Geology of the northern H.U. Sverdrupfjella, western Dronning Maud Land and implications for Gondwana reconstructions

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The complexly deformed Sverdrupfjella Group comprises various tonalitic, quartzofeldspathic and metapelitic gneisses with which are intercalated minor but extensive marbles and calc-silicate gneisses. These gneisses were derived from volcanic and sedimentary precursors. The Group was intruded over a long time-span by mafic/ultramafic dykes and sheets, monzonites and granites. The latter are characterized by their tabular geometry. Late- and post-tectonic intrusions include alkaline complexes and swarms of dolerite dykes. Remnants of granulite facies are preserved in the northeastern nunataks. Thermobarometry indicates that this metamorphism occurred at P between 9 and 11 kb and T ~ 850 °C. The greater part of the area was metamorphosed at T = 560 – 690 °C and P=5 – 6 kb. Thereafter a normal decompression path was followed. Preliminary age data suggest that the first metamorphism predates ~ 900Ma. Late-tectonic granitic intrusions were emplaced ~ 470 Ma. Reconstruction of Gondwana following Martin & Hartnady (1986) suggests that the Sverdrupfjella terrane represents a continuation of the Kibaran-Pan African Province of East Africa.

Die kompleks-vervormde Sverdrupfjella-groep bestaan uit tonalitiese, kwartsveldspaat- en metapelitiese gneise, waarin minder belangrike, maar uitgebreide marmer en kalksilikaatgneise voorkom. Hierdie gneise is van vulkaniese en sedimentêre oorsprong. Mafiese/ultramafiese gange en plate, monsoniet en graniet het oor 'n lang periode hierdie groep binnegedring. Laasgenoemdes word gekenmerk deur 'n plaatvormige voorkoms. Laat- en natektoniese intrusies sluit alkaliese komplekse en doleriet-gangswerms in. Oorblyfsels van granulietfasies het in die noordoostelike nunatakte behoue gebly. Termobarometrie dui aan dat die metamorfose by P van 9 tot 11 kb en T ~ 850 °C plaasgevind het. Die grootste gedeelte van die gebied het gemetamorfoseer by T = 560 – 690 °C en P = 5 – 6 kb, waarna 'n normale drukverligtingskurwe gevolg het. Voorlopige ouderdomsdata impliseer dat die eerste metamorfose ouer as ~ 900 Ma is. Laattektoniese granietintrusies is teen ~ 470 Ma geplaas. 'n Rekonstruksie van Gondwana, volgens Martin & Hardnady (1986) dui aan dat die Sverdrupfjella-gebied 'n voortsetting van die Kibarium-Pan Afrika-provinsie van Oos-Afrika is.

Introduction

Previous surveys of the H.U. Sverdrupfjella led to the recognition of the Sverdrupfjella Group (Roots 1963, 1969). Ravich & Solov'ev (1966) noted that the group had been metamorphosed at amphibolite grade and included schists, gneisses and migmatites as well as boudinaged layers of calciphyres and sheeted intrusions of metabasite. Subsequently, Hjelle (1974) proposed a provisional subdivision of the Sverdrupfjella Group into four formations, namely:

Sveabreen Formation – mainly almandine-bearing gneisses, locally containing sillimanite, and various augen and granitic gneisses.

Rootshorga Formation – pelitic and granitoid gneisses, the former containing variable amounts of sillimanite, almandine and cordierite.

Fuglefjellet Formation – biotite-hornblende plagiogneisses with discontinuous layers of marble and skarn.

Jutulrora Formation – biotite-hornblende gneisses and biotite and granitoid gneisses.

Hjelle (1974) suggested that the Jutulrora Formation might be included in the Fuglefjellet Formation as the only major difference was the presence of carbonate rocks in the latter formation. The current study has shown that carbonate rocks are sufficiently extensive to warrant their inclusion in a separate formation. Hjelle's (1974) stratigraphic framework has been modified by the recognition of the intrusive nature of augen and gneissic granites, originally included in the Sveabreen Formation. These gneisses have therefore been classified as the Vendeholten granite suite (Table 1).

Table 1

Stratigraphy of the H.U. Sverdrupfjella north of latitude 72°20'S

D. ***Late- and post-tectonic intrusions***
- 5. Tvora and Straumsvola alkaline complexes ~ 182 Ma ($^{39}Ar/^{40}Ar$) 170 ± 4 Ma (Rb-Sr)
- 4. Kirwanveggen dolerites ≡'Karoo dolerites (?)
- 3. Tourmaline-bearing pegmatites
- 2. Pink granitic and aplitic veins
- 1. Dalmatian granite ~ 470 Ma (Rb-Sr)

C. ***Mafic and intermediate intrusions***
- 6. A3 Amphibolite dykes and sheets
- 5. Anorthositic dykelets
- 4. Dioritic veins
- 3. Brattskarvet monzonite
- 2. A2 Amphibolite dykes and sheets
- 1. A1 Amphibolite dykes and sheets (pre-tabular granitoids)

B. ***Tabular granitoids***
- Vendeholten granite suite
- Roerkulten granite ~ 900 Ma (Rb-Sr)
- Brekkerista granite
- Jutulrora granite

A. ***Sverdrupfjella group***
- Sveabreen Formation
- Fuglefjellet Formation
- Jutulrora Formation

Note: Numbers indicate sequences of relative ages: unnumbered sequences indicate that no relative ages have been established.

The Rootshorga Formation has not been recognized as the present study refers only to that part of the H.U. Sverdrupfjella lying north of latitude 72°20′S.

Stratigraphy

It is convenient for descriptive purposes to group the lithologies cropping out north of latitude 72°20′S into four major subdivisions (Table 1).

Sverdrupfjella Group

Obliteration of primary textures by repeated metamorphic and deformational events militates against recognition of the original stratigraphic relations of the formations constituting this group. In simple terms the Jutulrora, Fuglefjellet and Sveabreen Formations respectively underlie successive zones from west to east.

