equivalents of the intrusives. An early generation of mafic dykes is also often stretched, boudined and transposed in these sheared areas (Figs. 14, 15).

Finally, the whole complex is cut by a bimodal sequence of dykes. The best exposure where cross-cutting relations can be studied is the southern part of the eastern slope of Svarthamaren (Fig. 16). The sequence here is from old to young: foliated amphibolite - porphyritic granite -?- aplite - meta-diorite -granitization veins -?- unfoliated amphibolitic rock - charnockite B. Granitization of the granulite host rock happened probably at several stages, but the most common type of fluid transporting veins can be seen to cut the meta-diorite dykes.

The mountain Hoggestabben ('Chopping Block'; Fig. 17) far west in Mühlig-Hofmannfjella has a dioritic composition and mainly a light-grey weathering colour. In its southern part, there is a mafic variant that also forms many xenoliths within the lighter-coloured meta-diorite, and possibly represents an earlier intrusive phase. The relations between the meta-diorites and the overall granulites/granites are uncertain.

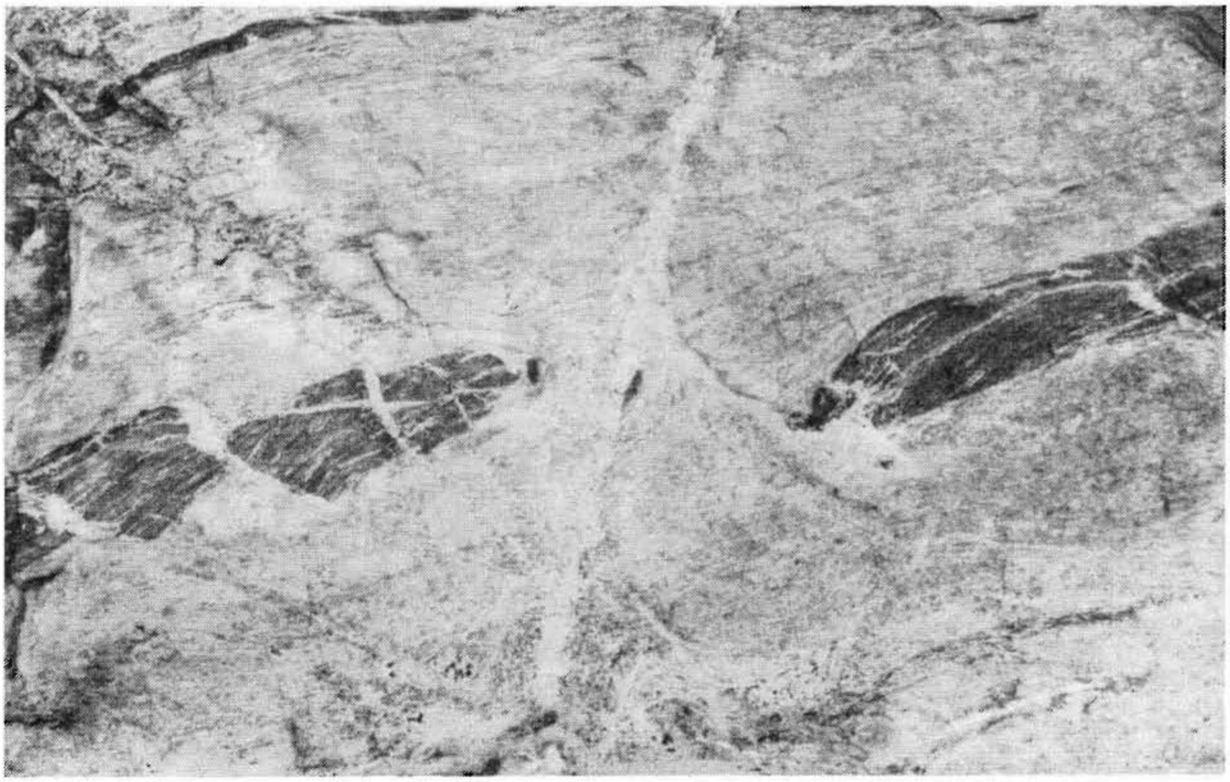


Fig. 15: Boudined mafic dyke and granitization veins in granulite, Hamarskorven, SE of Kvithamaren. Size of area c. 2x3 m.

Fig. 16a: Sequence of dyke intrusions within granulite, eastern wall of Svarthamaren. Elevation of the wall c. 200 m.

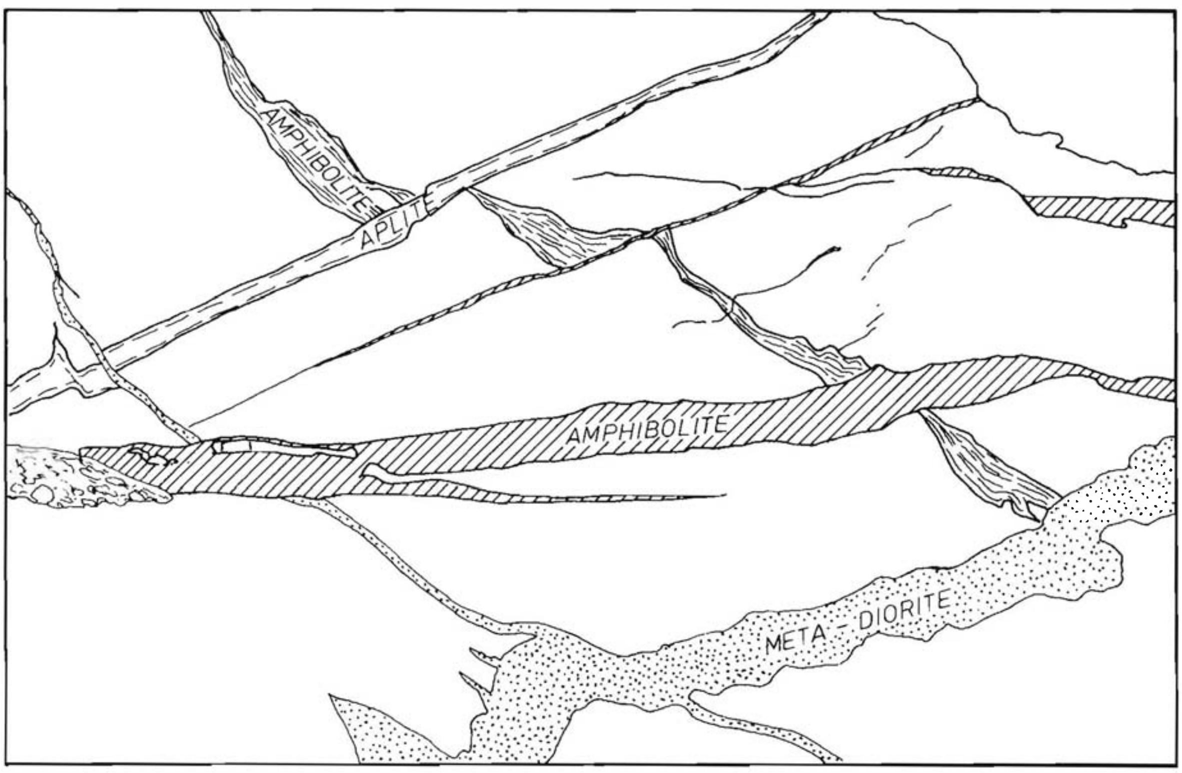


Fig. 16b: Interpretation of the dyke sequence shown on the photo above. With decreasing age: foliated amphibolite, aplite, meta-diorite, amphibolite.

