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Structural Investigations in the Precambrian of Western Neuschwabenland, Antarctica

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Summary: In western Neuschwabenland Precambrian rock complexes of different crustal levels occur. They are part of the western margin of the East Antarctic shield.
The mountains of the Ahlmannryggen are built up of a sedimentary-volcanogenic platform sequence with mainly mafic intrusions of Proterozoic age. Besides a prevailing fracture tectonic indicating extension, there occur steep shear zones and overthrusts. For the small-scale but numerous overthrusts an Early Palaeozoic age is assumed as the most probable. It is notable that all main tectonic structures of the Ahlmannryggen run NE-SW to NNE-SSW, which is parallel to the Jutulstraumen graben, an important regional rift structure.
Heimefrontfjella and Mannefallknausane are composed of metamorphic rock units of assumed and partly proved Precambrian age. The rock units are partly in amphibolite facies, partly in granulite facies and show retrograde metamorphism in places. Several different deformation acts can be recognized from polyphase structures. Fracture tectonics connected with metamorphic and non-metamorphic basic dikes occur as well as overthrust and nappe tectonics. Besides this, it is possible to distinguish at least two interfering fold generations. The older one runs NW-SE and shows a NE-vergence, the younger one runs NE-SW and shows a NW-vergence. An important steeply dipping shear zone separates metamorphic units of different structural levels over long distances.
Considerations on regional structural correlations between the Precambrian of the Ahlmannryggen and of Heimefrontfjella and Mannefallknausane lead to interpretations concerning the effects of the Ross Orogeny in the region of western Neuschwabenland. Similarities to the geologic structures of eastern South Africa are demonstrated.

Zusammenfassung: Im westlichen Neuschwabenland treten präkambrische Gesteinskomplexe mit verschieden tiefen Krustenanschnitten auf. Sie gehören zum Rand des ostantarktischen Schilds.
Die Berge des Ahlmannryggens sind aus einer schwach metamorphen, sedimentär-vulkanogenen Plattform-Gesteinsfolge aufgebaut mit im wesentlichen mafischen Intrusionen proterozoischen Alters. Neben vorherrschender und Dehnung anzeigender Bruchtektonik treten hier steile Scherzonen und Überschiebungen auf. Für die zwar kleindimensionalen, aber zahlreichen Überschiebungen wird ein altpaläozoisches Alter als wahrscheinlich angesehen. Auffällig ist, daß alle wesentlichen tektonischen Strukturen des Ahlmannryggens NE-SW bis NNE-SSW und damit parallel zum Jutulstraumen-Graben, einer bedeutenden regionalen Riftstruktur, streichen.
Die teils amphibolit-, teils granulitfaziellen, bereichweise auch retrograd überprägten metamorphen Gesteine der Heimefrontfjella und von Mannefallknausane, für die präkambrisches Alter angenommen wird und teilweise nachgewiesen ist, lassen mit verschiedenen Deformationsakten polyphase Tektonik erkennen. Neben mehrphasiger Bruchtektonik, verknüpft mit metamorphen und unmetamorphen basischen Gängen, und neben Überschiebungs- und Deckentektonik können mindestens zwei sich vergitternde Faltensysteme nachgewiesen werden: Ein älteres, NW-SE streichendes NE-vergentes und ein jüngeres, NE-SW verlaufendes NW-vergentes. Eine mächtige steilstehende Scherzone trennt über eine große Strecke Metamorphit-Komplexe verschiedenartiger Prägung.
Die Betrachtung der regionalgeologischen Zusammenhänge zwischen dem Präkambrium des Ahlmannryggens und dem der Heimefrontfjella und von Mannefallknausane führt zu Aussagen über die Auswirkungen der Ross-Orogenese im Gebiet des westlichen Neuschwabenlands. Ähnlichkeiten zum geologischen Bau des östlichen Südafrikas werden aufgezeigt.

1. INTRODUCTION

In the mountain ranges and nunatak groups of western Neuschwabenland predominantly Precambrian rock units are exposed (Fig. 1). Through large horst and graben structures different structural levels of the Antarctic crust reach the surface. They are part of the East Antarctic shield, presumably near its western boundary to younger fold belts from West Antarctica.

A first geologic review of the entire region has been given by ROOTS (1953). Several South African geologists investigated the Ahlmannryggen, Borgmassivet, and Kirwanveggen (Fig. 1). Their results have recently been summarized by WOLMARANS & KENT (1982). From Heimefrontfjella only reconnaissance mappings for its northeastern part by JUCKES (1972) and for its southwestern part by WORSFOLD (1967) and a petrographic description of some rock samples by THOMSON (1968) exist. Mannefallknausane has been described by JUCKES (1968). From these publications emerges that the age relations of several lithological units in these areas are questionable because of lacking radiometric age determinations and unsolved structural relations.

More detailed geological and specially structural investigations on the mountain ranges of western Neu-

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schwabenland are important for several reasons.

a) For the reconstruction of Gondwana the structures of Neuschwabenland have to be correlated with those of the eastern coast of southern Africa.

b) To correlate the different regions of the East Antarctic shield itself, detailed structural informations are necessary. E. g. Heimefrontfjella could be a geologic link to the Shackleton Range to which it is the closest located.

c) The position and significance of the Ross Orogen and indications of the Beardmore Orogeny and Ross Orogeny in the Weddell Sea sector of Antarctica are still little known. Detailed structural investigations should resolve this problem.

To carry out further structural investigations the senior author visited the northeastern and central Ahlmannryggen in 1983—84 and both authors visited the Heimefrontfjella and Mannefallknausane in 1985—86 (Fig. 1). During these field surveys more than 5000 structural data of different kind were collected. A first Interpretation of these data shall be given in this paper.

2. THE GEOLOGY OF WESTERN NEUSCHWABENLAND

A generalized geologic map of western Neuschwabenland with its mountain ranges, nunatak groups, and main rock units is given in Fig. 1. Western Neuschwabenland is confined to the north and west by the Weddell Sea. Its eastern boundary is the more than 200 km long Jutulstraumen glacier which is controlled

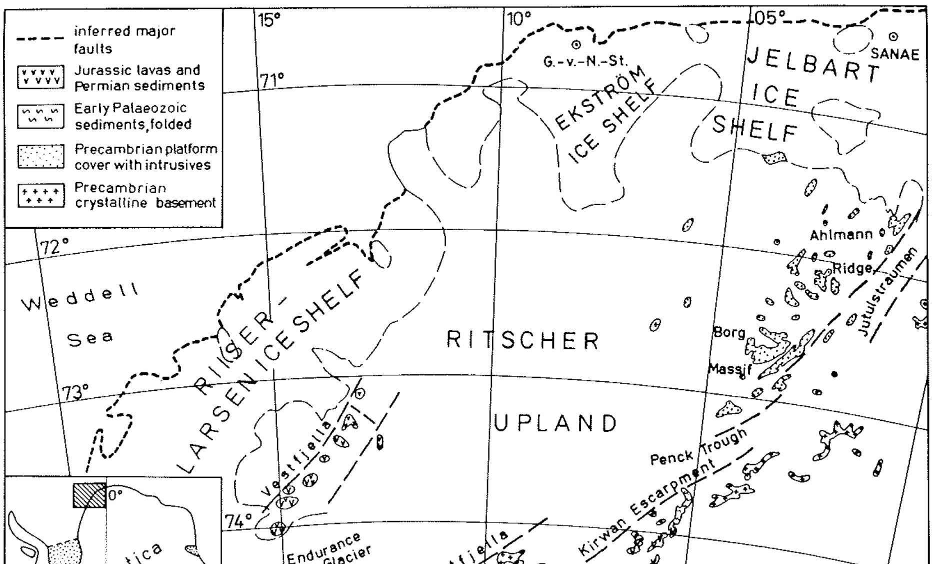

Fig. 1: Geological sketch map of western Neuschwabenland.

Abb. 1: Geologische Übersichtskarte des westlichen Neuschwabenlands.

by a large rift. Southernmost outcrops are in Tottanfjella (southern part of Heimefrontfjella). The mountain ranges trend NE-SW and are arranged as tilted fault blocks. The thus originating escarpments are thought to be due to Mesozoic and younger rifting and extension of the Weddell Sea in connection with the break-up of Gondwanaland (SPAETH & SCHÜLL, this volume). Investigations by West-German (expedition 1985—86) and South African geophysicists support this interpretation.

It is possible to distinguish at least three rock units of different crustal level and age.

a) The uppermost unit builds up Vestfjella and can be found as remnants in Heimefrontfjella and Kirwanveggen. It is mainly composed of Jurassic basic volcanic rocks with few thin sedimentary intercalations. In some places it is underlain by a Permian sedimentary sequence with local thin coal seams and deposits of glacial origin at its base.

b) The nunataks of the Ahlmannryggen and the Borgmassivet are composed of Proterozoic platform sediments which are intercalated with or grade into basic to intermediate volcanic rocks. Intrusions of intermediate, basic, and ultrabasic composition and Proterozoic in age cut this platform sequence.

c) Largest extent has the crystalline basement. It is of complex composition, its Precambrian age in detail still to be determined. These rock units build up Heimefrontfjella and Mannefallknausane, Kirwanveggen and its northeastern continuation. Middle to high grade (amphibolite to granulite facies) metamorphics are the main rock units. Specially interesting are the acid crystalline rocks of the isolated nunatak group of Annandagstoppane (approximately 80 km west of Borgmassivet), which yielded a radiometric age of nearly 3 Ga.

A questionable Early Palaeozoic to Late Precambrian age is attributed to an unmetamorphosed sedimentary rock sequence (Urfjell Group) of the southwestern part of Kirwanveggen.