The Jutulrora Formation comprises two dominant lithological types, namely, the Grey Gneiss complex and the Banded Gneiss complex, that are interlayered with each other. The two gneiss suites are distinguished by the scales of their layering. Whereas the Banded Gneisses are characterized by compositional layering on a metre scale, the Grey Gneisses display such banding on a scale of tens of metres.

Banded Gneiss sequences are composed typically of alternations of felsic and amphibolitic layers with subordinate intercalations of metapelitic (?) and magnesian schists. The felsic layers are leucotonalitic to tonalitic in composition with plagioclase (An_{30}) in excess of K-feldspar. The proportion of quartz is variable, some of the layers being locally quartzitic. Biotite and hornblende are the typical mafic minerals with accessory epidote, zoisite and sphene. Hornblende is the dominant mineral in the amphibolitic layers, typically altered partially or wholly to biotite. Plagioclase and minor quartz are the other minerals present.

Subordinate magnesian-rich layers are represented by talc-chlorite, actinolite-tremolite and anthophyllite-cummingtonite-phlogopite schists. Intercalated gneisses composed of quartz, feldspar, biotite, hornblende and garnet are provisionally interpreted to reflect the presence of pelitic interlayers but neither the available chemical nor mineralogical data are adequate to confirm this interpretation.

The calc-alkaline Grey Gneisses with contents of SiO_2 ranging from 53 – 67 per cent are mineralogically similar to the felsic layers in the Banded Gneisses. The large-scale banding results from variations in the proportions of hornblende and biotite with the result that the Grey Gneisses range from leucocratic to mesocratic. Locally, the Grey Gneisses contain conformable bands of granitic compositions which reflect the same deformational history as the enclosing tonalitic gneisses.

Amphibolite layers, commonly boudinaged and up to 2 m thick, are present in the Grey Gneisses arranged concordant to the foliation of the gneisses. Textural variation in the amphibolites is typical with some showing banding and grain-size inhomogeneity whereas others are homogeneous.

Locally, zones with abundant inclusions are present. The inclusions are compositionally similar to their Grey Gneiss host. The presence of an inclusion-rich zone adjacent to the contact with Banded Gneisses could reflect an intrusive relation between the Grey and Banded Gneisses.

Alternatively, these could represent original agglomeratic units in a sequence of felsic meta-volcanics. Discrimination between these alternatives is not yet possible. The latter alternative is favoured, because the Banded and Grey Gneisses are provisionally interpreted to reflect an original volcanic sequence of dominantly intermediate composition with minor intercalations of clastic sediments represented by the metapelitic (?) and quartzofeldspathic paragneisses. The magnesian-rich schists could reflect periods of basaltic volcanism or dyke intrusion, intense deformation resulting in the rotation of the dykes into parallelism with the regional foliation.

The Fuglefjellet Formation is best developed at and around the nunatak after which the formation is named (Fig. 1). The common presence of carbonate rocks interlayered with grey gneisses distinguishes this formation from the Jutulrora Formation. The grey gneisses in both formations are mineralogically and chemically identical.

The carbonate rocks range from fine- to coarse-grained marbles with which are intercalations of calc-silicate paragneisses. The fine-grained marbles contain variable but minor proportions of quartz and amphibole, whereas the coarse-grained marbles are composed almost exclusively of carbonate minerals. Amphibolites as well as metapelitic and quartzofeldspathic paragneisses are interlayered with the carbonate rocks. A lens, 2 – 3 m thick, of metaconglomerate occurs within the marbles in the neck between the main peaks of Fuglefjellet. Clasts of quartzofeldspathic composition are set in a quartz-rich matrix. The clasts are strongly deformed, some of them having long axes approaching 0,5 m in length with short axes up to 10 cm.

The Sveabreen Formation is characterized by quartzofeldspathic paragneisses with which significant volumes of feldspar-quartz-biotite and metapelitic gneisses are interlayered. The formation is best exposed in and around the northern nunataks (Vendeholten, Tverveggen and Brattskarvet, Fig. 1). The quartzofeldspathic paragneisses constitute homogeneous sequences up to 400 m thick separated by layers of metapelitic gneisses which are typically a few tens of metres thick. Feldspar-quartz-biotite gneisses several metres thick also occur within the quartzofeldspathic gneiss sequences.

The quartzofeldspathic paragneisses are composed dominantly of quartz with subordinate feldspar. Biotite typically constitutes $\sim$ 5 vol. per cent of the rock. Sparsely disseminated, fine-grained garnet is present locally. Metaquartzites are present in these gneisses on the upper southwest ridge of Vendeholten and in the Romlingane area. Fine layering and cross stratification are preserved locally in these units.

The feldspar-quartz-biotite gneisses are distinguished from the quartzofeldspathic paragneisses by the presence of garnet and between 10 and 20 vol. per cent biotite. Both plagioclase and microcline are present together with minor amounts of hornblende. Zircon, apatite and sphene are the main accessory minerals.

Metapelitic gneisses are variable in composition. There are subtle changes in lithology along strike from semi-pelitic (i.e. more quartz- rich) to pelitic gneisses. As a consequence the proportions of minerals such as quartz, garnet, cordierite, sillimanite and biotite are variable. Gneisses comprising an alternation of garnet-bearing quartzofeldspathic and biotite-rich layers are preserved sporadically. The layers range in thickness from a few centimetres to several metres. Some layers are characterized by abundant garnet, sillimanite and, rarely, cordierite.

All gneisses of the Sveabreen Formation contain numerous quartz-feldspar veinlets, particularly the felspar-quartz-biotite and metapelitic gneisses. In the former, irregularly spaced leucosomes 0,5 – 2 cm thick are parallel to the foliation and have undergone the entire deformational history. These leucosomes locally constitute up to 40 vol. per cent of the gneisses. Younger quartz-feldspar intergrowths are present in dilational sites.