The charnockite B intrusions

Northern areas of the Svarthamaren charnockite complex belong to a younger charnockite generation that locally shows clear intrusive contacts with the older charnockites or granulites. They are usually darker brown coloured. Other criteria are the lack of a cross-cutting dyke sequence (except for occasionally minor aplitic or pegmatitic veins), and the minor extent of granitization. The special mode of weathering of the charnockite B is responsible for the most spectacular pinnacle-shaped mountains like Skigarden (the 'Paling'), Vedkosten (the 'Besom'), etc. (Figs. 17, 18).

In several places dykes of charnockite B can be observed to cross-cut the granulites. They form probably the youngest dykes within the Svarthamaren charnockite complex, except for the mentioned aplitic to pegmatitic veins that locally are responsible for an initial retrograde process.

Fig. 19 shows an intrusive contact, where charnockite B intrusion had fluidized the host rock, which then sent out a pegmatitic vein cutting back into charnockite B, where it caused local granitization.

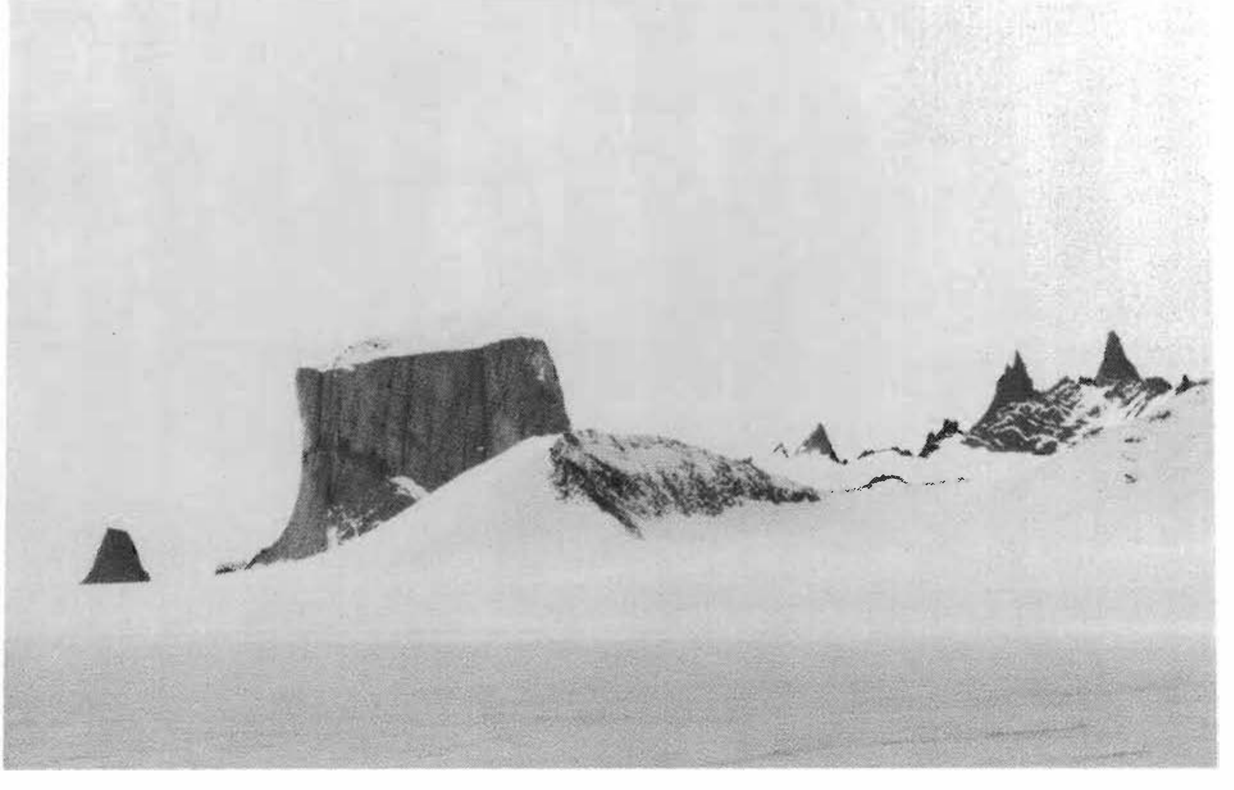


Fig. 17: The 800 m high vertical walls of the mountain Hoggestabben (the 'Chopping Block', 2410 m), a diorite intrusion, and the charnockite B pinnacles of Vedkosten (the 'Besom') to the right.

Fig. 18: Vedkosten (S of Hoggestabben), the c. 300 m high charnockite B pinnacles with their characteristic shape due to wind erosion.

Fig. 19: Intrusive contact at Plogskaftet: Charnockite B (dark) intruded granulite. The mobilized granulite sends a granitic vein back into the charnockite B, which then was granitized along the contact with the vein.

The Jutulsessen area

Lithology

The Jutulsessen area forms part of the Jutulsessen granitic gneiss regime and the Risemedet migmatite regime (Figs. 8, 20). Many gneiss lithologies in the eastern and southern ridges are transitional. Two younger intrusive bodies, the Stabben monzonite and the Stabben gabbro, cut the migmatites in the northeastern continuation of the mountain area (Fig. 20).

Granitic gneisses

General remarks:
All of the gneiss lithologies have a granitic (to tonalitic) bulk composition. Lithologic differences are due to a different degree of migmatization, varying compositional banding, transposition of cross-cutting veins and dykes and varieties of other structural features. It is therefore appropriate to consider the Jutulsessen gneisses as orthogneisses, or, more specifically, as a strongly deformed granitic intrusive complex.

Modal composition:
The basic composition of the rocks is plagioclase, microcline, quartz and biotite (1-50%). Garnet occurs preferentially in biotite-rich rocks or layers. Hornblende is restricted to a few layers or localities in western areas, but is more abundant in the eastern, migmatitic areas. Apatite occurs as an abundant accessory and may locally constitute up to 1% of the rock volume. Other common accessories are zircon, orthite, sphene, monazite, rutile and ilmenite.

Poikiloblastic muscovite occurs locally replacing feldspars, suggesting a secondary alteration, possibly under participation of alumosilicates. Both sillimanite and andalusite have been reported by Ohta et al. (1990), indicating a high-temperature metamorphic facies series at a later stage of metamorphism.

Furthermore, Ohta et al. (1990) have reported pinitized cordierite and hercynite, occasionally included in later andalusite, from certain layers within mica-rich gneisses. Kyanite grains were found as inclusions in garnet. This suggests that the earlier stage of metamorphism belongs to the intermediate pressure-temperature metamorphic facies.

Sphene often accompanies biotite and hornblende.

Sericitization of microcline and saussuritization of plagioclase form minor amounts of sericite, epidote and calcite, whereas biotites occasionally are chloritized.

Mineral parageneses show stable amphibolite facies metamorphic conditions, but feldspar textures indicate frequently that the gneisses have been subjected to strong later recrystallization. Zones of inclusions cut the twin banding of plagioclase grains, and even grain boundaries. Mesoperthitic decomposition of ternary feldspars indicates that the former mineral composition was stable at high-grade metamorphic conditions.

The Grjotlia granitic gneisses:
This type of gneisses forms most of the eastern and southern parts of Jutulsessen. It has a well defined boundary towards the underlying banded gneisses to the northwest of Sætet, but turns gradually into the Armlenet migmatites to the southeast.