Basic dikes and dike swarms of proved or presumed Mesozoic age are very common in western Neuschwabenland (SPAETH & SCHÜLL, this volume). Their orientation follows the regional fault pattern. In some areas (Vestfjella, Mannefallknausane, and Heimefrontfjella) they are associated with basic sills of approximately the same age.

3. THE GEOLOGY OF THE AHLMANNRYGGEN

3.1 *Rock units and age relations*

The nunataks and massifs of northeastern and central Ahlmannryggen are composed of an at least 3500 m thick sedimentary-volcanogenic platform sequence. It is part of the probably Proterozoic Ritscherflya Supergroup (WOLMARANS & KENT 1982).

The sedimentary rock units of the central Ahlmannryggen around and at some distance from the South African summer station Grunehogna (Fig. 2) belong to the *Ahlmannryggen Group* (lower unit of the Ritscherflya Supergroup). It is composed of coarse to fine grained clastics (conglomerates, greywackes, arcoses, sandstones, quartzites, siltstones, mudstones, shales), in its upper part also of red beds and volcanoclastic rocks. Hematite-rich layers appear as well.

The sequence of the Ahlmannryggen Group is invaded by the *Borgmassivet Intrusives,* mainly mafic sills and intrusions of doleritic to dioritic composition (Fig. 3). Ultramafic and felsic intrusions are less frequent.

The nunataks of northeastern Ahlmannryggen (= Straumsnutane) are nearly completely composed of

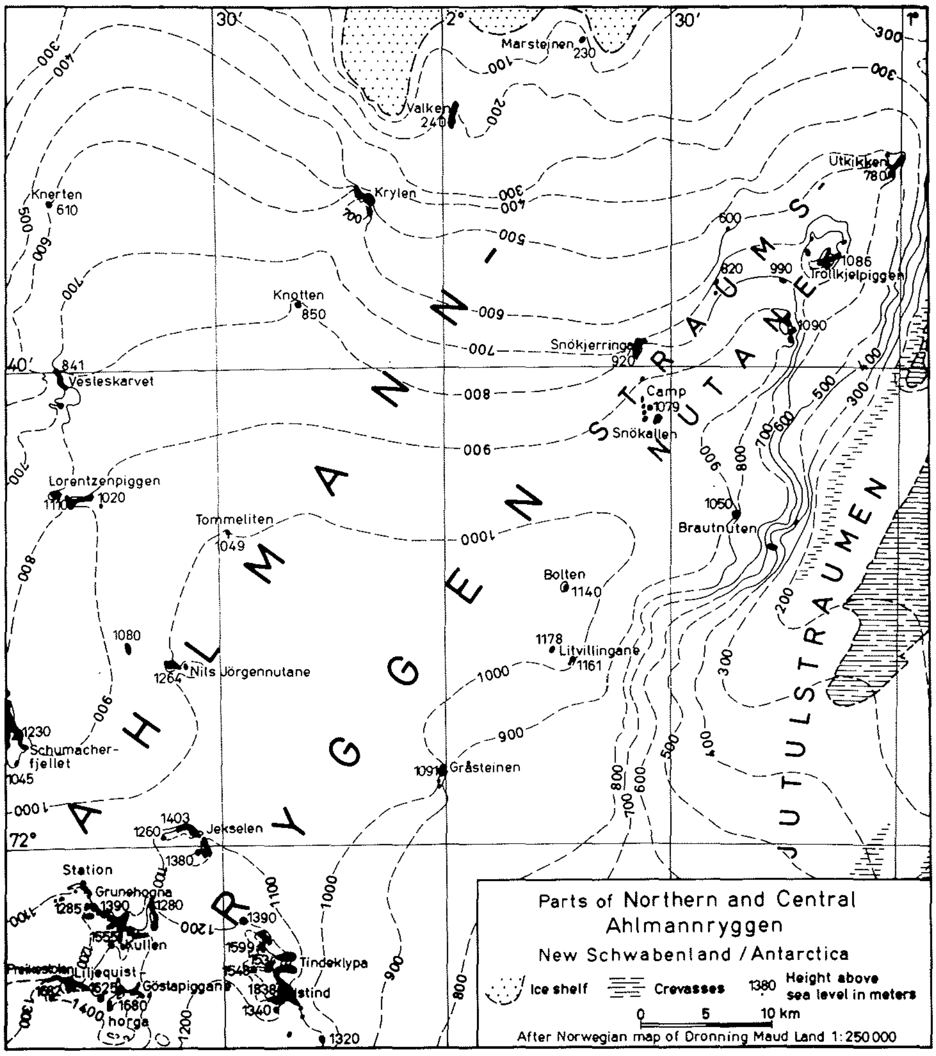

Fig. 2: Topographic map of northern and central Ahlmannryggen. Drawn after the Norwegian topographic map of Dronning Maud Land 1:250 000.

Abb. 2: Topgraphische Karte des nördlichen und zentralen Ahlmannryggens. Gezeichnet nach der norwegischen topographischen Karte von Dronning Maud Land 1:250 000.

volcanic rocks of the *Straumsnutane Formation* which is part of the predominantly volcanic Jutulstraumen Group (upper unit of the Ritscherflya Supergroup). Basaltic to andesitic lava flows rich in amygdales, with some tuffs and pillow lavas are the main rock types (WATTERS 1972). Thin sedimentary intercalations rarely occur.

Except for contact-metamorphic phenomena due to the Borgmassivet Intrusives the rocks of the whole platform sequence underwent only a low grade *regional metamorphism.* Chlorite, epidote, and sericite are the main indicator minerals. In some places epidote is very common.

Radiometric age datings of rocks from the Borgmassivet Intrusives yielded indications of an approxima-

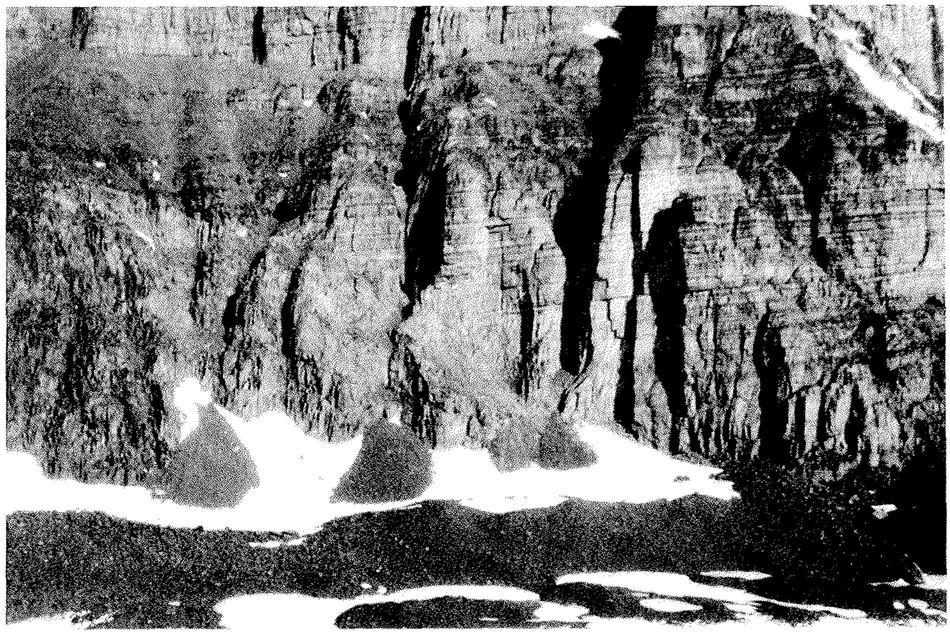

Fig. 3: Sedimentary rocks of the Ahlmannryggen Group with horizontal layering, cut by a diorite of the Borgmassivet Intrusives (left). The contact runs from the upper left to the lower right. Height of outcrop approximately 80 m. Northern wall of Nunatak 1285 m, shortly south of the South African summer station Grunehogna, central Ahlmannryggen.

Abb. 3: Flach liegende Sedimentgesteine der Ahlmannryggen-Gruppe, durchdrungen von einem Diorit der Borgmassivet-Intrusionen (linke Bildhälfte). Der Kontakt zieht von links oben nach rechts unten. Höhe der Felswand ca. 80 m. Nordflanke des Nunataks 1285 m, dicht südliche der südafrikanischen Sommerstation Grunehogna, zentraler Ahlmannryggen.

tely 1100 Ma event and an approximately 1700 Ma event (WOLMARANS & KENT 1982). This would indicate an age of more than 1700 Ma for the sediments of the Ritscherflya Supergroup. Some volcanic rocks of the Jutulstraumen Group yielded up to now a radiometric age of approximately 820 Ma (WOLMARANS & KENT 1982). Rocks from an apparently younger shear zone inside the volcanic rocks of the northern Straumsnutane region gave a radiometric age of 526 Ma (PETERS & al. 1986).

Field work was carried out in the large nunatak group of Grunehogna (Fig. 2), Jekselen, and Schumacherfjellet, but mainly at the nunataks of Straumsnutane (Fig. 2) in northeastern Ahlmannryggen: Snökallen, Snökjerringa, Trollkjelpiggen, Utkikken, Bolten, and several unnamed nunataks. The tectonic data are mainly from these last named places.

3.2 *Structures*

The *layering* of the lava beds is mostly horizontal or dips gently to the SE and NW. Also occurring steep dipping is associated to shear zones of assumed normal faults and to the western border of the Jutulstraumen. The gently dipping lava beds in some cases form synclines which can sometimes be observed on larger nunataks.