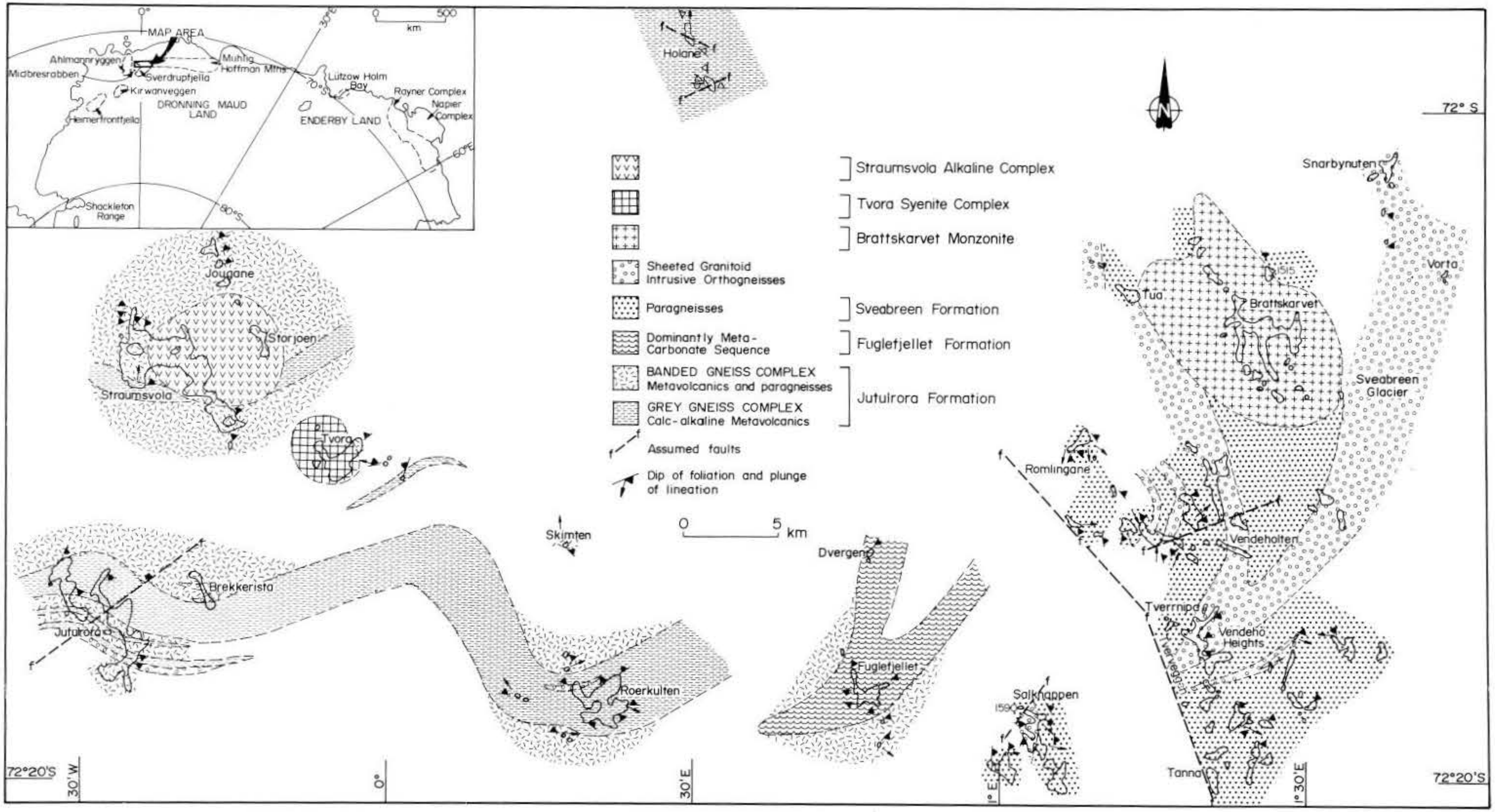

Fig. 1. Simplified geological map of the northern H.U. Sverdrupfjella. Outcrop is limited to nunataks (areas surrounded by heavy line). Geology beyond these areas by interpolation.

Metabasite remnants occurring as pods, lenses, boudins and dykes are present in metapelitic gneisses in the northern and northeastern nunataks. These metabasites are composed of garnet, pyroxene and plagioclase.

Pre-tectonic Tabular Granitoids

Hjelle (1974) recognized that, on a regional scale, tabular granitoid intrusions are common in the H.U. Sverdrupfjella. The present study confirms Hjelle's finding. The thicker granitoid sheets are located typically at or near the contacts between the major lithological units described above. In addition to the large intrusions, numerous thinner sheets up to 20 m thick can be recognized throughout the area (Fig. 2).

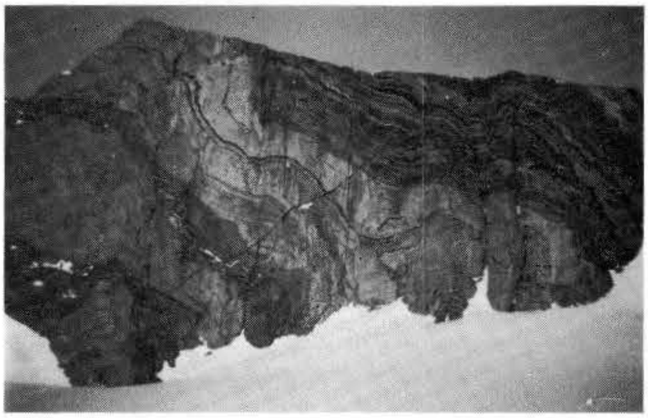

Fig. 2. Photograph of the sheeted Jutulrora Granite overlain by Banded Gneisses and underlain by Grey Gneisses. The height of the exposure is approximately 300 m.