The rocks are usually characterized by a well-developed gneissosity. Abundant folded leucosomes, partly occurring as rods and boudins, are lying in a granitic gneiss matrix (Fig. 21). Layers were biotite ia an abundant constituent can be seen at both micro-, meso- and macro-scale, the latter attaining several tens of meters of thickness. Those are roughly indi-

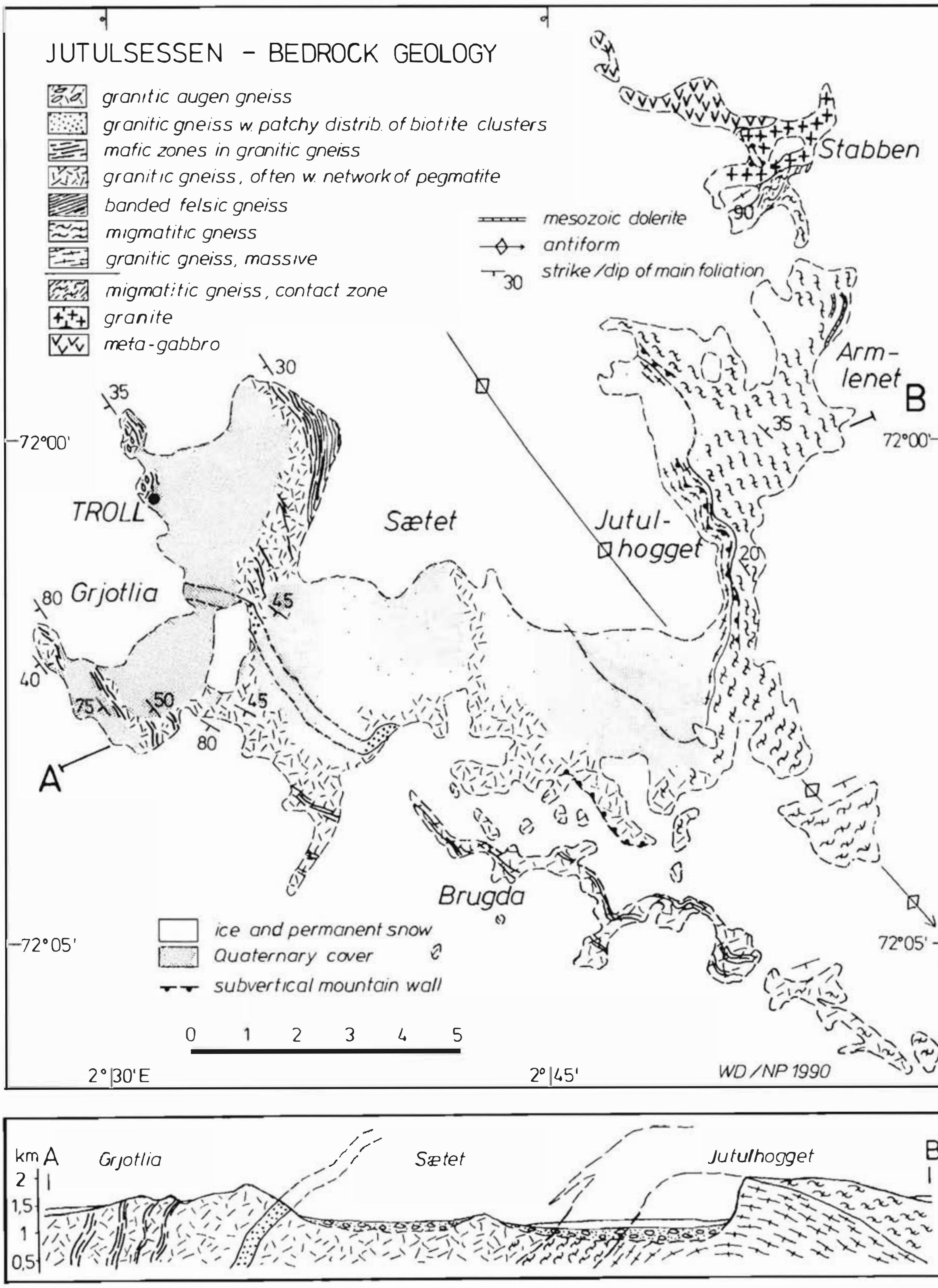


Fig. 20: Bedrock geology map of Jutulsessen, Gjelsvikfjella.

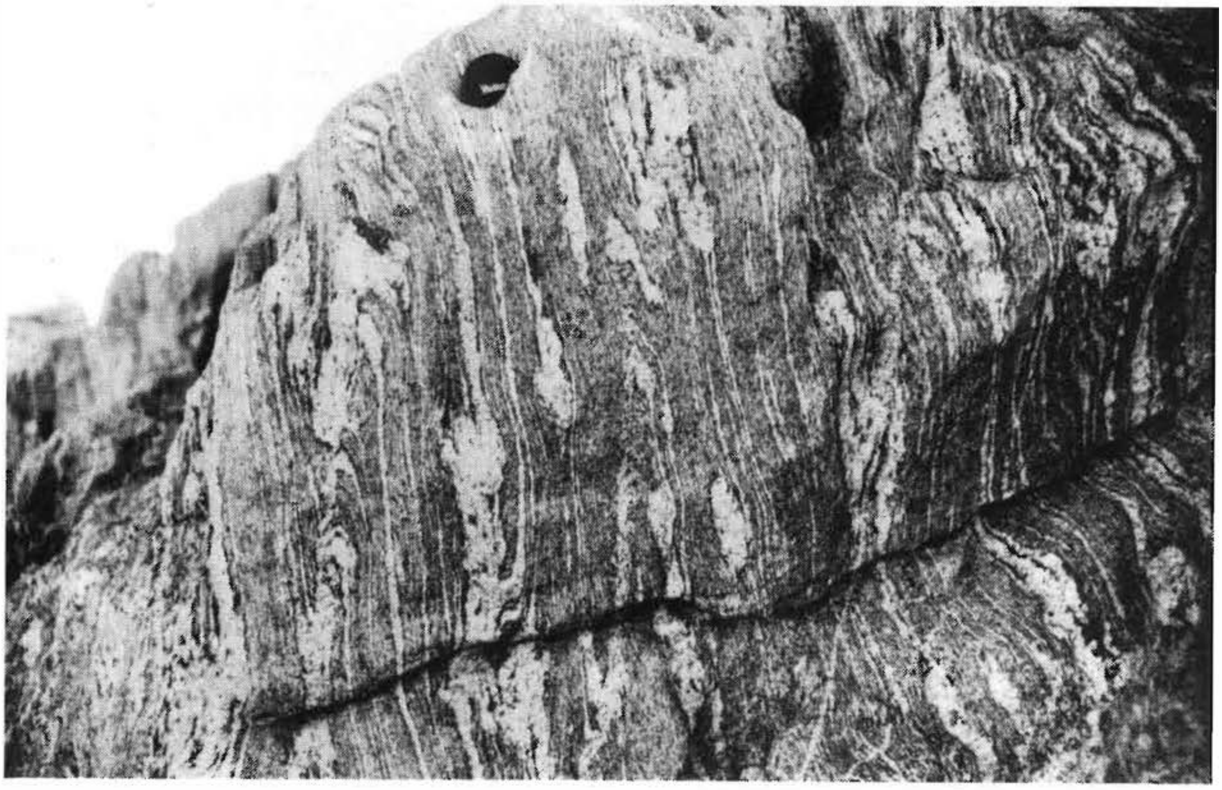


Fig. 21: Granitic gneiss in Grjotlia; S_1 gneissosity with isoclinally folded leucosomes.