Shearing is a notable feature in the volcanic rocks of Straumsnutane. Generally the shearing increases from west to east and is most intensive near the Jutulstraumen (Fig. 4). The most altered rocks are also the most intensively sheared. Where shearing is weakly developed, the shear planes have intervals of a few millimeters to a few centimeters. In some special shear zones and along the margin of the Jutulstraumen the shearing produced schistosity. The measurements of the shear planes and schistosity (s) show a NNE to NE strike and a generally steep dip (about 70°) to the ESE and SE (Fig. 5a).

Fig. 4: Weakly metamorphosed basaltic-andesitic volcanic rocks of the Straumsnutane Formation (Jutulstraumen Group) with cleavage dipping to the SE (left). Folded quartz-epidote-veinlets (above hammer) with axial planes parallel to the cleavage.
Summit area of the nunatak Utkikken. Straumsnutane, northeastern Ahlmannryggen.

Abb. 4: Geschieferte und schwach metamorphe, basaltisch-andesitische Vulkanite der Straumsnutane-Formation (Jutulstraumen-Gruppe). Die Schieferung fällt halbsteil nach SE (links). Gefältelte Quarz-Epidot-Gängchen (oberhalb Hammer) mit Achsenflächen parallel zur Schieferung.
Gipfelbereich des Nunataks Utkikken, Straumsnutane, nordöstlicher Ahlmannryggen.

Another conspicuous structural feature of the Straumsnutane region is a system of *small overthrusts.* They are very frequent and have a relatively regular distribution. Fig. 5b shows that they constitute a conjugate system of overthrust planes (o.t.1 and o.t.2). They strike roughly NE-SW and dip approximately with 25° to the SE or NW. The NW dipping planes are less frequent. Scatter of the poles is insignificant (Fig. 5b). Measurements from 58 of these small overthrusts were taken, but many more could be observed. The thrust planes are always thickly coated with epidote. As far as it could be recognized the offset is not very important, amounting to a few meters at maximum, but more frequently only to a few decimeters. Both differently dipping sets of thrust planes are probably of the same age. Where two differently inclined planes meet each other, one frequently passes into the other by bending. The overthrust planes with their coatings of epidote are not cut by the steep shear planes and the schistosity. The observed dole-

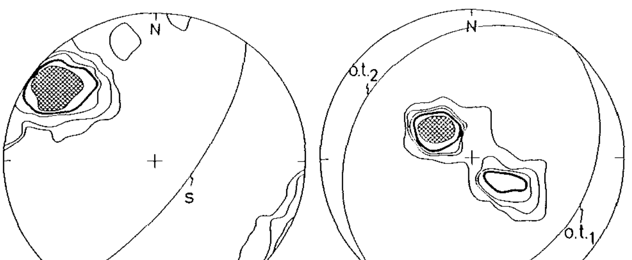

Fig. 5: Pole diagrams with structural data from the Ahlmannryggen. (a) Narrow-spaced shear planes and schistosity (s), 258 poles. (b) Small overthrusts (o.t.1 and o.t.2), 171 pole from 58 thrust planes. Contours 1, 3, 5, 7, 10%. Schmidt net, lower hemisphere.

Abb. 5: Gefügediagramme der tektonischen Daten vom Ahlmannryggen. (a) Engständige Scherflächen und Schieferung (s), 258 Polpunkte. (b) Kleinüberschiebungen (o.t.1 und o.t.2), 171 Polpunkte von 58 Überschiebungsflächen. Dichtelinien 1, 3, 5, 7, 10%. Schmidtsches Netz, untere Halbkugel.

rite dikes, however, cross them and are never cut by them. A few of these small overthrusts were also found in the nunataks of Grunehogna.

The young *dolerite dikes* are presumably of Mesozoic age and are found in limited number in the Ahlmannryggen (SPAETH & SCHÜLL, this volume). They are not affected by younger tectonic events and show no shearing.

4. THE GEOLOGY OF HEIMEFRONTFJELLA AND MANNEFALLKNAUSANE

Heimefrontfjella is a heavily dissected, steep escarpment which drops from approximately 2000—2600 m altitude on its top to 1200—1500 m altitude at its base (Fig. 6). Geophysical investigations (German expedition 1985—86) demonstrated its descent below ice-level reaching partly more than 2000 m within a few kilometers northwest of the mountain range. Mannefallknausane can be regarded as a smaller similar escarpment which has differences in altitude between approximately 1300 and 700 m. These escarpments are thought to be part of a system of tilted fault blocks which originated by rifting and extension of the Weddell Sea (HINZ & KRAUSE 1982; SPAETH & SCHÜLL, this volume).

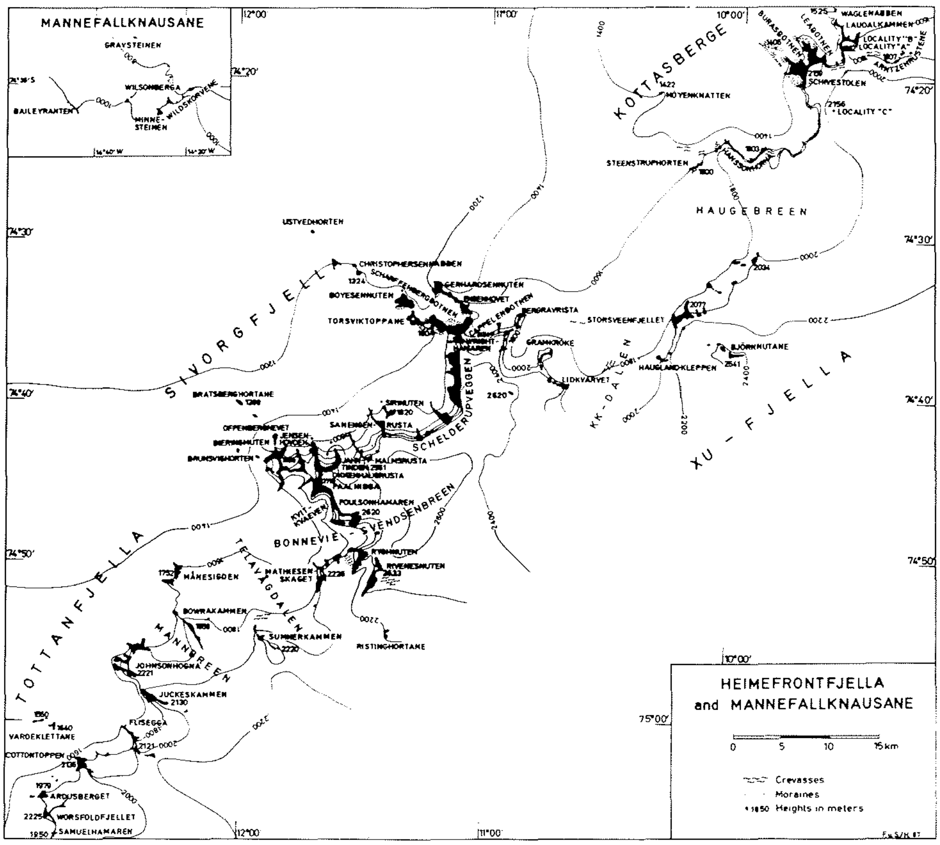

Fig. 6: Topographic map of Heimefrontfjella and Mannefallknausane. Compiled after WORSFOLD (1967) and JUCKES (1972) and supplemented. This map is only preliminary and poorly accurate regarding its grid due to insufficient sources. To the geographical nomenclature the satellite image map 1:1 000 000 of the IfAG (1986) was additionally used.

Abb. 6: Topographische Übersicht von Heimefrontfjella und Mannefallknausane. Zusammengestellt nach WORSFOLD (1967) und JUCKES (1972) und ergänzt. Diese Karte ist nur eine vorläufige und in ihrem Gradnetz aufgrund unzureichender Vorlagen nicht exakte Darstellung. Zur geographischen Namengebung diente weiterhin die Satellitenbildkarte 1:1 000 000 des IfAG (1986).

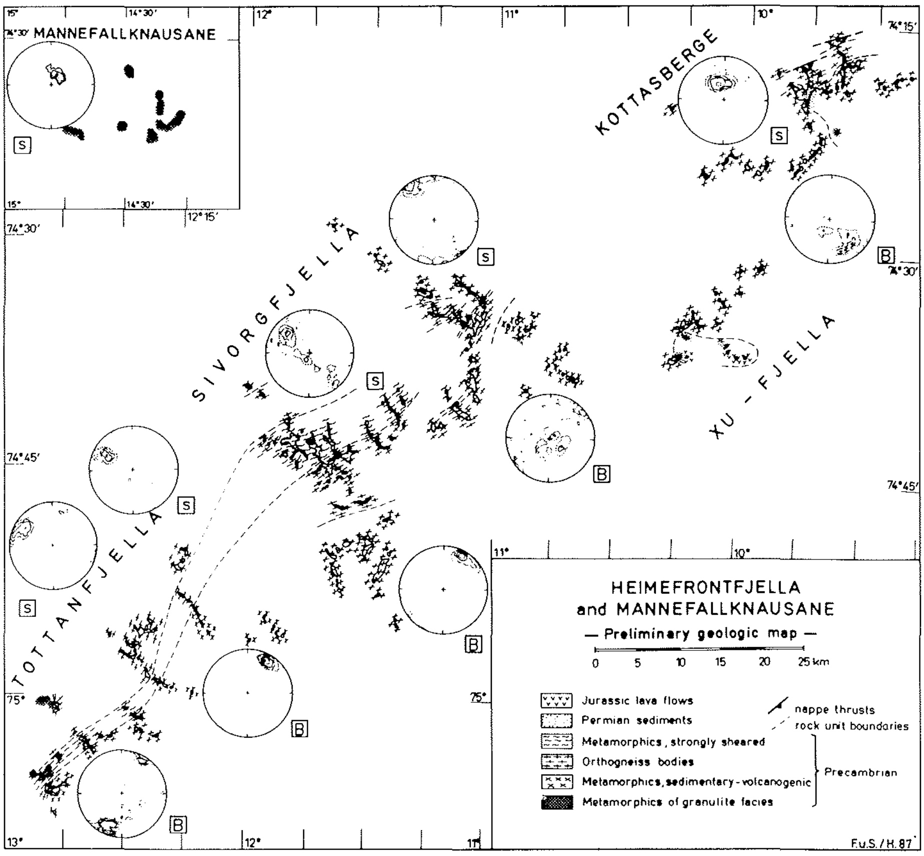

Fig. 7: Preliminary geologic map of Heimefrontfjella and Mannefallknausane. Compiled after own observations and supplemented after WORSFOLD (1967) and JUCKES (1972).