Four major tabular intrusions have been recognized, the Vendeholten, Jutulrora, Roerkulten and Brekkerista granitoids. This classification reflects the spatial distribution of the intrusions and emphasizes that no mutual contacts between them have been identified. All the granitoids exhibit a strong planar foliation. This foliation is locally disrupted by minor shear zones with displacements of a few centimetres.

Augen and granitic gneisses exposed along the western margin of the Sveabreen glacier have been named the Vendeholten granitic suite. A thickness of at least 2 km is estimated for the tabular intrusion at Vendeholten, although some tectonic duplication is possible. Three main lithological varieties constitute the suite. Coarse-grained, typically leucocratic augen gneisses range in composition from granite to granodiorite. In areas of low strain the augen are euhedral and up to 30 cm in length, but elsewhere they are strongly deformed and stretched. The augen consist dominantly of plagioclase but augen of microcline and of composites of microcline and plagioclase also occur. The augen are set in a groundmass of quartz and feldspar with variable but limited amounts of biotite, hornblende and garnet. Sillimanite has been observed rarely as a minor constituent. Ragged lenses of dark-coloured augen gneiss, several metres long and up to 2 m across, define large-scale fold closures in the augen gneiss. These mesocratic rocks contain up to 40 vol. per cent mafic minerals. Melanocratic dykes containing large feldspar augen cross-cut the foliation of the Vendeholten augen gneiss at Snarbynuten.

Equigranular gneissic leucogranite is interlayered with the augen gneiss and occurs as discrete tabular intrusions 20 – 200 m thick in the Sveabreen Formation. These gneisses are composed of quartz, microcline, plagioclase, (An_{34}) and biotite. Plagioclase is present typically as porphyroclasts with complexly sutured margins.

The third main lithologic unit in the Vendeholten suite is a dark-coloured, medium-grained porphyroclastic granodiorite that is found as a 100 m-thick sheet of limited outcrop on the southwestern and central ridges of Vendeholten and at the northern tip of Tverveggen cross-cutting the Sveabreen Formation. Biotite and hornblende, together constituting between 10 and 20 vol. per cent are responsible for imparting the dark colour to this rock. Quartz, plagioclase and microcline make up the remainder of the rock. This tabular granitoid is characterized by the presence of abundant xenoliths of the Sveabreen Formation along its upper contact. The relation of the body to the Vendeholten granite suite is uncertain in view of the fact that it post-dates a basic intrusion (now garnet amphibolite) in the gneissic leucogranites.

The Jutulrora and Roerkulten granites are equigranular, medium-grained rocks with a pinkish colour, composed of quartz, microcline, plagioclase, biotite and hornblende. Subordinate garnet is also present, typically enclosed by laths of plagioclase. The lack of exposed contacts leads to uncertainty whether the Jutulrora granite is intrusive but the presence of xenoliths near the base of this tabular intrusion and its greater homogeneity compared to the quartzofeldspathic paragneisses support the interpretation that it is intrusive. Both granitoid sheets are at least 100 m thick. At Roerkulten the granite displays discordant contacts with the Sverdrupfjella Group. The western contact is highly irregular with numerous apophyses invading the adjacent Grey Gneisses (Jutulrora Formation). The eastern contact shows a slight angular discordance to the foliation of the gneisses and is devoid of apophyses.

The Brekkerista granite crops out as two discrete bodies at Brekkerista nunatak. Each tabular intrusion is approximately 70 m thick, and the two outcrops are considered to represent part of a single deformed sheet. This conclusion is supported by the presence of M-type folds in Banded Gneisses between the granite outcrops. The granite displays a porphyroclastic texture defined by rodded crystals of microcline. The absence of hornblende and the presence of abundant accessory sphene distinguishes the Brekkerista intrusion from those at Jutulrora and Roerkulten.

Mafic and Intermediate Intrusions

Intrusions of mafic and intermediate compositions were emplaced over a long time-span. This group includes all those intrusions that have been deformed and metamorphosed. The earliest intrusions are mafic dykes that were emplaced prior to D_1.

Three generations of thin ($\sim$ 1 m) discordant mafic sheets and dykes can be recognized on structural grounds. These intrusions have been metamorphosed to amphibolite. The earliest generation is recognized by the development of an S_1 fabric and the presence of folded quartzofeldspathic veinlets having an axial planar foliation generated during the D_1 deformational event. In the northeastern nunataks other examples of this generation of mafic magmatism have granulite facies mineral assemblages with no planar fabric. S_1 foliation is deflected around these metabasite remnants, which comprise pods, boudins and dykes that are most commonly preserved in metapelitic gneisses of the Sveabreen Formation. The metabasites are characterized by the assemblages: garnet-orthopyroxene-clinopyroxene-plagioclase and garnet-brown hornblende-plagioclase.

The second generation of mafic intrusions is discordant to the S_1 foliation in their host rocks. Third generation mafic sheets have been recognized at Brekkerista and on south Vendeholten. A planar fabric, defined by hornblende and biotite laths, is developed locally at Brekkerista but in other areas the amphibolite is not foliated but a coarse fracture cleavage is developed. The amphibolites at Brekkerista and Vendeholten contain relict phenocrysts up to 2 cm long which now consist of a granoblastic aggregate of plagioclase and subordinate garnet.

The third generation amphibolites post-date the emplacement of the Brattskarvet monzonite which underlies the nunatak of the same name (Fig. 1). The monzonite is intruded into the core of a major fold involving the Sveabreen Formation and the Vendeholten granite suite. Vertical to near vertical contacts of the intrusion are exposed on peak 1515 and the northwest and southeast extremities of Brattskarvet nunatak.