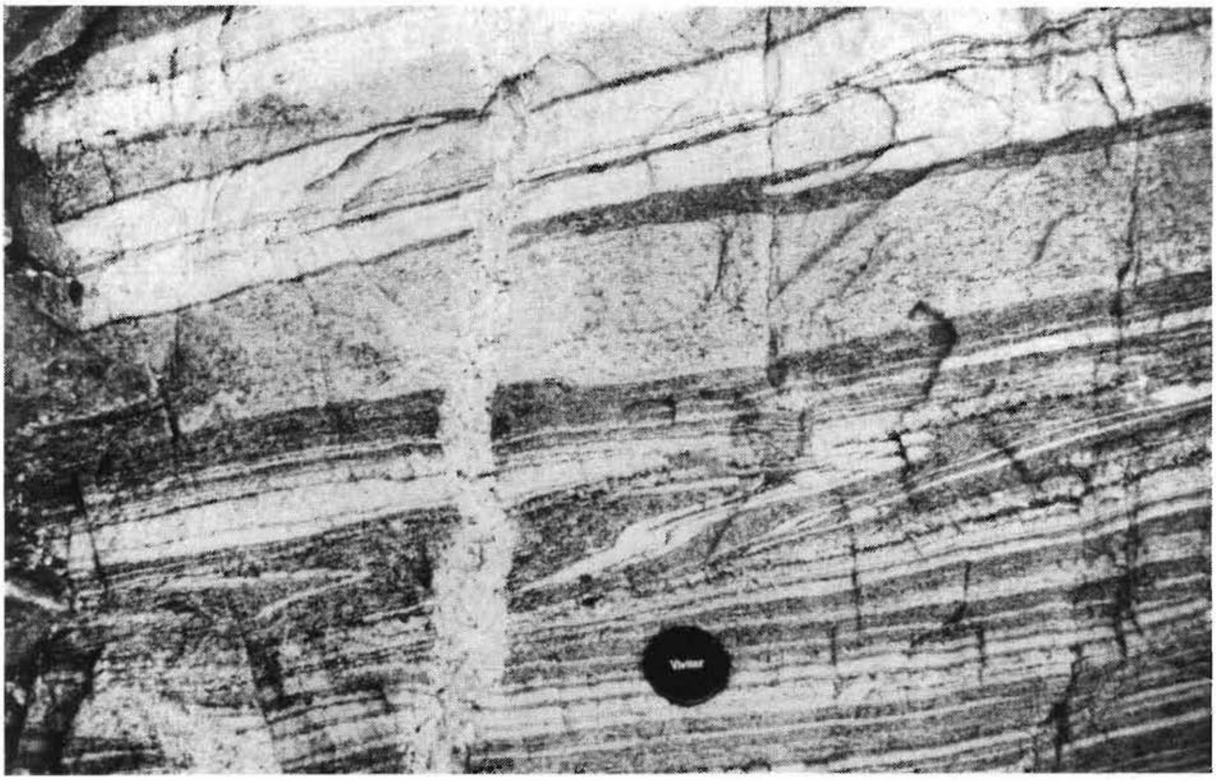


Fig. 22: Granitic gneiss with biotite-rich bands (dark), northwestern Sætet, showing granulite-amphibolite facies transition. The thick granite band just above the middle of the photo is somewhat darker and exhibits greenish-yellow feldspars typical for granulite facies. The vertical granite vein is 'decolouring' the granulite.

cated on Fig. 20. Thicker mafic layers may locally contain hornblende. Hornblende (occasionally together with garnet) also forms dm-size nodules in fold hinges.

Augen gneisses are only poorly developed in the Jutulsessen area, and occur only in the northern part of Grjotlia, north of Troll Station, along the crest of the hills. The augen are aggregates of microcline and subordinate other minerals. They are usually elongate and seldom larger than 1 cm. The matrix is a biotite granitic gneiss.

In the middle part of Grjotlia, one layer has a distinct patchy texture, with patches or clusters of biotite and garnet of cm-size in a felsic matrix. This lithology has not developed a distinct gneissosity.

The banded felsic gneisses of western Sætet:

These rocks occur with a distinct upper boundary below the Grjotlia type gneisses. Here, a compositional banding of felsic and mafic (biotite) layers is developed at cm- to dm-scale. Intrafolial isoclines are abundant. Locally, the felsic layers have yellowish to greenish feldspars characteristic of granulite facies rocks. In the vicinity of granitic veins cutting the banding, where there was sufficient support of granitizing fluid, the feldspars are completely 'decoloured' (decomposed) (Fig. 22).

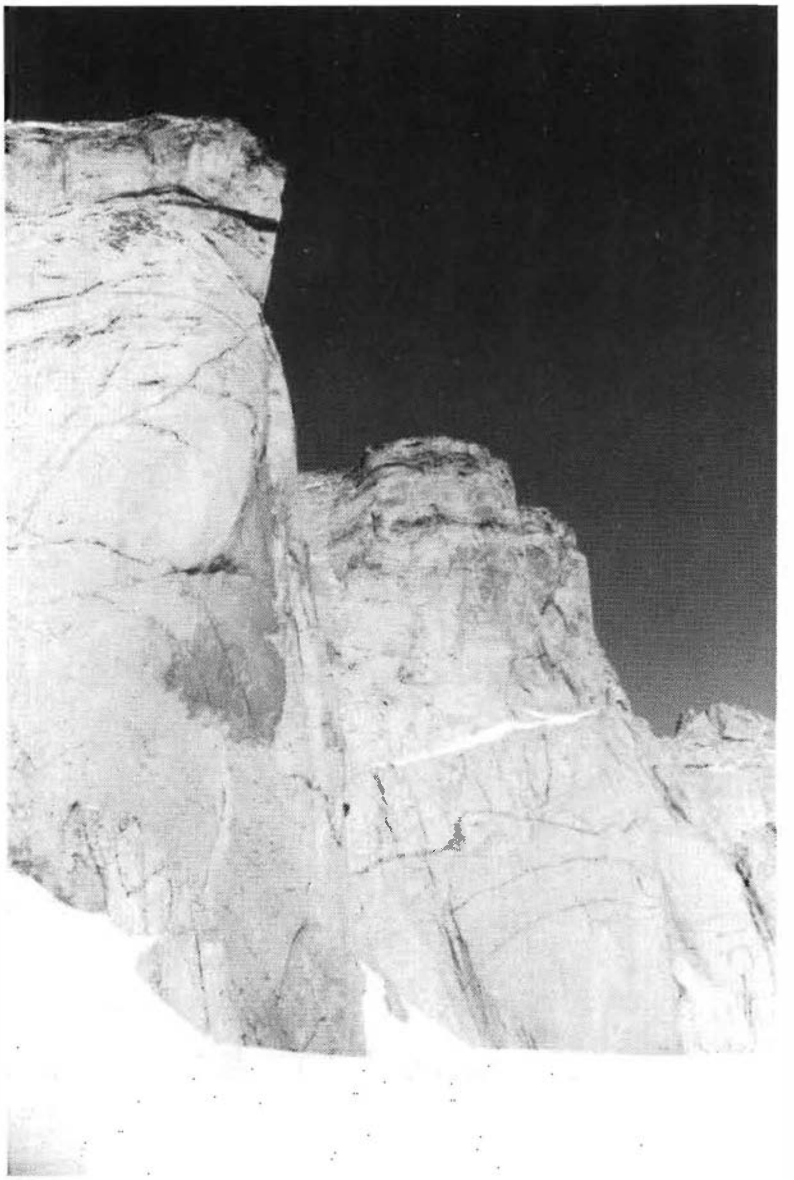


Fig. 23: Jutulhogget (the 'Stroke of Jutul'), the 900 m high vertical mountain wall, consisting of massive granitic gneiss.