Abb. 7: Vorläufige geologische Übersichtskarte von Heimefrontfjella und Mannefallknausane. Zusammengestellt nach eigenen Aufnahmen und ergänzt nach WORSFOLD (1967) und JUCKES (1972).

The Heimefrontfjella can be subdivided physiographically in four major mountain blocks which are separated by large glaciers (Fig. 6). These blocks are called from NE to SW Kottasberge (= Milorgfjella), XU-Fjella, Sivorgfjella, and Tottanfjella.

4.1 *Rock units and age relations*

The preliminary geologic map of Fig. 7 shows the major rock units found in Heimefrontfjella and Mannefallknausane. They can be divided in six major units:

— Jurassic magmatic rocks
— Permian sediments
— Precambrian sedimentary-volcanogenic metamorphics
— Precambrian orthogneiss bodies
— Precambrian metamorphics of granulite facies
— Precambrian strongly sheared metamorphics.

The main outcrops are composed of the Precambrian metamorphic rock units. A summarizing description of these rock units will be given in the following. This description of the rock units is only preliminary and will be worked out in detail, concerning petrography and petrology, geochemistry, and radiometric age determinations, by other expedition members and their coworkers (see also ARNDT & al. 1986).

Jurassic magmatic rocks. The Precambrian rocks of Heimefrontfjella and Mannefallknausane are both crossed by a limited number of dolerite dikes and sills. One large sill intrudes also the Permian sediments of Schivestolen in the Kottasberge. In two places (Björnnutane in XU-Fjella and Sembberget east of the Kottasberge) thick sequences of basaltic lava flows are exposed. These fresh looking basic rocks are believed to be of Jurassic age. More detailed descriptions were given by JUCKES (1968, 1972) and SPAETH & SCHÜLL (this volume).

Permian sediments. The Precambrian crystalline rocks are overlain, separated by a sharp unconformity, by a clastic sequence of coarse to fine grained sandstones and siltstones, interbedded with some coal-bearing shales and one coal seam. At the base of this sequence very coarse grained rocks with indications of glacigenic origin were found, overlying a surface with glacial striations. This unit is of Lower Permian, in its lowermost part perhaps of Upper Carboniferous age (JUCKES 1972). The main outcrops are situated in the Kottasberge. A few small occurrences have been found also in XU-Fjella. JUCKES (1972) gives a more detailed description of these sediments.

Sedimentary — volcanogenic metamorphics. A common and widespread rock unit of the whole Heimefrontfjella are the sedimentary-volcanogenic metamorphics, which contain a large variety of all kinds of metamorphic rocks from both sedimentary and volcanogenic origin.

The metasediments can range from single beds in metavolcanics to sequences with a thickness of several hundred to a few thousand meters. They occur partly as pure sediments, partly interbedded with volcanic rocks. They contain mostly paragneisses, mica schists and in much less extent amphibolites, metaquartzites, and calc-silicate rocks. They are often migmatitic, and rock boundaries are mostly gradational. Except for the main massif of the Kottasberge they are generally garnet- and muscovite-rich. Metaquartzites form mostly single layers in larger sequences, but at Ristinghortane nearly all the outcrops show a very pure, bright quartzite with a strong pencil structure, and at Ustvedhorten mainly dark, low-grade quartzites appear with minor metapelites.

The calc-silicate rocks mainly form lenses parallel to the bedding and have less extension, except for a large outcrop at Rivenesnuten (Sivorgfjella). This occurrence in an anticlinal position contains besides calc-silicate rocks even a notable white and coarse grained marble. Another occurrence of marble is reported by JUCKES (1972) from Hanglandkleppen (XU-Fjella).

The metavolcanics with partly some meta-sedimentary intercalations have sharp rock boundaries and form often sequences of amphibolites and leucocratic quartz-feldspar-gneisses of pink, grey or white colour. Occurrences of augen gneisses also appear. The metavolcanics often contain biotite and less muscovite. In many cases they can be deduced from a bimodal volcanic sequence. Some subvolcanic sills, now amphibolite bodies, can be assumed and metamorphic basic dikes are common. These dikes range from fairly fresh looking ones to completely amphibolitized ones with all degrees of deformation.

Orthogneiss bodies. Orthogneiss bodies are very common and form large outcrops. They can be deduced from different plutonites, which have nearly all been metamorphosed to some degree into orthogneisses, except for a few locations (Laudalkammen in the Kottasberge, Torsviktoppane in Sivorgfjella, Månesigden and Samuelhamaren in Tottanfjella). They have granitic to dioritic composition. They are partly garnet-bearing and mostly coarse grained and contain often xenoliths of ortho- and paragneisses. Sometimes porphyritic textures and wide-spread augen structures can be seen.

Metamorphics of granulite facies. Charnockites, anorthosites and granulites can be found in whole Mannefallknausane and in western Tottanfjella (Vardeklettane, Ardusberget). Vardeklettane is built up mainly of migmatitic granulitic gneisses of at least partly sedimentary origin (shown by metaquartzitic and calc-silicate layers) and of anorthosite. In Mannefallknausane and Ardusberget granulites of mafic and felsic composition and anorthosites can only be found as sometimes very large xenoliths. They are included in the most common of these granulite facies rocks, an intrusive, brown, middle to coarse grained, equigranular charnockite without schistosity. It builds up most of these nunataks. At Ardusberget it is intruded again by leucocratic charnockites.

Strongly sheared metamorphics. Starting in the region of Scharffenbergbotnen (Sivorgfjella) a 2 to 3 km wide shear zone can be followed down to southern Tottanfjella. It is built up of strongly sheared mylonitic metamorphics. These metamorphics were mostly augen gneisses, but also rocks of the sedimentary-volcanogenic and the granulite facies sequence.

Metamorphism. The sedimentary-volcanogenic metamorphics and the orthogneiss bodies have undergone an amphibolite facies metamorphism. This led to the many garnet-rich para- and orthogneisses and amphibolites of Sivorgfjella and Tottanfjella. The main massiv of the Kottasberge, although undergone the same metamorphism, is garnet-poor. The garnet and pyroxene bearing rocks and charnockites are of granulite facies. All Precambrian rock units have been affected by retrograde metamorphism, which is indicated by the common appearance of chlorite and epidote, specially concentrated in shear zones, mylonites and adjacent joint systems. The Permian and Jurassic rocks are unaffected by metamorphism.

Age determinations. With the exception of data for an altered basic dike (458 and 452 Ma, REX 1972) no radiometric age determinations from the Precambrian metamorphics of Heimefrontfjella were known up to now. ARNDT & al. (1986) for the first time determined an age of metamorphism from a garnet-amphibolite (1032 Ma) and an extrusion age from a metarhyolite (1158 Ma), both of the sedimentary-volcanogenic metamorphics.

4.2 *Structures*

The following paragraphs contain, besides their presentation, tentative analysis and interpretations of the structural data. More detailed analysis in regard of regional and local as well as structural aspects are in progress.

s-planes. Bedding in the sedimentary-volcanogenic metamorphics and schistosity in all the Precambrian rock units have been measured the most extensively. The bedding of the sedimentary-volcanogenic metamorphics also corresponds to a well recognizable bedding-parallel schistosity. The schistosity is also well developed in the orthogneisses, where it results in augen gneisses, which grade in some places into nearly undeformed, granite-like rocks without schistosity. Foliation is very well developed in the shear zone. All these measurements have been combined as s-planes (S) in the pole diagrams of Fig. 8, separated for the main regions of Heimefrontfjella and for Mannefallknausane.

The pole diagrams show that the s-planes strike NE-SW and dip mainly to the SE in the Sivorgfjella and Tottanfjella region. In the Kottasberge region they strike more E-W and dip to the S. An exception are the southwestern nunataks of the Kottasberge (Hanssonhorna area), where they strike mostly NW-SE and are in a vertical position. This different striking can also be seen as a weak maximum in the diagram of the whole Kottasberge region. The diagrams of Sivorgfjella-S and Tottanfjella-N show a distinct girdle. This can be less clearly recognized also in the diagram of Sivorgfjella-N, which contains additionally NW-SE and W-E striking s-planes. From the girdles pi-circles can be deduced with pi-poles in the NE, which correspond to the B_2-folds (Fig. 9). The diagram from Tottanfjella-S has a second, weaker maximum, which corresponds to ESE-WNW striking, SSW dipping s-planes. These are all from the Vardeklettane-Ardusberget region and belong to the granulite facies metamorphics. The different orientation of the s-planes in this region indicates a different structural unit coinciding with rock units of other composition and metamorphic grade.