Leucocratic monzonite and quartz monzonite constitute ~ 95 per cent of the Brattskarvet intrusion. Melanocratic monzonite is present either as thin layers (2 – 10 cm thick) or as zones about 20 m thick near the top of the intrusion. The monzonite consists of quartz (1 – 5 vol. %), oligoclase (40 – 50 vol. %) and microcline (35 – 45 vol. %). Mafic minerals typically do not exceed 5 vol. per cent but locally they may constitute as much as 15 vol. per cent. A pale green amphibole (kataphorite ?) is the most abundant mafic mineral with subordinate biotite diopside. In addition to the difference in quartz content, the monzonites are distinguished from the quartz monzonites by the presence of coarse perthite and antiperthite. The abundance and scale of these intergrowths diminishes upwards in the intrusion. The melanocratic monzonite contains up to 45 vol. per cent diopside, kataphorite and biotite in a matrix of microcline and oligoclase. Sphene, allanite, monazite and zircon are abundant accessory minerals in the melanocratic monzonite. All varieties of monzonite are medium-grained, with a fabric defined by aligned laths of biotite being evident near the contacts of the intrusion. This fabric and the layering are inclined towards the east. Dips are gentle in the central outcrops but become steeper towards the western side of Brattskarvet nunatak and the easternmost limits of the outcrop. This warping reflects late deformation (D_4?). Mafic dykelets, correlated with the third generation amphibolites, that intrude the monzonite are commonly deformed into ragged isoclinal folds probably as a result of shear along planes generated during D_3 deformation. The deformation recognized in the monzonite suggests that its emplacement age is older than the date of 400 – 450 Ma (K-Ar) assigned to it by Ravich & Solov'ev (1966).

Three felsic veins, ± 2 m thick, have been found on Tua and Romlingane nunataks (Fig. 1). They are composed of ~ 90 vol. per cent plagioclase (An_{27}) with minor amounts of K-feldspar and quartz, corresponding to andesine-type anorthosites (Anderson & Morin 1968). The age relations of these andesine-type anorthositic veins is uncertain but they are provisionally regarded as being pre-Brattskarvet monzonite.

Veins of dioritic composition up to 30 cm thick intrude the Brekkerista porphyroclastic granite and gneisses of the Sveabreen Formation. These veins are medium-grained and are composed of granoblastic groundmass of plagioclase and minor quartz in which are set crudely aligned laths of biotite and hornblende, defining a weak foliation. The genetic relations of these dioritic veins are uncertain at present. They are, however, truncated by the anorthositic veins.

Late and Post-tectonic Intrusions

These intrusions are represented by the Dalmatian granite, various pink granitic and aplitic veins, tourmaline-bearing pegmatites, the Kirwanveggen dolerites and two alkaline complexes.

The Dalmatian granite occurs as sheet-like intrusions up to 10 m thick, the orientation of the sheets being highly variable. Lithologic heterogeneity is characteristic. The granite is typically leucocratic, and some outcrops are distinguished by the presence of large (up to 10 cm in diameter) orb-like patches of tourmaline surrounded by a rim composed of quartz, muscovite and feldspar. This leucocratic rim is not present around all the tourmaline orbs. The tourmaline in the cores of the orbs poikilitically encloses quartz and feldspar. Elsewhere, tourmaline orbs are absent and the granite is distinguished by large (up to 1 cm in diameter) grains of magnetite surrounded by thin felsic rims similar to those around the tourmaline orbs. At Dvergen, the tourmaline orbs are developed where the granite cross-cuts carbonate rocks. Away from the carbonate, the granite contains porphyritic magnetite grains but no tourmaline. This relation at Dvergen suggests that the generation of tourmaline was influenced by fluids from the carbonate rocks.

The groundmass in which the tourmaline orbs and magnetite grains are set comprises an aggregate of quartz, K-feldspar, plagioclase, muscovite and biotite. The presence of primary muscovite distinguishes the Dalmatian granite from the other granitoids in the Sverdrupfjella. The Dalmatian granite has been affected by open folding which post-dates the main tectonic events.

Undeformed pink granitic and aplitic veins and tourmaline-bearing pegmatites are common particularly at Roerkulten, Holane and the central nunataks at Jutulrora. The distribution of these minor intrusions shows no spatial relation to either the Dalmatian granite or the carbonate rocks of the Fuglefjellet Formation.

Undeformed mafic dykes, oriented north-south, are intruded into all the preceding rock-types. The abundance of dykes decreases from west to east, with the result that they are most common in the Jutulrora, Brekkerista and Roerkulten areas adjacent to the Jutulstraumen. The dykes range in width from a few centimetres to 50 m. The wider dykes commonly have fine-grained margins with coarse-grained cores composed of olivine gabbro. The pyroxene in most of the dykes is titanaugite which reflects their alkali olivine basalt affinity as does the presence of nepheline in the norm. One dyke at nunatak 1590 west of Salknappen shows prominent vertical layering with compositions ranging from olivine gabbronorite to feldspathic gabbro. The narrow fine-grained dykes commonly contain vesicles filled by either calcite or chlorite. All dykes have high contents of opaque minerals (magnetite, ilmentite ?) and accessory red-brown biotite laths.

Two alkaline complexes (Tvora and Straumsvola) occur adjacent to the Jutulstraumen (Fig. 1). The Tvora complex consists of an early, mesocratic hornblende-quartz syenite and a later, leucocratic hornblende syenite. The leucocratic phase contains xenoliths of the mesocratic syenite which is also cross-cut by dykelets up to 2 m thick of leucocratic syenite. Both varieties of syenite are composed of alkali feldspar, hornblende and biotite, the quartz syenite containing in addition ~ 5 vol. per cent quartz.

The Straumsvola complex consists of three concentrically arranged zones around a central core of syenite that is intrusive into the innermost concentric zone. Centripetally dipping layering in the central core is defined by subtle changes in mineral proportions and a strong fabric resulting from the alignment of platy alkali feldspar.

The core of the complex is surrounded by an inner, coarse-grained, mineralogically homogeneous phase which displays a centripetally dipping fabric defined by platy alkali feldspar. The next succeeding concentric zone is ~ 20 m wide and consists of mesocratic syenite. Contacts of this zone with the inner and outer homogeneous syenites are locally sharp but no chilled margins have been observed. Like the innermost two zones, the mesocratic syenite has strong fabric, the orientation of which is not as regular as in the inner zones. The outermost zone is similar to the inner homogeneous zone except that no fabric was recognized.