The Jutulhogget massive granitic gneisses:

At Jutulhogget, a 900 m high, vertical mountain wall is composed of a rather homogeneous, slightly folded, fine-grained granitic gneiss (Fig. 23). This lithology constitutes the lowermost tectonostratigraphic level exposed in the Jutulsessen massif. The peculiar feature of this rock type is its pattern of cm-thick veins parallel to the axial surfaces of the folds at dm-scale. The veins are leucocratic, mainly composed of quartz, but contain clusters of biotite.

The Armlenet migmatitic gneisses:

Migmatitic gneisses overlie the Jutulhogget type gneisses and build up most of Armlenet, while they grade into the Grjotlia type gneisses in southeastern Jutulsessen. As mentioned previously (p. 16), they are probably equivalents of the latter, though they have a different tectonometamorphic history. They are penetrated by a much more irregular pattern of leucosomes, and locally also affected by a diffuse distribution of mafic material. In thin section, clinopyroxene occurs together with biotite.

The Stabben monzonite

At Stabben, north of Armlenet, the migmatitic gneisses are intruded by a coarse-grained monzonite (Fig. 24). Abundant xenoliths of the gneisses are found close to the intrusion contact. The contact with the gabbro in the north, however, is straight and sharp.

Also the Stabben monzonite shows strong recrystallization of feldspars in thin sections, decomposition of ternary (?) feldspars, and two generations of myrmekite. Beside microcline/perthite/mesoperthite, plagioclase and minor amounts of quartz, the rock contains brown biotite and some dark green hornblende. Accessories are apatite, sphene, tourmaline, zircon, ilmenite and epidote.

The Stabben gabbro

To the north, the monzonite is bordered by a gabbro intrusion (Fig. 24). The boundary relations in the field do not give evidence of the age relation of the intrusions. In thin section, the gabbro reveals a completely magmatic texture without any evidence of later deformation or recrystallization. The gabbro may therefore be post-tectonic and younger than the monzonite, though it alternatively could represent an undeformed lens.

The gabbro has a large range of composition from olivine gabbro to biotite hornblende gabbro. The olivine gabbro is composed of olivine, both clino(Ti-augite)- and orthopyroxene, plagioclase, biotite and small amounts of hornblende and ilmenite. No biotite-pyroxene reactions can be observed. Biotite occurs poikilitic around olivine grains.

The Stabben gabbro contains xenoliths of strongly recrystallized metadiorite, and is cut by the youngest generation of aplitic dykes.

Dykes

Dykes of different ages with cross-cutting relations are frequent all over the Jutulsessen area. Their composition is basic to acid, though most are aplites and pegmatites.

The most basic composition has been observed in a metabasaltic dyke, which is the oldest one found in the Jutulhogget granitic gneiss. It is mainly composed of clinopyroxene and green biotite, and minor amounts of plagioclase and hornblende, and accessories (tour-

Fig. 24: The Stabben monzonite intrusion and, in the foreground, the darker Stabben gabbro. Both are cut by subhorizontal, reddish aplite dykes. The mountain wall is c. 300 m high.

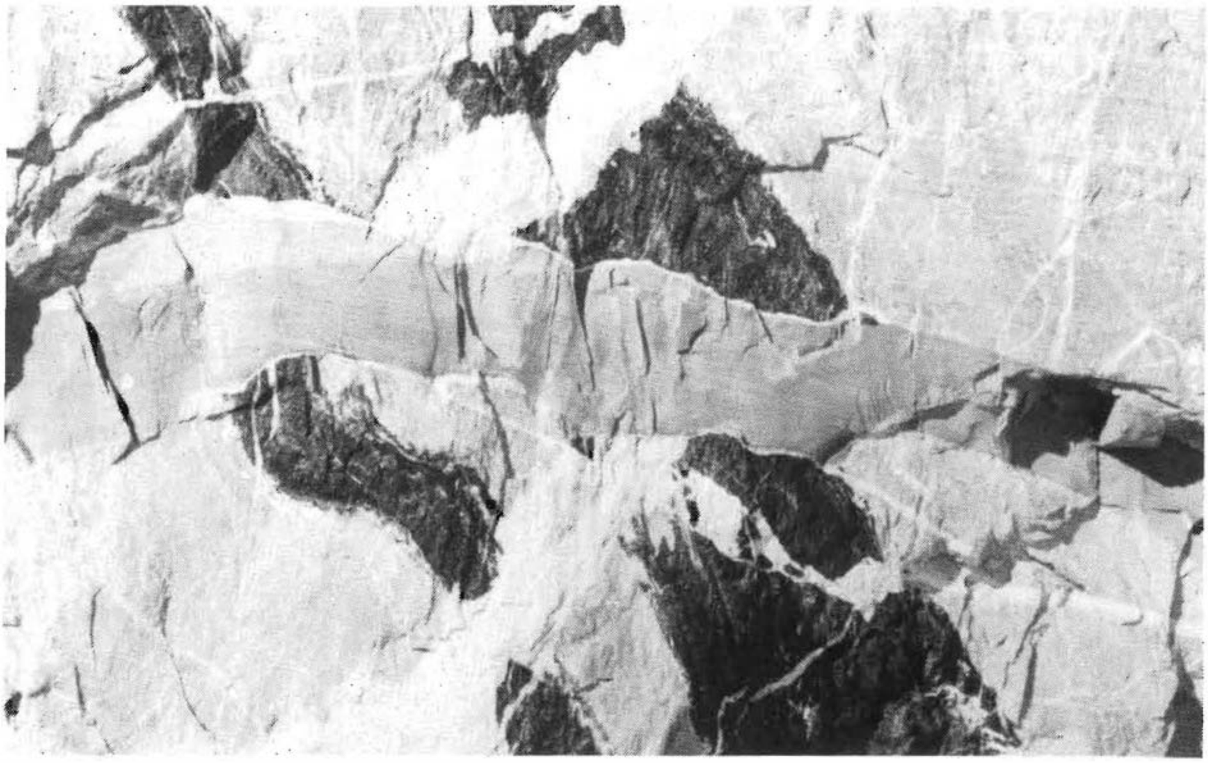


Fig. 25: Dyke sequence at Jutulhogget: biotite-clinopyroxene dyke (black), pegmatite (white), reddish granite (grey on photo). The photo shows an area of c. 20x30 m.

Fig. 26: Dyke sequence in granitic gneis, Grjotlia: pegmatite (white), altered amphibolite (black), aplite (grey), pegmatite (white).