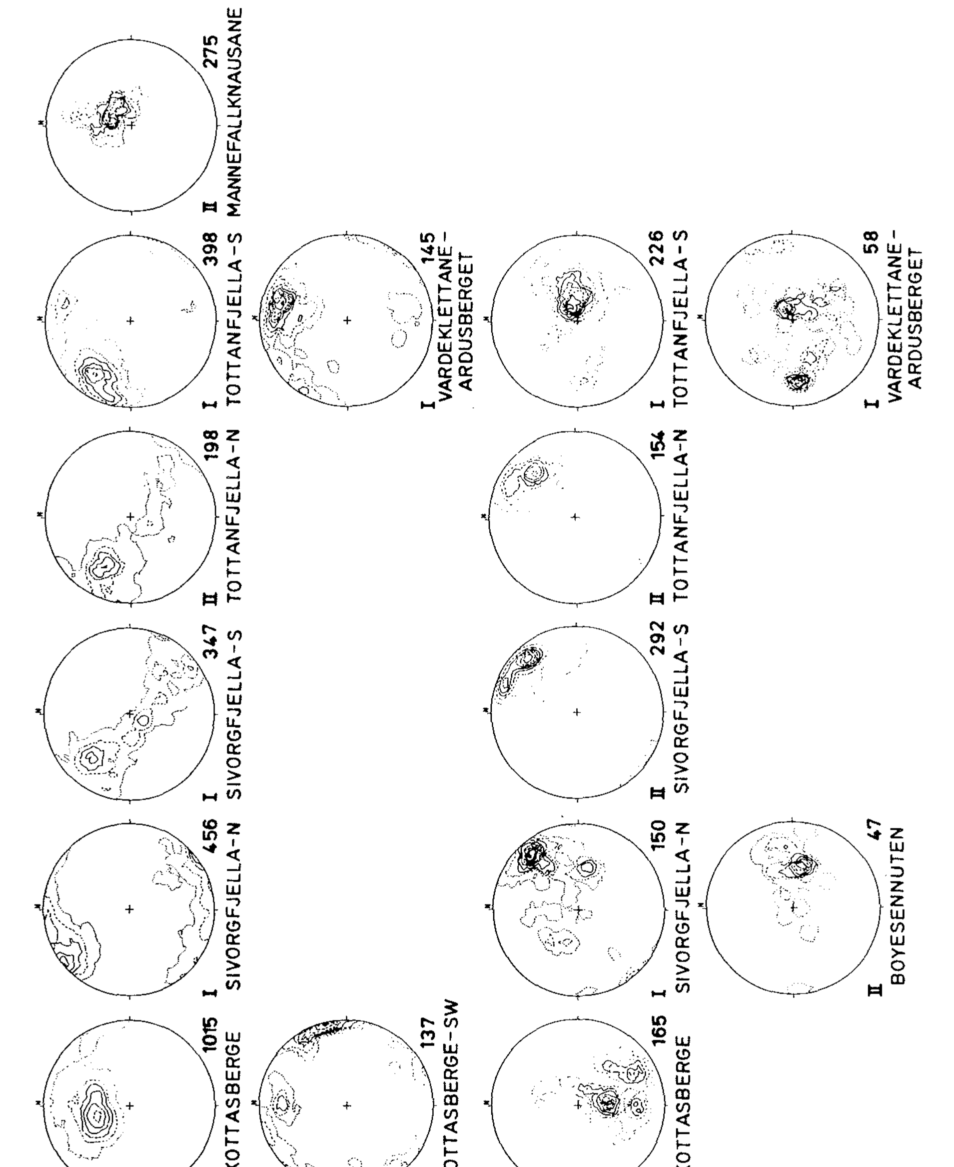

Fig. 8: Pole diagrams with structural data from Heimefrontfjella and Mannefallknausane. S = schistosity and shear planes, L = lineations. Contours starting with 1% and gradation I = 2%, II = 4%. Number of poles are indicated at each diagram. Schmidt net, lower hemisphere.

Abb. 8: Gefügediagramme der tektonischen Daten von Heimefrontfjella und Mannefallknausane. S = Schieferung und Scherflächen, L = Lineare. Dichtelinien beginnend mit 1% und mit den Abständen I = 2%, II = 4%. Anzahl der Polpunkte jeweils rechts neben dem Diagramm. Schmidtsches Netz, untere Halbkugel.

The pole diagram for Mannefallknausane also shows a different orientation of the s-planes. They strike ESE-WNW like in Vardeklettane-Ardusberget, but are only gently dipping to the SSW. Because they are from a presumed large granulite-xenolith in otherwise undeformed charnockites, they could not be representative and should be regarded only as an indication for a possible structural trend, specially by comparing them with the granulite facies rocks of Tottanfjella-S.

Lineations. Lineations are very common on schistosity planes. Not seldom they coincide with strongly tectonized rocks with an important elongation of the rock minerals parallel to the lineations (R-tectonites). This is particularly true for many places of Sivorgfjella. Sometimes two lineations are visible. The combined measurements of all lineations (L) are shown in Fig. 8.

Again the Kottasberge region has a different orientation of these tectonic elements. The somewhat scattering lineation plunges mainly to the S and SSE and is about perpendicular to the striking of the schistosity. Sivorgfjella and Tottanfjella-N have a common strong lineation plunging to the NE. This lineation, corresponding also to the lineation of the R-tectonites, has the same orientation as the B_2-folds (Fig. 9, more further on), to which it is related. It is a fold-parallel lineation. The diagrams of Sivorgfjella-S and Tottanfjella-N have a maximum, which can be subdivided in two submaxima. The more NNE pointing submaxima can be correlated to the outcrops situated more to the SE (Ristinghortane, Rivenesnuten, Ryghnuten, Mathiesenskaget, and Sumnerkammen), the more NE pointing ones to the outcrops situated more to the NW (Paalnibba and Bieringmuten area, Bowrakammen and Månesigden). The direction of the lineations agrees with a somewhat similar trend of the B_2-axes, specially in Sivorgfjella-S. Actually it is probably a more continuous transition from NNE trending to more NE trending lineations (and B_2-fold axes). The existence of two submaxima, specially in Sivorgfjella, may only be the result of lacking measurements from unvisited outcrops between both areas.

Sivorgfjella-N shows a second maximum with lineations plunging to the E. As can be seen in a separate pole diagram, these were measured at the nunatak Boyesennuten. They correlate best with B_1-fold axes of the same outcrops. Tottanfjella-S has different lineations plunging to the E. They can best be connected with the schistosity of the area which strikes nearly perpendicular to them. A small maximum of lineations plunging to the W is related to the Vardeklettane-Ardusberget nunataks (see separate pole diagram).

Folds. Folds are frequent, specially in the sedimentary-volcanogenic and strongly sheared metamorphics. Measurements of the fold axes (B) are shown all together in Fig. 9. It is possible to distinguish clearly two fold-generations which superpose each other. This was observed in several places on outcrops and is confirmed also by the combined diagrams of all unclassified B-axes (Fig. 9). Indications for a third, older fold generation could be found, but it was not possible to determine their direction and plunging. Therefore Fig. 9 only shows the two clearly recognizable fold generations, which were named B_1 and B_2. The fold nomenclature is only preliminary and for practical purposes, because presumed or observed other fold generations cannot yet be described in detail or by their orientation.

B_1-folds are mostly similar folds with NE-vergence and often combined with imbricate structures (Fig. 10). They have a NW-SE direction. In places a non-cylindrical fold-shape can be observed. They occur mainly in the regions of the Kottasberge and northern Sivorgfjella (Scharffenbergbotnen), but can also be found to a lesser extent in the remaining Sivorgfjella and Tottanfjella regions (Fig. 9). This could be related to the fact that the shearing and mylonitization connected with the important shear zone obliterate the older folds. The directions of the B_1-fold axes scatter distinctly which can be explained by the refolding through the B_2-folds.

B_2-folds are similar or parallel folds, mostly more open and cylindrical. They have a NE-SW direction and frequently a NW-vergence. In some places SE-vergence can also be observed (e. g. Mathiesenskaget and Rivenesnuten). Homoaxial refolding was found in some outcrops (Fig. 11). The B_2-folds occur main-

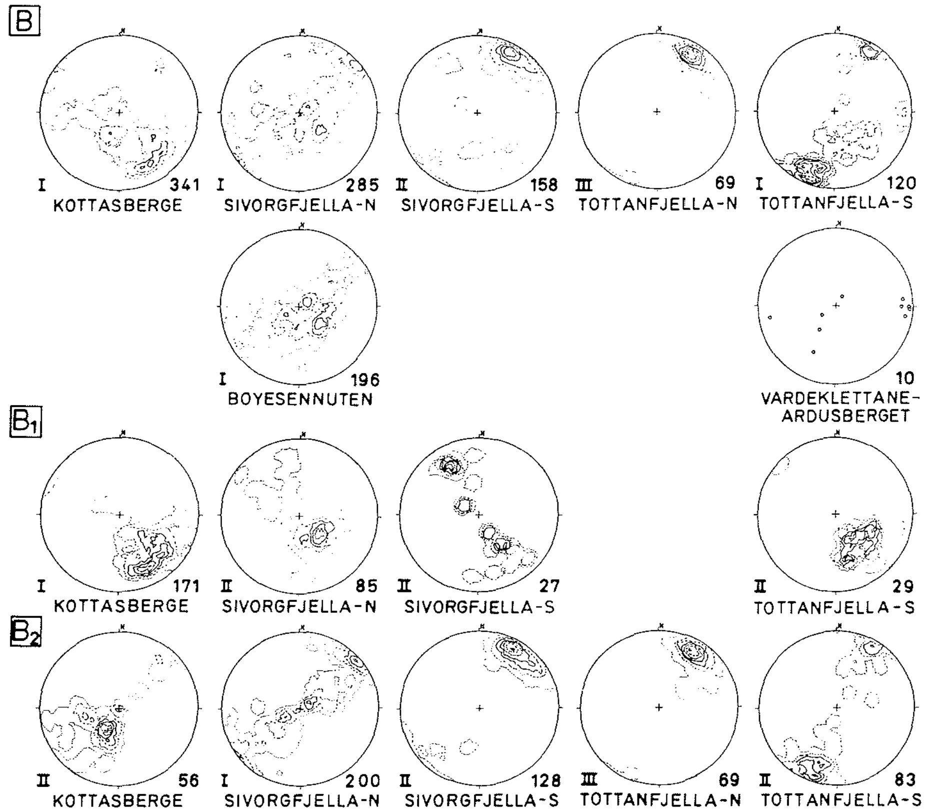

Fig. 9: Pole diagrams with structural data from Heimefrontfjella and Mannefallknausane. B = all fold axes, B_1 and B_2 = fold axes separated to deformations stages. Contours starting with 1% and gradation I = 2%, II = 4%, III = 6%. Number of poles are indicated at each diagram. Schmidt net, lower hemisphere.