All phases of the complex are composed of alkali feldspar, nepheline, biotite, aegerine augite and hornblende (kataphorite). Eudialite is present near the top of the layered central core where it occurs as large clots up to 3 cm in diameter and in fracture fillings. An increase in the proportions of dark minerals towards the top of individual layers is a common feature in the central core. Locally, an increase in the proportions of kataphorite and nepheline results in the development of lenses of melteigite.

Numerous dykes genetically related to the alkaline intrusions cross-cut both the Tvora and Straumsvola complexes. These dykes range in composition from lamprophyric to albititic.

Structure and metamorphism

The area shows evidence of a complex tectonic history which is the subject of on-going research. The following account is thus of a preliminary nature.

The earliest deformation, D_1, comprises isoclinal F_1 folds with axial planar S_1 foliation. This foliation is parallel to the lithological layering which suggests that this deformational event is recumbent. The folds are defined by quartzofeldspathic veins and lithological banding.

D_2 is characterized by isoclinal refolding of F_1 folds to produce class 3 interference structures (Fig. 3). Axes of F_2 folds are commonly of similar orientation to those of F_1 folds. Locally, refoliation of S_1 by S_2 is recognized. Thus in areas where a single foliation is preserved, the relative age of the foliation is equivocal. The foliation in the tabular granitoids is parallel to that in the enclosing gneisses, and consequently these granitoids may predate either D_1 or D_2. Two cleavages intersecting at low angles have been recognized in the Vendeholten suite indicating its pre-D_1 age.

The orientations of F_1 and F_2 are variable. Although fold axes are most commonly inclined towards the southeast, axial planes in the northeast are inclined eastwards whereas those in the western part of the area dip towards the south.

A subsequent episode of folding, F_3 produced tight angular folds but also locally isoclinal folds. This deformational event is indicated by the presence of biotite laths aligned axial planar to F_3 folds. The variability in shape and orientation of F_3 folds reflects the influence of variations in attitude of pre-D_3 layering and the effects of later gentle, open folding of which at least two generations can be recognized.

Ductile shears with displacements of only a few metres are common throughout the area. They are most easily recognized in the texturally more homogeneous tabular granitoids. Analysis of the orientation of the strain ellipses based on data derived from conjugate pairs of shears in the Brekkerista granite suggests that ductile shearing at this locality pre-dated F_3 folding.

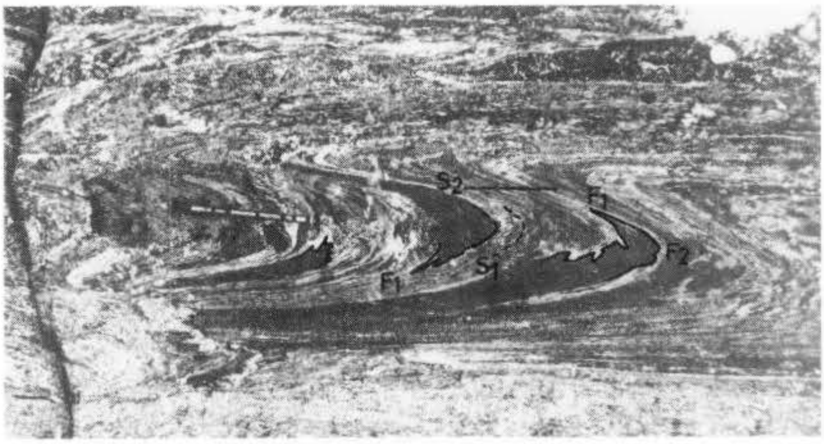

Fig. 3. Annotated photograph of F_2 refolding of F_1 folds to produce a class 3 interference structure (Ramsay 1967, p. 208). An incipient S_2 axial planar cleavage is developed within F_2 folds but S_2 obliterates S_1 in the upper and lower parts of the photograph. Second generation leucosomes are present at lower left. Pencil is 15 cm long. The outcrop is on the SW ridge of Vendeholten.

Brittle deformation is represented by normal faults and cataclastic textures at Midbresrabben (see inset, Fig. 1), Jutulrora and Roerkulten. Whereas normal faults are common in the west, they have not been recognized east of the latter nunatak. These faults post-date the emplacement of the alkaline complexes (Tvora and Straumsvola) in which a strong fracture cleavage parallel to the faults is developed at Tvora. Analysis of the strike orientations of the faults and fractures indicates a maximum between N75° and N90°. Faults trending approximately northwestward are inferred to underlie some of the tributary feeders of the Jutulstraumen.

Midbresrabben is a critical nunatak with respect to interpreting the nature of the boundary between the high-grade Sverdrupfjella terrane and the relatively undeformed volcano-sedimentary sequences building the Borgmassivet. The western portion of this nunatak is underlain by quartz diorite/granodiorite that does not display a penetrative fabric nor are pegmatites present that are typical of granitoids to the east. Xenoliths in the quartz diorite are not highly strained but, locally, the quartz diorite exhibits quartz-leaf fabrics and flaser textures. Brittle deformation is reflected by the displacement of unfoliated pegmatites by faults.

Banded Gneisses in the eastern part of Midbresrabben, together with dolerite dykes, 1 – 40 m wide, intruding the gneisses, exhibit strong cataclastic textures. Lack of outcrop militates against correlation of this brittle deformation with that found in nunataks to the east, but, in both areas, cataclasis represents the last deformational event.