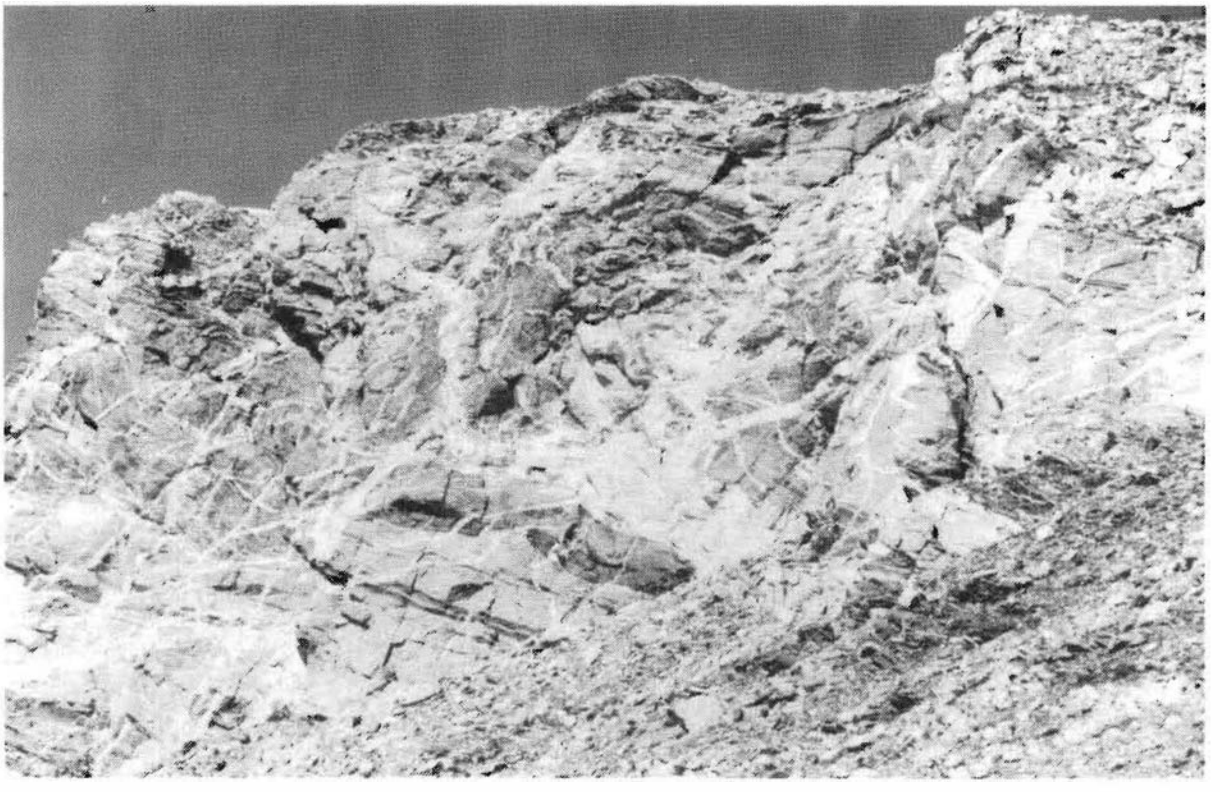


Fig. 27: Network of aplites and pegmatites in granitic gneiss, NW Sætet.

maline, leucoxene, ilmenite, apatite). The dyke is strongly foliated, though no reaction has occurred between the pyroxene and the biotite. The dyke is cut by two generations of granitic dykes (Fig. 25).

Other basaltic dykes are also very early within the sequence of intrusions (Fig. 26), but are less mafic. They are mainly composed of plagioclase, biotite and Fe-rich hornblende, are foliated and show a breakdown of the hornblende.

Dykes of granitic composition have varying grain sizes and colours. They are mostly white- to pink-coloured pegmatites, or grey- or red-coloured aplites. They have a high content of apatite in common with the granitic gneisses of the area. Saussuritization of plagioclase and sericitization of microcline and perthite are common. There has not been observed mesoperthitic exsolution, but strong recrystallization and growth of new feldspars along grain boundaries. Recrystallized grains may be strongly deformed, even in the younger pegmatitic phases.

Parts of the Grjotlia granitic gneisses west and south of Sætet are penetrated by a tight network of pegmatites and aplites constituting up to 50% of the rock mass (Fig. 27). They belong to several generations, but are mostly younger than the basic dykes.

The latest granitic dyke phase is one of reddish aplites that even cut the Stabben gabbro (Fig. 24).

Mesozoic dolerite dykes have only been observed in the Armlenet area along a fault zone and in the eastern wall of Sætet. They have a fresh doleritic texture and are composed of olivine, Ti-augite and plagioclase.

Structural geology

General style of deformation

The gneiss lithologies at Jutulsessen provide two generations of fabric-forming structures (D_1 and D_2). The first is characterized by a complex, probably composite gneissose banding (S_1) which completely transposes earlier structures. The second is usually developed as asymmetric shear folds (F_2) (Figs. 21, 22). They overprint the gneissose banding to a varying extent and may tighten towards certain shear zones where a new transposition banding (S_2) may be formed. These zones are naturally those composed of micaceous lithologies.

The fabric-forming structures are mainly of pure-shear type and suggest that considerable flattening has occurred. The preferred shear sense within folds of both generations, however, seems to be to the northeast. There was no occasion to gather sufficient data during the expedition, but there seems to be an overprinted simple shear component in this direction.

Post-fabric structures are confined to few generations. One is the overall regional folding about a gently southeast dipping fold axis. Jutulsessen forms a wide antiform or elongate dome (Fig. 20) with minor flexures and subordinate undulations overprinted at a 100-m scale.

Ohta et al. (1990) describe a subvertical, E-W trending fault, the Armlenet Fault, in the northeastern part of Armlenet. The fault plane is not exposed, though strongly differing orientations of the gneissosity on both sides indicate its existence. It may be related to the emplacement of Mesozoic dolerites in the same area.

A local, late structure is a SSE-directed shear zone with a c. 2 m thick mylonite zone (Fig. 28). It is situated in the migmatitic gneisses south of Stabben where it follows a pegmatitic dyke. It is a clearly late-tectonic structure and may be associated with the intrusion of the Stabben gabbro that pressed the monzonite body into the surrounding rocks to the south.

Finally, the intrusion of dykes into fractures and minor faults occurred at several late syn- to post-tectonic stages. (Early syn-tectonic dykes may be involved in the S_1 gneissose banding and are difficult to discriminate from their host rocks.)

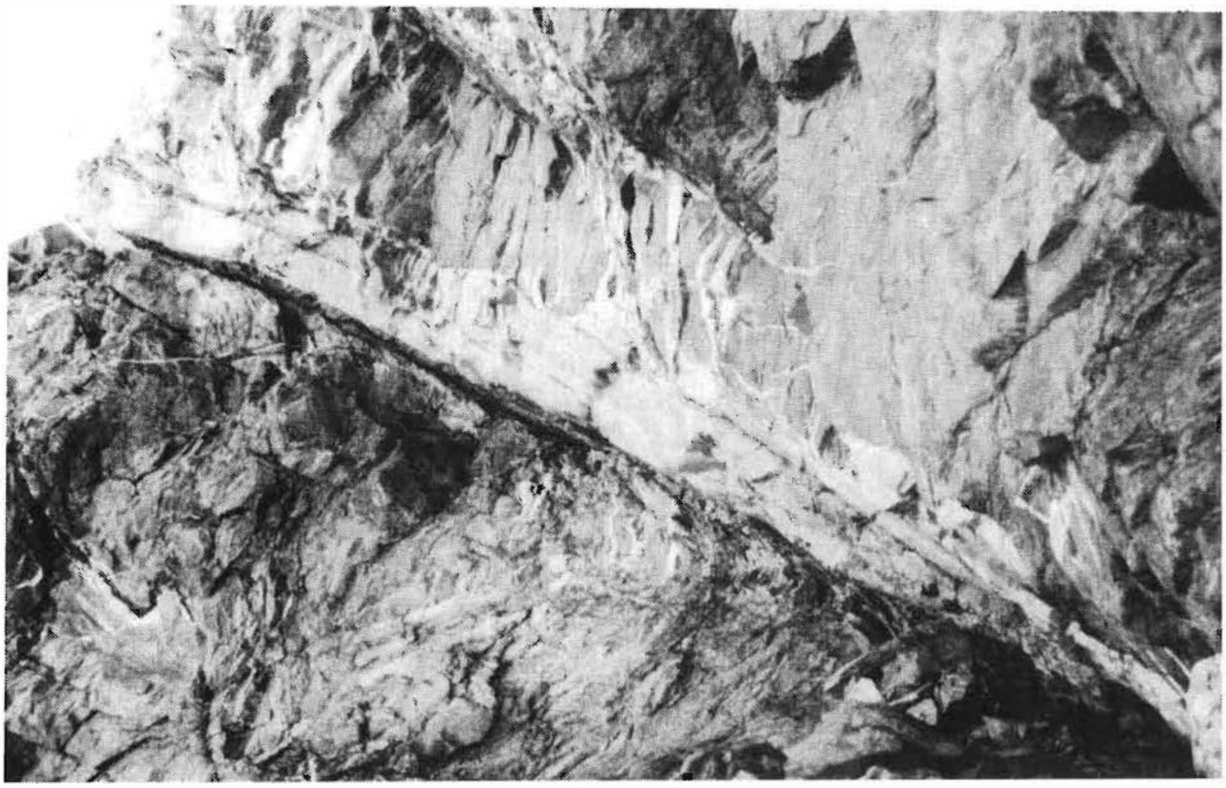


Fig. 28: Mylonite zone (light coloured, c. 2 m thick) within a SSE(left)-directed thrust fault in migmatitic gneisses, Stabben, close to the intrusive boundary with the Stabben monzonite.