Abb. 9: Gefügediagramme der tektonischen Daten von Heimefrontfjella und Mannefallknausane. B = Faltenachsen gesamt, B_1 und B_2 = Faltenachsen getrennt nach Deformationsakten. Dichtelinien beginnend mit 1% und mit den Abständen I = 2%, II = 4%, III = 6%. Anzahl der Polpunkte jeweils rechts neben dem Diagramm. Schmidtsches Netz, untere Halbkugel.

ly in the Sivorgfjella and Tottanfjella areas (Fig. 9). Their relative lacking in the main part of the Kottasberge area (more than half of the B_2-measurements are from the Hanssonhorna nunataks in the southwestern Kottasberge) could be due to another structural level of the area, where folds were substituted by S to SE dipping overthrusts and nappe structures with N to NW senses of movement (see Fig. 13 and the following). The sheared gneisses of Sivorgfjella and Tottanfjella are in parts strongly folded by the B_2-deformation. The direction of the B_2-folds is fairly consistent and scatters less than the B_1-folds (Fig. 9). Plunging of the B_2-folds is mostly also very gentle. These observations can be explained by the fact that the B_2-folds were not refolded and thus represent the younger major deformation act. Some scattering in direction and steeper plunging folds in Sivorgfjella-N and Tottanfjella-S could be due to misinterpretation of some folds which belong to the B_1-folds. This explanation is supported by the fact that Sivorgfjella-N is situated closely to the Kottasberge (main area of outcropping B_1-folds) and that Tottanfjella-S has again more B_1-fold measurements than the preceding areas of Tottanfjella-N and Sivorgjella-S. B_2-folding is often associated with a strong lineation or deformation parallel to its axes (R-tectonites).

B-axes and s-planes of the different regions are shown again in the geologic map (Fig. 7) for synoptic presentation. A curved trend of the s-planes with structures striking ENE-WSW at the Kottasberge to more

Fig. 10: Southward dipping gneisses of the sedimentary-volcanogenic metamorphics. B_1-folds with NE-vergence, combined with imbricate structures. Height of outcrop approximately 100 m. Southern corner of Leabotnen, Kottasberge, Heimefrontfjella.

Abb. 10: Nach Süden einfallende Gneise der vulkano-sedimentären Metamorphitfolge mit NE-vergenten, verschuppten B_1-Falten. Höhe des Aufschlusses ca. 100 m. Südecke von Leabotnen, Kottasberge, Heimefrontfjella.

Fig. 11: Amphibolites and biotite-muscovite-gneisses of the sedimentary-volcanogenic metamorphics with homoaxially refolded small scale folds. Northeast side of northern ridge of Mathiesenskaget, Sivorgfjella, Heimefrontfjella.

Abb. 11: Amphibolite und Biotit-Muskowit-Gneise der vulkano-sedimentären Metamorphitfolge mit homoaxial überfalteten Kleinfalten. Nordostflanke der Nordspitze von Mathiesenskaget, Sivorgfjella, Heimefrontfjella.

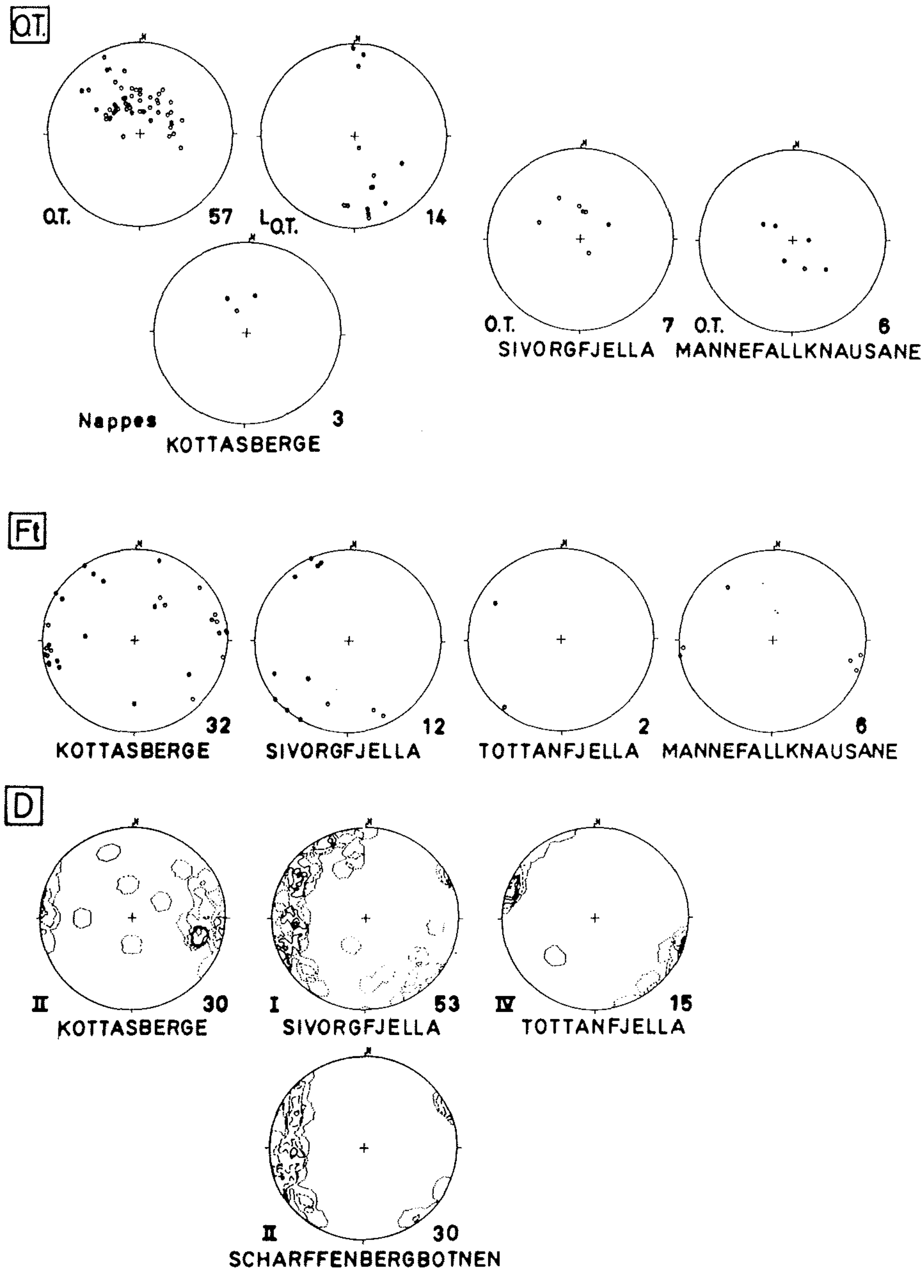

Fig. 12: Pole diagrams with structural data from Heimefrontfjella and Mannefallknausane. O. T. = overthrusts, Lo.T. = lineations on overthrust planes, Ft = steep faults, D = old basic dikes. Contours starting with 1% and gradation I = 2%, II = 4%, IV = 8%. Number of poles are indicated at each diagram. Schmidt net, lower hemisphere.

Abb. 12: Gefügediagramme der tektonischen Daten von Heimefrontfjella und Mannefallknausane. O. T. = Überschiebungen, Lo.T. = Lineare auf Überschiebungsflächen, Nappes = Deckenüberschiebungen, Ft = steile Bruchstörungen, D = alte basische Gänge. Dichtelinien bginnend mit 1% und mit den Abständen I = 2%, II = 4%, IV = 8%. Anzahl der Polpunkte jeweils rechts neben dem Diagramm. Schmidtsches Netz, untere Halbkugel.

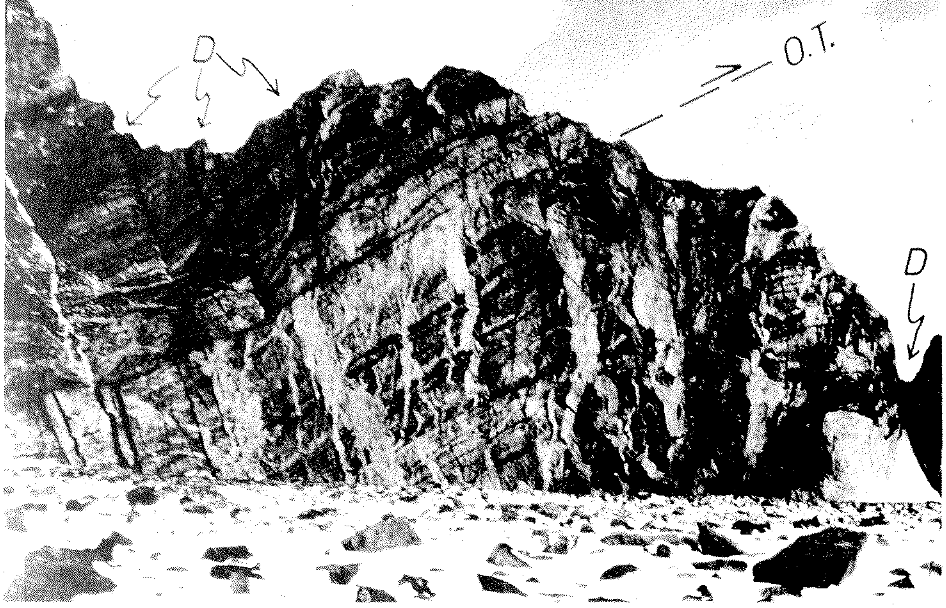

Fig. 13: Southeastward dipping gneisses of the sedimentary-volcanogenic metamorphics cut by steep pegmatite dikes, which are crossed by metamorphic basic dikes (D). An overthrust (O. T.) cuts off all previous structures. Height of outcrop approximately 120 m. Northern part of the southwestern ridge of Leabotnen, Kottasberge, Heimefrontfjella.

