Polarforschung 66 (3), 7 – 18, 1996 (erschienen 2000)

The pre-Permo-Carboniferous Rocks and Structures from Southern Kirwanveggen, Dronning Maud Land, Antarctica

By Georg Kleinschmidt[1], Stefan Helferich[1], Friedhelm Henjes-Kunst[2], Chris Jackson[3] and Hartwig E. Frimmel[3]

Summary: The basement of southern Kirwanveggen (western Dronning Maud Land) is formed by a SSW-dipping section consisting of (from SW to NE): migmatic gneisses; granitoid; low-grade/prograde meta-pelites, meta-psammites and meta-basalts (= "Polaris Formation"); ortho-gneiss; quartzite mylonite; Polaris Formation; quartzite mylonite; meta-turbidites.

These units are (partly) separated by at least four SSW-dipping, NE to N directed major thrusts. Most probably, this thrust system is of Pan-African age. Towards north, the section is followed by the molasse-like Urfjell Group, deposited later than approx. 550 Ma and earlier than 450 Ma. Similarities with the Pan-African of the Shackleton Range (thrusting, molasse) led to the assumption, that the East/West Gondwana suture runs from the Shackleton Range towards Sør Rondane (eastern Dronning Maud Land) passing southern Kirwanveggen at its south-east.

Zusammenfassung: Das Grundgebirge im südlichen Kirwanveggen (Neuschwabenland, Antarktis) bildet eine SSW-fallende Gesteinsfolge aus (von SW nach NE) migmatischen Gneisen, Granitoid, schwach metamorphen prograde Metapeliten, Metapsammiten und Metabasiten (= "Polaris-Formation"), Orthogneis, Quarzitmylonit, Gesteinen der Polaris-Formation, Quarzitmylonit, Metaturbiditen.

Diese Einheiten werden von mindestens vier SSW-fallenden, nach N bis NE gerichteten Überschiebungszonen durchschnitten. Dieses Überschiebungssystem dürfte panafrikanisch sein. Nach NE zu wird das Profil durch die molasseartige Urfjell-Gruppe abgelöst, die zwischen ca. 550 Ma und 450 Ma abgelagert wurde.

Ähnlichkeiten mit dem panafrikanischen Bau der Shackleton Range (Überschiebungssysteme, Molasse) führten zu der Annahme, daß die Sutur zwischen Ost- und Westgondwana von der Shackleton Range südöstlich am Südende von Kirwanveggen vorbei in Richtung auf Sør Rondane (östliches Dronning Maud Land) zu verläuft.

INTRODUCTION

Kirwanveggen is situated in western Dronning Maud Land (DML) between 73 °S, 74° 15'S, 06° 30'W, and 1° 30'W. The neighbouring mountain ranges are: the Borgmassivet and Ahlmannryggen to the north, the H.U. Sverdrupfjella to the NE, the Heimefrontfjella to the SW; the Shackleton Range is located some 750 km to the SSW (Fig. 1). Borgmassivet and Ahlmannryggen form the most important part of the Grunehogna Craton and are consisting mainly of the subhorizontal and undeformed Proterozoic sediments of the Ritscherflya Supergroup intruded by the ca. 1 Ga old Borgmassivet Intrusives. The Archaean basement of the Grunehogna Craton is exposed scarcely west of the Borgmassivet (Annandagstoppane). The Grunehogna Craton in turn is thought to be part of the African Kalahari Craton (e.g. GROENEWALD et al. 1995).