The S_1 gneissose banding

Within the dominating lithology, the Grjotlia granitic gneisses, the gneissosity is characterized by the following parametres (jfr. Figs. 21,22):

1. Decomposition of felsic and mafic material (compositional banding);
2. formation of leucosomes that are isoclinally folded, boudined or teared apart forming rods;
3. intrafolial flow folds;
4. stretching of parts of syn-kinematic felsic dykes, but
5. less strain in protected areas adjacent to syn-kinematic, cutting dykes;
6. a high-grade metamorphic mineral paragenesis and composition (mostly not preserved).

The banded gneisses in the northwestern part of Sætet provide a more distinct banding caused by stronger decomposition and transposition (Figs. 22, 29). More continuous intrafolial folds and stronger stretching of syn-kinematic leucosomes and dykes suggest a higher ductile flow and thus possibly higher temperatures during deformation.

The gneissose banding is less developed in the Jutulhogget granitic gneisses. These are far more homogeneous and provide only a slight cm-scale banding defined by laminae of biotite.

The migmatitic lithologies in eastern Jutulsessen show generally a development similar to the Grjotlia gneisses, though the banding there is strongly undulating. Leucosomes are often developed as schlieren, and transposition is more irregular due to a higher mobilization of the material. However, there occur all transitions between the two types of deformation.

The gneiss zone with patchy distribution of biotite clusters in the middle part of Grjotlia does not show any considerable transposition structures at all, though there is no evidence from the thin sections of a later (post-kinematic) emplacement of this layer.

The F_2 shear folding

F_2 shear deformation is best developed within the Grjotlia gneisses. Going from west to east along the ridges in southern Grjotlia, one first observes occasional zones of asymmetric shear folds with a northeast vergence affecting the S_1 gneissosity (Fig. 21). Fold axes plunge gently to steeply S to SSE or moderately NNW.

In more homogeneous parts of the Grjotlia gneisses, which may have abundant leucosomes, these leucosomes show ptygmatic fold shapes.

These folded zones tighten to the east, developing a new foliation along mica-rich zones within the gneisses. These zones dip steeply southwest. Fold hinges provide nodules of hornblende +/- garnet and show that this fold phase still was associated with a high mobility, probably under amphibolite facies conditions.

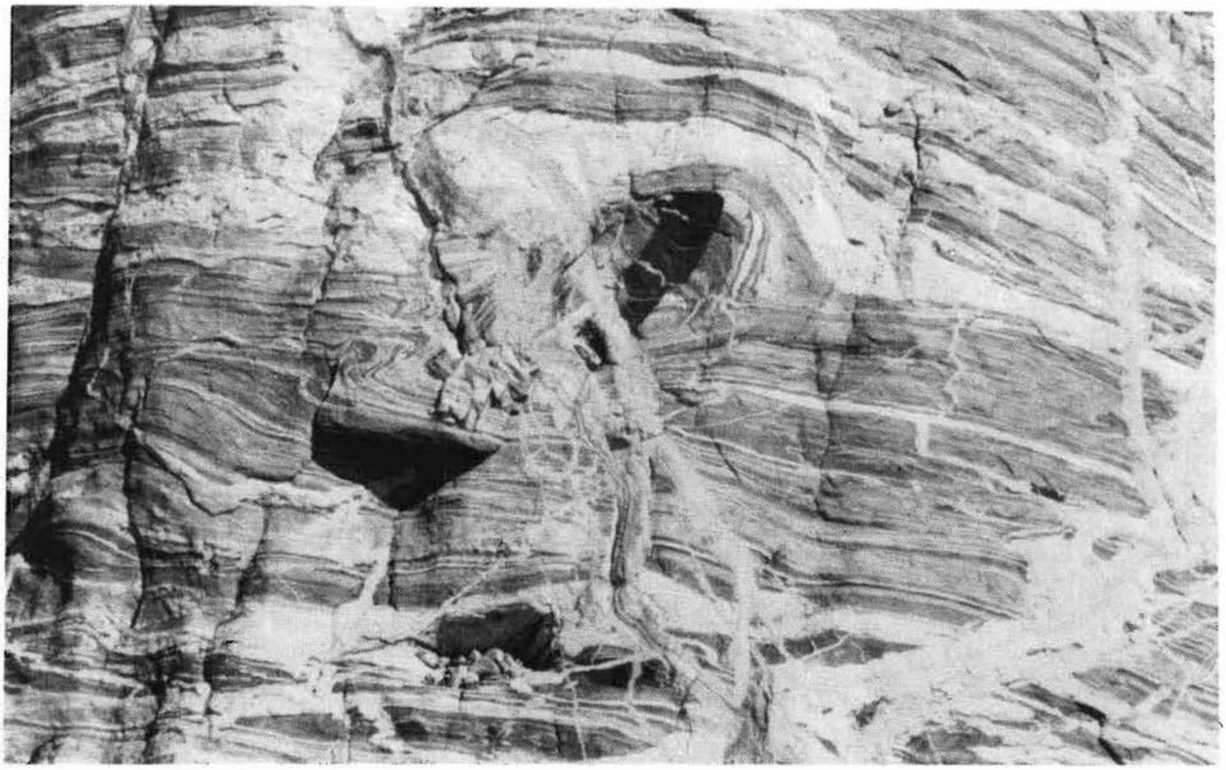


Fig. 29: Banded gneiss, NW Sætet, showing a strong compositional banding and transposition structures, refolded by later shearing. Irregularities are developed close to amphibolite dyke fragments. The gneiss is cut by a sequence of aplites and pegmatites. Size of area c. 20x30 m.

F_2 folding probably also occurs occasionally in the banded gneisses at NW Sætet, where it has a shear sense subparallel to S_1 and also mainly a northeast vergence (Fig. 29). It also occurs within the Jutulhogget gneisses as regular similar folds. In the migmatitic gneisses to the east, it is difficult to discriminate from earlier, incompletely transposed structures.

Sequence of events

From the above observations the general sequence of the events leading to the geological structure of Jutulsessen can be deduced, though further research is needed to ascertain details:

1. emplacement of a granitic intrusive complex under high-grade metamorphic conditions (suggested age: older than 1200 m.y.);

2. D_1 tectonic event with formation of the gneissosity, abundant leucosomes, syn-tectonic pegmatites, still high-grade conditions (suggested age: c. 1000-1200 m.y.);

3. intrusion of Stabben monzonite and migmatization in eastern areas, at least in parts of the area high-grade conditions; dyke intrusions: a. pegmatoids, b. mafic dykes (e.g. pyroxene-biotite dyke in Jutulhogget);

4. D_2 tectonic event with folds and shear zones under medium-grade metamorphic conditions, locally leucosomes, possibly mega-scale isoclinal folding (observed at Risemedet) (suggested age: c. 450-500 m.y.);

5. post-D_2 intrusions; a. grey aplites, b. pegmatoids, c. Stabben gabbro (?), d. red aplites;

6. D_3 regional flexure folding;

7. brittle faulting and dolerite dyke intrusions (Mesozoic).