Abb. 13: Nach SE einfallende Gneise der vulkano-sedimentären Metamorphitfolge werden von steilen Pegmatitgängen durchschlagen, die wiederum von metamorphen basischen Gängen (D) gequert werden. Eine Überschiebung (O. T.) schneidet alle älteren Strukturen ab. Höhe des Aufschlusses ca. 120 m. Nordteil des südwestlichen Grates von Leabotnen, Kottasberge, Heimefrontfjella.

NNE-SSW at Tottanfjella is clearly recognizable. This trend is repeated somewhat less distinctly by the B_2-folds.

From the granulite facies metamorphics only the Vardeklettane area shows some folds (Fig. 9). These have partly an E-W direction, different from the rest of Heimefrontfjella, which supports another structural position of these rock units again.

Overthrusts. Overthrusts are frequent and well developed in the main massif of the Kottasberge. They strike E-W to NE-SW (Fig. 12, O. T.) and dip gently to the S or SE. These overthrusts are the youngest tectonic elements in the areas of occurrence and cut all previous structures (Fig. 13). They are associated with thin bands (10 to 50 cm) of mylonites and ultramylonites. The sense of movement is from S to N and SE to NW respectively, as being deduced from lineations (Lo. T., Fig. 12) and drag folds. Where recognizable, the amount of displacement due to the overthrusts reaches only a few meters to a few tenth of meters, but they appear in a relatively regular spacing about every 20—50 m. It is possible to distinguish an older, more frequent type of overthrusts, which is connected with ductile mylonites (Fig. 12, O. T.) from a younger, nappe-like type (Fig. 12, Nappes, Fig. 14 and 15). The last type of overthrusts is combined with cataclastic rocks, indicating a higher structural level. The cataclastic zones are thick (up to several meters) and they probably have larger displacements. They are indicated on the geologic map (Fig. 7). Another nappe thrust with klippen structure is presumed on the ridge between Leabotnen and Burasbotnen. It is not shown on the geologic map because it could not be visited due to inaccessibility.

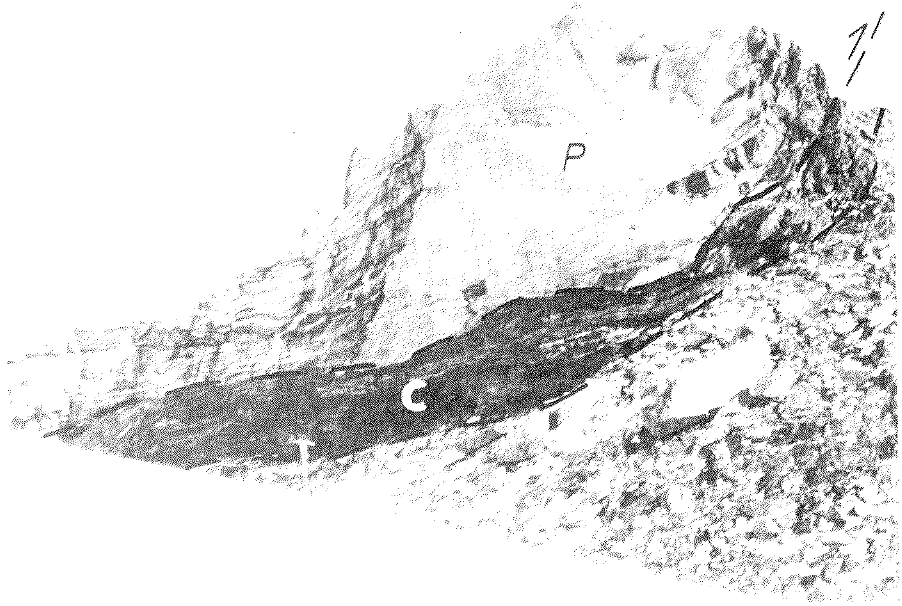

Fig. 14: Nappe overthrust with thick sheet of cataclastic rocks (C) in biotite-gneisses with a pegmatite (P) from the sedimentary-volcanogenic metamorphics. Height of outcrop approximately 20 m. Northern tip of the southwestern ridge of Leabotnen, Kottasberge, Heimefrontfjella.

Abb. 14: Deckenüberschiebung mit mächtiger Zone kataklastischer Gesteine (C) in von Pegmatit (P) gequerten Biotit-Gneisen der vulkano-sedimentären Metamorphitfolge. Höhe des Aufschlusses ca. 20 m. Nördlichste Spitze des südwestlichen Grates von Leabotnen, Kottasberge, Heimefrontfjella.

Fig. 15: Detail from Fig. 14, showing the dark cataclastic rocks of the nappe-thrust. Height of outcrop approximately 7 m.

Abb. 15: Detail aus Abb. 14 mit den dunklen kataklastischen Gesteinen der Deckenüberschiebung. Höhe des Aufschlusses ca. 7 m.

The Sivorgfjella area has only a few ductile overthrusts (Fig. 12) and in the Tottanfjella area none was found. As mentioned above, it seems that the overthrusts replace the B_2-folds. This is indicated by the fact that areas with many B_2-folds (Sivorgfjella, Tottanfjella) present few or no overthrusts and that the area with few B_2-folds (Kottasberge) shows the greatest amount of overthrusts.

Mannefallknausane also presents a few overthrusts (Fig. 12). At present they cannot be correlated to any previously mentioned deformation stages because of the nearly undeformed granulitic rocks, in which they appear, and the isolated situation of the nunataks.

Normal faults. A limited number of normal faults could also be recognized (Fig. 12, Ft). At the Kottasberge one preferential N-S striking direction appears which is also found at Mannefallknausane. The other measurements are too scattered or too few to give a clear structural trend. At Sivorgfjella a NW-SE and a NE-SW striking direction may occur. Air and satellite fotos give indications to major NW-SE striking fractures which are at present occupied by glacier-filled valleys (e. g. Telavågdalen).

Metamorphic basic dikes. Some older basic dikes clearly occupy faults, but in most cases the nature of the fractures they occupy is not recognizable. Presumably these are mostly normal faults. The older basic dikes have one preferential N-S striking direction (Fig. 12, D, Kottasberge region and Scharffenbergbotnen area as part of Sivorgfjella region). But a second, NE-SW striking direction is additionally visible (Fig. 12, Sivorgfjella region without Scharffenbergbotnen area and Tottanfjella region). At least some dikes are younger than the shear zone and are folded by B_2-folds.

The structures connected with younger basic dikes probably of Mesozoic age, being unmetamorphosed and unfolded, are discussed in SPAETH & SCHÜLL (this volume).

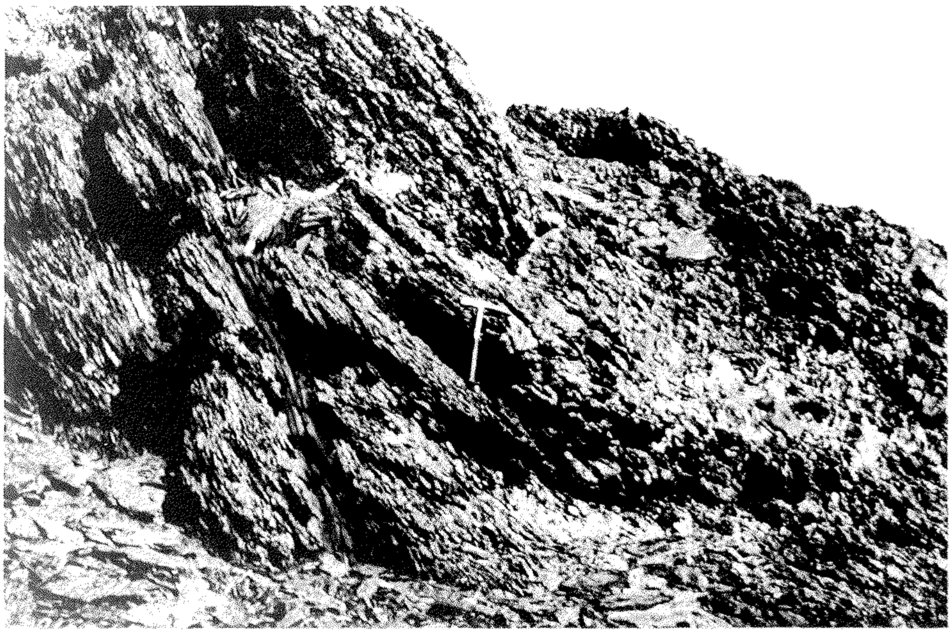

Fig. 16: Strongly sheared augen gneisses from the wide shear zone of southern Heimefrontfjella. Northern end of the ridge of Sanengenrusta, Sivorgfjella.