The earliest metamorphism was of granulite grade associated with D_1. Mineral assemblages typical of M_1 granulite grade are restricted to mafic lenses and dykes most commonly preserved in metapelitic gneisses of the Sveabreen Formation in the northern and northeastern nunataks. The metabasite remnants show no metamorphic s-planes and no preferred mineral orientations, the S_1 foliation being deflected around them. These pre-F_1 metabasites are characterized by the assemblages: garnet-orthopyroxene-clinopyroxene-plagioclase and garnet-brown hornblende-plagioclase. In rocks of possible pelitic parentage, mineral assemblages involve garnet, hypersthene, sillimanite, feldspar and quartz.

Ultramafic dykes in the Rømlingane nunataks are characterized by corona structures consisting of a series of concentric shells. A core of relict olivine is enclosed by successive shells composed of radiating orthopyroxene, granular clinopyroxene, garnet-clinopyroxene symplectite and garnet. The outer shell abuts relict plagioclase grains.

The dykes in which coronas occur contain local areas of relatively undisturbed primary mineralogy. Based on the assumption that the original chemistry of these phases has been preserved, pressure and temperature may be calculated using various thermodynamic relations and mineral chemistry obtained by microprobe analysis. The equilibrium conditions of crystallization are calculated provisionally as 1180 °C at 13,4 kb. This implies

(a) that intrusion occurred at a depth of some 40 km, and

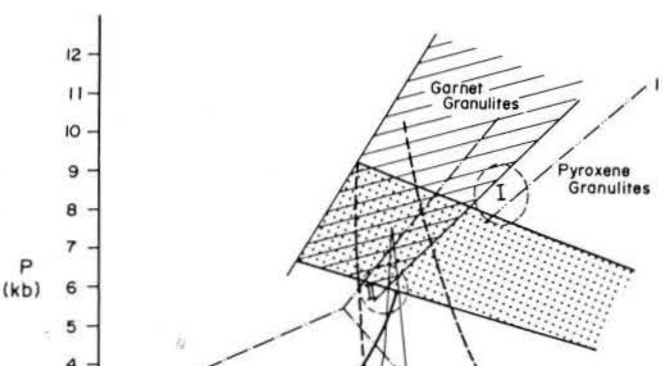

Fig. 4. P-T diagram showing metamorphic conditions applicable to the Sverdrupfjella Group. Fields I and II (M_1 and M_2) calculated for the Sveabreen Formation from garnet – pyroxene – plagioclase thermobarometry. Pelites of the same formation fall within the field (stippled) in which almandine, cordierite, sillimanite and quartz coexist (Hensen & Green 1971, MgO/FeO + MgO ~ 3). Field of garnet granulites and reaction 1:Al-pyx + An + spinel → garnet + cpx from Ringwood & Green (1966). Transition from M_1 to M_2 in western nunataks crosses isograd 2a: Enstatite + water → talc + forsterite (reactions from Chernosky *et al.* 1985). Isograd 3: garnet + anorthite + magnetite + water → epidote + quartz (Liou 1973) crossed during transition to M_3.

(b) that the coronas formed as a response to re-equilibration during isobaric cooling from liquidus temperatures to ambient granulite facies conditions. Thermobarometric relations applied to the co-existing metamorphic mineral sets suggest that these conditions were T = 850 °C and P between 9 and 11 kb (Fig. 4, Table 2).

Table 2

Provisional thermobarometry for the northern H.U. Sverdrupfjella

	T °C	P kb
Igneous assemblage		
(olivine gabbronorite)		
Liquidus conditions	1180[a]	13,4[b]
M_1		
Garnet pyroxenite cores		
of relict phases.	850[c]	9,6[d] 8,8[e]
Olivine gabbronorite coronas	840-880[c]	9-10[f]
M_2		
Garnet pyroxenite		
SF 8528	590[a] 560[c]	6,1[e] 5,7[d]
SF 8525	655[a] 660[c]	5,9[d]
Garnet-pyroxene-quartz rock	590[a] 675[c]	5,7[d] 6,3[e]

(a) Pyroxene thermometry of Lindsley (1983)
(b) Derived from thermodynamics of reactions: $Mg_2SiO + SiO_2 \rightarrow 2MgSiO_3$ and $CaAl_2SiO_6 + SiO_2 \rightarrow CaAl_2Si_2O_8$ using graphical solution. Constants from Robie *et al.* (1978). Formulation of CaTsc – An relation form Ellis (1980), modified for $a^{Liq}_{SiO_2} < 1$.
(c) Garnet-clinopyroxene thermometry based on Fe-Mg exchange equilibria (Ellis & Green 1979).
(d) Garnet-clinopyroxene-plagioclase geobarometry (Newton & Perkins 1982).
(e) Clinopyroxene-plagioclase-quartz barometry (Ellis 1980).
(f) Garnet-orthopyroxene barometry (Harley & Green 1982).

The greater part of the area is at upper amphibolite grade (M_2). This event is characterized by the presence of minerals such as sillimanite, green hornblende, garnet, biotite and feldspar in rocks of appropriate composition. Sillimanite is not stable in all rock-types during M_2 and breaks down to form white mica in some rocks. Reactions between garnet, clinopyroxene and quartz in certain lithologies are suitable for thermobarometric study. Using a variety of thermodynamic relations (Table 2) M_2 conditions are provisionally estimated at T = 560 – 690 °C and P = 5 – 6 kb.

The metamorphic conditions prevailing during successive events are summarized in figure 4.

Discussion

The foregoing summary of the geology of the H.U. Sverdrupfjella provides a basis for considering the possible correlation of this terrane. The earliest metamorphic event reached its peak in the northern and eastern parts but only minor relicts are preserved. Until more detailed structural studies have been completed, the possibility cannot be excluded that the high-grade relicts represent allochthonous thrusts sheets or nappes. This granulite grade metamorphism occurred at 9 – 11 kb and ~ 850 °C. Subsequent decompression is marked by retrogressive textures at P 5 – 6 kb and T 560 – 690 °C. The lack of radiometric age data precludes identification of the timing of these events. A provisional

Rb-Sr date of ~ 900 Ma from the Roerkulten granite may represent a metamorphic age (A. Moyes, pers. comm.). The late tectonic Dalmation granite has yielded a preliminary Rb-Sr date of ~ 470 Ma which may reflect the emplacement age of this granite (A. Moyes, pers. comm.). Rb-Sr whole rock data from the Kirwanveggen (73°S – 74°S, 0°E – 4°W) indicate ages between 1018 and 1173 Ma (Elworthy in Wolmarans & Kent 1982). Biotite separated from seven of the whole rock samples shows a narrow range of Rb-Sr mineral ages between 460 and 485 Ma with a mean of 475 ± 14 Ma (Elworthy in Wolmarans & Kent 1982).