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Appendix

Suggested future research topics
by Kurt Bucher-Nurminen

The Norwegian Antarctic Station 'Troll' is situated within one of the world's largest granulite/charnockite terranes and is thus well suited for the study of igneous and metamorphic petrology of deep crustal rocks, especially with respect to the significance and nature of granulite-amphibolite facies transitions, fluid-rock interactions in the deep crust, etc. Also, the area provides good possibilities for analyses of deformation mechanisms within rocks undergoing partial melting. Further, more detailed regional geological surveying as well as some Quaternary geological and mineralogical investigations should be carried out and could easily be combined with the above mentioned main research topics.

In the following, an outline of suggested future research topics is given (for locality names see Figs. 1, 8 and 20):

1. Descriptive regional geology.

Geological maps at the scale of 1:250.000 of Gjelsvikfjella and Mühlig-Hofmannfjella are under compilation and can be used as a basis for future work in the area. For Sverdrupfjella of some southern portions of Mühlig-Hofmannfjella the maps can be improved even at the scale of 1:250.000. Information at the scale of 1:100.000 on particularly interesting areas (Hoggestabben, Svarthamaren, Jutulsessen) is also available now. However, the considerable local complexity of the geology of Gjelsvikfjella and western Mühlig-Hofmannfjella requires remapping of the entire area at the scale of 1:100.000 by future expeditions in order to supply the basis for further petrology projects.

2. Metamorphic petrology of the gneisses and marbles.

The expedition area has a great potential for future studies of fundamental rock forming processes at middle to lower crustal levels. Metamorphic mineral assemblages (Ohta et al. 1990 and NARE 89/90) from various rock types have a great potential for deciphering parts of the tectono-metamorphic history and evolution of the mountain chain. Research projects related to this general topic include:

- Regional metamorphism in the three main areas (western Mühlig Hofmannfjella, Gjelsvikfjella and H.U. Sverdrupfjella).
- Petrology of high-grade metapelitic gneisses in the Hochlinfjellet area (Cordierite-garnet-spinel gneisses).
- Petrology of two occurrences of high-grade marbles at Hochlinfjellet and Skorvetangen (SE of Kvithamaren) (diopside-garnet-wollastonite marbles). This project includes the study of local mass transfer at marble-gneiss contacts.
- Petrology of granulite-facies mafic inclusions (gneiss xenoliths) in the charnockites.
- Petrology of garnet-rich restites in migmatites of Gjelsvikfjella.
- Geochronology of metasedimentary sequences in Gjelsvikfjella and western Mühlig-Hofmannfjella.
- Petrogenesis of migmatites (geochemistry, isotope geochemistry, and petrology).
- Contact metamorphism in the Stabben aureole.

3. Petrology of the charnockite complex.

The Svarthamaren charnockite complex has previously been described by e.g. Ohta et al. (1990) and Bucher-Nurminen et al. (in press). Several interesting assimilation and contact phenomena as well as a multitude of dyke systems have been reported from the boundary zone of the charnockite complex. Charnockites and granulites represent deep crustal material. The nature of the deep continental crust and processes of granulite (charnockite) formation are key research subjects in today's geology. A research effort on the Svarthamaren charnockite complex is, therefore, clearly a major objective for future Norwegian Antarctic research expeditions' geological activities. Projects may include:

- Geochemistry and petrology of various generations of charnockite in western Mühlig-Hofmannfjella.
- Geochronology of charnockites in western Mühlig-Hofmannfjella.
- Intrusion mechanisms of charnockites .
- Subsolidus history of intrusive charnockites.
- Assimilation processes and interaction between xenoliths and charnockites.
- Formation of hydration veins in charnockite.
- Fluid-charnockite interaction processes (e.g. white-wash process).

4. Structures and deformation.

The structural geology of the Jutulsessen gneisses and the Risemedet migmatites is dominated by large-scale polyphase ductile deformation which interplays in a complex manner with the emplacement of igneous rock bodies. Within the Svarthamaren charnockite complex, faulting and fracturing are additional (in many parts the only) predominant deformation processes. Possible research topics related to structural geology include:

- Analysis of regional fault systems in western Mühlig-Hofmannfjella and the geometry and mechanism of formation of vein-intruded conjugate faults.
- Regional ductile deformation (transposition, formation of compositional banding, shear zone formation) in Gjelsvikfjella; especially deformational control of the formation of the banded gneisses of Jutulhogget.
- Geometrical analysis of granitoid net-vein systems in Gjelsvikfjella.
- Structural analysis of the ductile deformation history at key localities in Gjelsvikfjella (e.g. Armlenet).
- Intrusion mechanism of charnockite (and other) igneous bodies.

5. Amphibolite-granulite facies transition (AGT).

As outlined in this volume, the entire area shows excellent examples of rocks which preserve the transition from amphibolite-facies to granulite-facies metamorphic conditions (or vice versa). The nature of the AGT and associated processes in the deep continental crust represent some of the most discussed petrologic research topics of wide international interest today. The area accessible from 'Troll' offers excellent opportunities to study the AGT and problems related to the petrogenesis of granulite-facies rocks:

- Hydration-dehydration reactions in gneisses of western Mühlig-Hofmannfjella and Gjelsvikfjella and the nature of the AGT.
- Fluid-rock interaction related to dehydrating xenoliths in charnockite.
- Mechanism of fluid transport and mass transfer in granulite-facies deep crustal rocks.
- Transport properties of charnockites.

6. Igneous petrology and geochronology.

The large number of igneous rock bodies (stocks, batholiths, dyke systems) offer possiblities for numerous projects related to magmatic petrology. Well-exposed intrusive contacts and complex dyke systems permit to resolve the relative sequence of magmatic events. This can be used as a sound basis for extensive geochronological work and the production of meaningful absolute ages of the igneous activity in the area. Possible projects:

- The Stabben monzonite.
- Co-magmatic dyke systems in the charnockite complexes.
- Exotic dykes in the charnockite complexes.
- Two-phase mafic dykes and evidence for immiscible basic magmas.
- Source and genesis of charnockite magmas.
- Intrusive sequence of igneous complexes in the Hochlinfjellet-Remplingen area.
- Partial melting of metapelitic gneisses under granulite-facies conditions (fluid absent melting).
- Igneous petrology of gabbros at Jutulsessen.
- Igneous petrology of composite dykes (felsic-mafic dykes).
- Net-vein systems.

7. Quaternary geology.

The only area with a Quaternary cover is found in the inner part of Jutulsessen (in the immediate surroundings of the 'Troll' station. There, some km^2 are covered with scree, till and polygon ground. This area bears a limited potential for the study of the local Quaternary geology. It appears unlikely that more than one future expedition can carry out Quaternary geological projects here.

8. Mineralogy.

During NARE 89/90 a crystal cave with extensive hydrothermal mineralization was found in the Stålstuten area. Minerals found at this locality include K-feldspar, black quartz, excellent scepter quartz, fluorite, and a large number of unidentified low-temperature minerals. The mineralogy of this occurrence could be studied in a separate small project.

Many of the outcrops of the area are locally covered by salt crusts. The mineralogy of the salt covers could be studied on a regional scale.