Abb. 16: Stark zerscherte Augengneise aus der breiten Scherzone der südlichen Heimefrontfjella. Nordende des Grates von Sanengenrusta, Sivorgfjella.

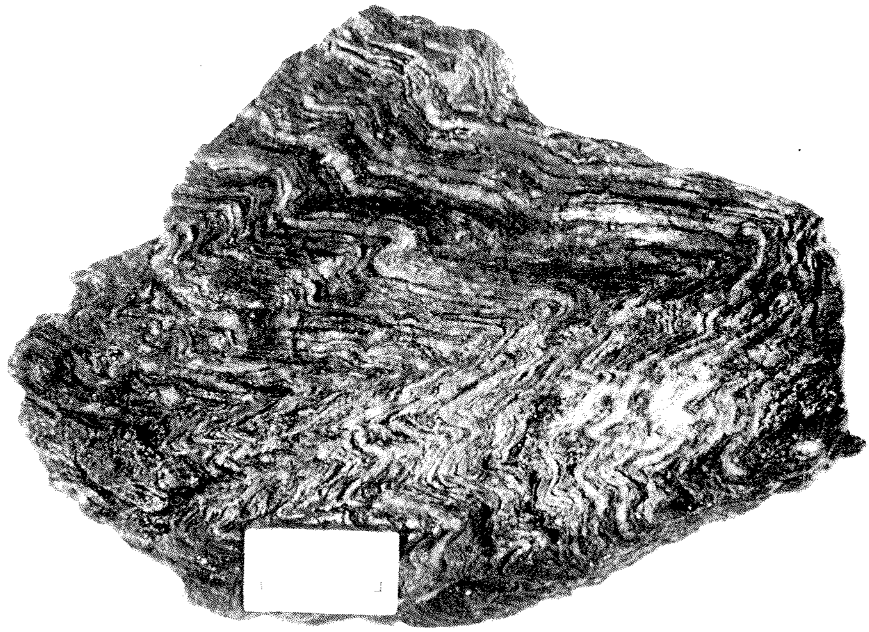

Fig. 17: Strongly sheared and intensively folded (B_2) augen gneisses from the shear zone of southern Heimefrontfjella. Near northwestern end of the ridge of Flisegga, Tottanfjella.

Abb. 17: Intensiv gefältelte (B_2), stark zerscherte Augengneise aus der Scherzone der südlichen Heimefrontfjella. Nahe Nordwestende des Grates von Flisegga, Tottanfjella.

Shear zone. The Sivorgfjella and Tottanfjella regions are accompanied at their northwestern parts by a roughly NE-SW striking shear zone (see geologic map of Fig. 7). This in its largest part 2 to 3 km wide steeply dipping shear zone separates mainly granulite facies rocks on its northwestern side from the other, amphibolite facies rock units on its southeastern side. It is composed of strongly sheared to mylonitic gneisses (Fig. 16), mostly appearing as sheared augen gneisses, with lenses of less deformed granulite or amphibolite facies gneisses. The lenses are between a few meters and several hundred meters long. The strongly sheared gneisses are partly intensively folded by B_2-folds (Fig. 17). The shear zone is specially connected with retrograde metamorphism.

5. CONCLUSIONS AND COMPARISONS

Western Neuschwabenland has many outcrops of Permocarboniferous sediments (Vestfjella, Heimefrontfjella, Kirwanveggen) and Jurassic lavas and intrusions (all regions), where interesting features as glacigenic deposits and structures or young dolerite dikes can be observed. The rock units of the young cover shall not be discussed further in this paper.

The Proterozoic Ritscherflya Supergroup comprising the mainly sedimentary Ahlmannryggen Group with the Borgmassivet Intrusives and the mainly volcanic Jutulstraumen Group are believed to be deposited on a stable platform. They could be interpreted as belonging to a nearly unaffected, stable foreland of a zone affected by the Ross and Beardmore Orogeny situated probably more to the S and SE. The base of these rock units was never observed, but they can be assumed laying on top of a crystalline basement like it is represented by the exposures of the few isolated nunataks of Annandagstoppane situated further to the W. Plutonic rocks of felsic (granitic) composition build up these nunataks. The Archean age is confirmed (WOLMARANS & KENT 1982) by an age determination of 2.77 Ga on granites. A connection with the still undated, but probably very old charnockites and granulites of Mannefallknausane and southern Tottanfjella (Heimefrontfjella) may be possible. At least, these are located to the SW in the striking continuation of the same fracture bounded block of western Neuschwabenland. The metamorphic rocks of Mannefallknausane and Vardeklettane-Ardusberget (southern Tottanfjella) have a structural style distinctly different from the adjacent much larger exposures of the major parts of Heimefrontfjella. Apart from their granulite facies grade of metamorphism they exhibit E-W running fold axes (Fig. 9) and lineations (Fig. 8) and a southward dipping schistosity (Fig. 8) which do not appear in the amphibolite facies rocks of the adjacent regions of Heimefrontfjella.

Both different structural units are separated by the described large shear zone of probably pre-Mesozoic age. Its NE-SW striking has the same direction as the Mesozoic fractures of Neuschwabenland. These fractures and connected dolerite dikes may often be controlled by Precambrian and possibly Early Palaeozoic tectonic structures. This is presumed for the Ahlmannryggen and seems also to be true for an escarpment forming fault system of Heimefrontfjella which is parallel or subparallel to the shear zone. The existence of such a fault system is supported by results of geophysical research during the German Expedition 1985—86. The nature of the shear zone is not yet clear. It dips steeply but dip could be more gentle in the depth. It may then have an overthrust or nappe-thrust nature as indicated by steeply running lineations. A transcurrent fault character can be possible too, but is not indicated by the observed lineations. More investigations for a clearer understanding of the shear zone are still necessary.

ARNDT & al. (1986) made the first radiometric age determinations on the gneissic rocks of Heimefrontfjella. Their age data of 1032 and 1158 Ma are in good agreement with age determinations from the Ahlmannryggen (on rocks of the Borgmassivet Intrusives) and Kirwanveggen (on metamorphics of the crystalline basement) which indicate an approximately 1100 Ma event (WOLMARANS & KENT 1982). These ages may represent an event correlated with the Nimrod Orogeny.

The metamorphic basic dikes of Heimefrontfjella are younger and must be due to extensional events. Age determinations of REX (1972) on rocks from Heimefrontfjella yielded, besides such on Jurassic rocks, an age of about 455 Ma for a basic dike cut by the Permian unconformity. This age still has to be verified. The dike could have been metamorphosed in a later stage of the Ross Orogeny giving the age determined by REX. Those dikes could indicate an extensional event prior to the Ross Orogeny.

The old dikes are cut by south- and southeastward dipping overthrusts (Fig. 12 and 13) at the Kottasberge region (Heimefrontfjella). These overthrusts are probably of two structural levels, a deeper one with narrow ductile mylonite zones and a shallower one with younger, larger cataclastic thrust zones. NE-SW running folds (B_{21} Fig. 9) predominate in the remaining Heimefrontfjella. Numerous small overthrusts in the Ahlmannryggen strike NE-SW too. They must be younger than 526 Ma, an age which has been determined on minerals from a steep shear zone in the northeastern Ahlmannryggen (PETERS & al. 1986) and older than the Jurassic dolerite dikes, by which they are crossed. At Kirwanveggen NNE-SSW to E-W running folds of the sedimentary Urfjell Group, which is placed by analogy into the Lower Palaezoic, and an also NE-SW running fold generation in the polyphase deformed crystalline basement (WOLMARANS & KENT 1982) complete this structural trend of western Neuschwabenland.

These tectonic features (NE-SW striking overthrusts, NE-SW running folds) fit well in direction and age into the framework of a compressional tectonic event acting during the Ross Orogeny. Further mineral-whole-rock isochron ages of 460 and 485 Ma from Kirwanveggen (WOLMARANS & KENT 1982) point to a thermal event causing rejuvenation which could relate to this orogeny. There are only questionable indications to this day concerning existence and trend of the proper Ross Orogene in the Weddell Sea sector of Antarctica. The structural investigations in the Precambrian of western Neuschwabenland described in this paper may indicate at Heimefrontfjella and Kirwanveggen a belt of crystalline rock units affected by Ross orogenic movements and rejuvenation with a less deformed foreland to the west and northwest (e. g. Borgmassivet and Ahlmannryggen).

Heimefrontfjella shows at least two distinct fold generations (B_1 and B_2). B_1 runs NW-SE and is older than the shear zone and the overthrusts. The B_2-folds are younger than the shear zone and may correlate in age with the overthrusts. From the above discussions a possible correlation with the Ross Orogeny results. Kirwanveggen shows comparable structures. The observed interference patterns in places indicate a second folding with a NE-SW trend perpendicular to a first one with NW-SE trend (WOLMARANS & KENT 1982). The Shackleton Range, situated much farther to the south and linking to the Transantarctic Mountains, presents complex structures in its crystalline Precambrian rock units also affected by at least two interfering phases of folding (HOFMANN & PAECH 1980). A comparison with the Heimefrontfjella is still an open problem.

All observations mentioned until now give indications to the reconstruction of the Gondwana continent by correlation with the probably juxtaposed South Africa. Partly already discussed in WOLMARANS & KENT (1982) and by PAECH (1985), the presumed Archean basement of western Neuschwabenland (Annandagstoppane, Mannefallknausane, southern Tottanfjella) may correlate with parts of a greater Kapvaal Craton. The younger rock complexes of Heimefrontfjella and Kirwanveggen could correspond to the Namaqua-Natal Mobile Belt in the eastern parts of South Africa, affected also by two phases of deformation, the Kibaran and the Panafrican tectogenesis. The refered age datings and structural trends give hints to this model.

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