Although these data are provisional, they suggest that metamorphic events may have occurred between ~ 500 and 1000 Ma ago, i.e. ranging from Pan African to Kibaran. Sacchi **et al.** (1984) have reported details of the geology of the southernmost part of the Mozambique Province in Mozambique. These authors recognize a number of formations that have lithological similarities with the Sverdrupfjella Group as well as granitoids characterized by planar fabrics with Rb-Sr dates of ~ 1100 Ma and other granitoids with ages ~ 500 Ma. Sacchi **et al.** (1984) also describe poorly exposed granulites and intrusive garnetiferous norites. The granulites are preserved in two allochthonous nappes.

Andreoli (1984) recognized, in Malawi, granulites that developed by prograde metamorphism, the climax of this tectonothermal event spanning a period between ~ 1100 and 850 Ma when P-T conditions approached 7 – 9 kb and 800 – 950 °C over wide areas. Similarly, an earlier metamorphic event at P 8 – 11 kb and T 725 – 800 °C in northeastern Zimbabwe was succeeded by a second period of metamorphism at P 5 – 8 kb and T 725 – 700 °C (Treloar 1987).

Although correlations based on lithologic and metamorphic similarities are not reliable, the fact that the Martin & Hartnady's (1986) Gondwanan reconstruction juxtaposes the Sverdrupfjella and East African terranes suggests that the Sverdrupfjella is an extension of the Pan African-Kibaran tectonothermal province. This conclusion would also be consistent with the suggested correlation of the Ritscherflya Supergroup (cropping out west of the Jutulstraumen) with the Umkondo Group of Zimbabwe (Ferreira 1986). Further support derives from the proposal that the rocks of the Shackleton Range, located between 80° and 81°S and 19° and 31°W, formed part of a complex of intra-Gondwana mobile belts of Pan-African Age (Fig. 5; Marsh 1983).

The nature of the boundary between the high-grade H.U. Sverdrupfjella terrane and the relatively undeformed, low-grade volcano-sedimentary Ritscherflya Supergroup remains uncertain. The emplacement of a swarm of dolerite dykes and two alkaline complexes adjacent to the eastern flank of the Jutulstraumen reflects late, crustal dilation. Normal faulting and fracturing post-date the intrusion of the alkaline complexes but it is not yet possible to correlate this event with the late cataclasis observed in the isolated Midbresrabben nunatak. These events appear to post-date the juxtaposing of the two disparate terranes. However, significant crustal dilation appears to have affected only the eastern side of the Jutulstraumen as dyke swarms are not prominent in the Ritscherflya Supergroup west of the Jutulstraumen.

Correlation of the Ritscherflya Supergroup with the Umkondo Group might imply that, prior to dilation, the boundary was similar to that observed along the border between Zimbabwe and Mozambique where the high-grade terrane is thrust westwards onto the Umkondo Group. However, such a relation in Antarctica has yet to be demonstrated.

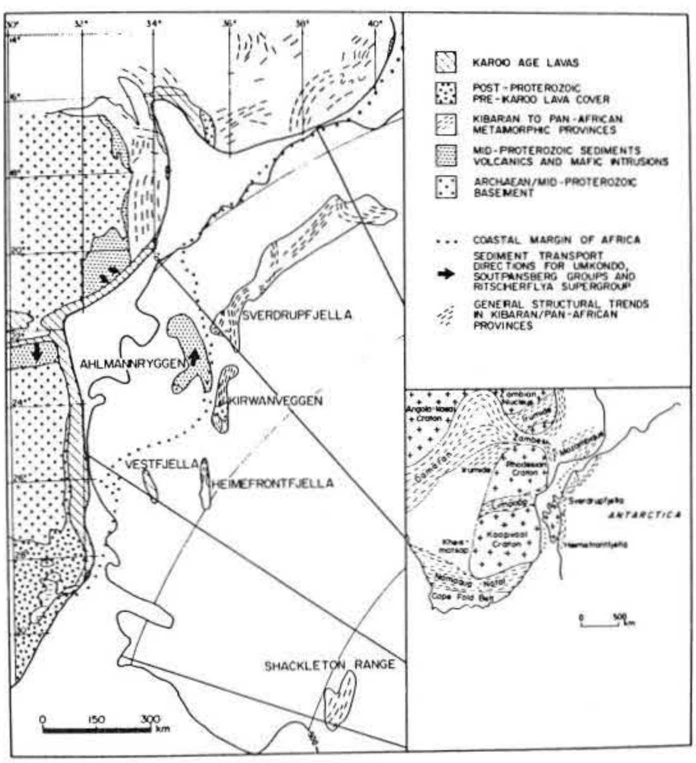

Fig. 5. Gondwana reconstruction to show relation of H.U. Sverdrupfjella to the Kibaran-Pan-African tectonothermal province of southern Mozambique and possible continuation of this province across Antarctica to the Heimefrontfjella and Shackleton Range.

Acknowledgements

The logistical and financial support from the Departments of Transport and Environment Affairs, acting on the advice of the South African Committee for Antarctic Research, C.S.I.R. is gratefully acknowledged. G.H.G. and P.B.G. also wish to thank A.R. Allen for introducing them to the H.U. Sverdrupfjella. Freda Richards prepared the illustrations and Barbara Rimbault typed the manuscript.

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