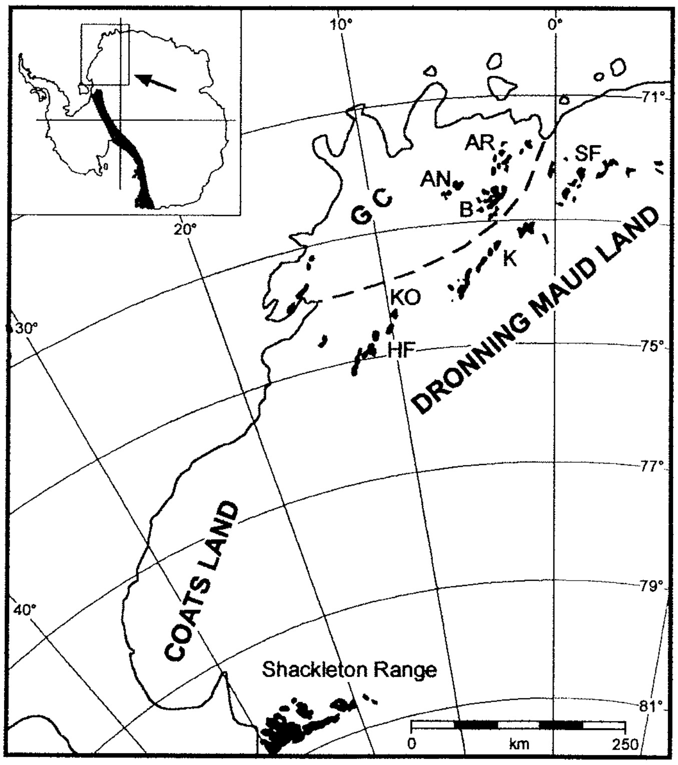

Fig. 1: Positiones of Kirwanveggen (K), Borgmassivet (B), Annandagstoppane (AN), Ahlmannryggen (AR), H.U. Sverdrupfjella (SF), Heimefrontfjella (HF), Kottasberge (KO) and Shackleton Range. - - - - Boundary of the Grunehogna Craton (GC).

Abb. 1: Lage von Kirwanveggen (K) in der Antarktis mit Borgmassivet (B), Annandagstoppane (AN), Ahlmannryggen (AR), H.U. Sverdrupfjella (SF), Heimefrontfjella (HF), Kottasberge (KO) und Shackleton Range. - - - - Begrenzung des Grunehogna-Kratons (GC).

The H.U. Sverdrupfjella forms the north-eastern end of the "Grenvillian" Maud Belt characterized by the polyphasely deformed and strongly metamorphosed Sverdrupfjella Group (ROOTS 1969). In places, it is intruded by younger "Pan-African" granitic rocks; moreover, the significance of a possible "Pan-African" tectonic overprint is discussed (e.g. GRANTHAM et al. 1995, GROENEWALD et al. 1995, OHTA 1996).

The Heimfrontfjella forms the south-western end of the "Grenvillian" Maud Belt (GROENEWALD et al. 1995, JACOBS et al. 1996).

---

[1] Geologisch-Paläontologisches Institut, J.W.Goethe-Universität Frankfurt, Senckenberganlage 32, D-60054 Frankfurt am Main, Germany

[2] Bundesanstalt für Geowissenschaften und Rohstoffe, Postfach 510153, D-30655 Hannover, Germany

[3] Department of Geological Sciences, University of Cape Town, Rondebosch 7700, South Africa

Manuscript received 03 November 1999, accepted 20 October 2000

No "Pan-African" magmatics are known. It is characterized by a longitudinal dextral shear zone, separating a predominantly "Grenvillian" formed terrane to the north-west from an intensely "Pan-African" reworked terrane to the south-east (JACOBS et al. 1999). The northern most part (Kottasberge) is only 90 km away from Kirwanweggen's south end. The Kottasberge are dominated by Grenvillian structures and metamorphism, but contain some discrete north-westward directed thrusts of Pan-African age (e.g. JACOBS et al. 1996, JACOBS et al. 1999).

The Shackleton Range is lacking any Grenvillian imprint, its structures and metamorphism are dominated by Pan-African (= Ross) ages, partly overprinting mid-Proterozoic event(s) (e.g. TESSENSOHN et al. 1999).

Kirwanveggen is divided into a northern (73 °S - 73° 15'S), a central (73° 20'S - 73° 43'S) and a southern part (73° 45'S -74° 15'S). The northern and the central parts belong to the "Grenvillian" Sverdrupfjella Group with few Pan-African overprints, i.e. mainly north-westward directed discrete shear zones (GRANTHAM et al. 1995, WOLMARANS & KENT 1982). Apart from unconformably overlying Permotriassic sediments of the Amelang Formation (e.g. AHLBERG et al. 1992) and Jurassic Kirwan Volcanics (e.g. HARRIS et al. 1990), which are not subject of this paper, southern Kirwanveggen (Fig. 2) is dominated by the Urfjell Group (localities: Dråpane, Urnosa, Framranten, Kuvungen, Utrinden, Kuven, Tunga, Uven and Fault Nunatak). The Urfjell Group consists of unmetamorphosed, weakly deformed sandstones, quartzites and conglomerates of unknown age, previous assumptions were Riphean to Lower Palaeozic (PAECH et al. 1991). AUCAMP et al. (1972) and WOLMARANS & KENT (1982) think of the possible correspondence with the Blaiklock Glacier Group, which is the Ordovician molasse of the Pan-African orogen in the Shackleton Range (BUGGISCH et al. 1999).

The basement of the southernmost Kirwanveggen was assigned to the Sverdrupfjella Group (WOLMARANS & KENT 1982). The particular localities are: Ladfjella, Lagfjella with Muskeg Cliff, Concretion Point, Frostbite Bluff, Petrel Peak and Polaris Ridge, and three isolated nunataks Drabanten, Klakknabben and Gavlpiggen.

From our work in southern Kirwanveggen, we expect results concerning the relation of "Grenvillian" to "Pan-African" events in western DML and a better understanding of the palaeo-geodynamics in the area DML/Coats Land.

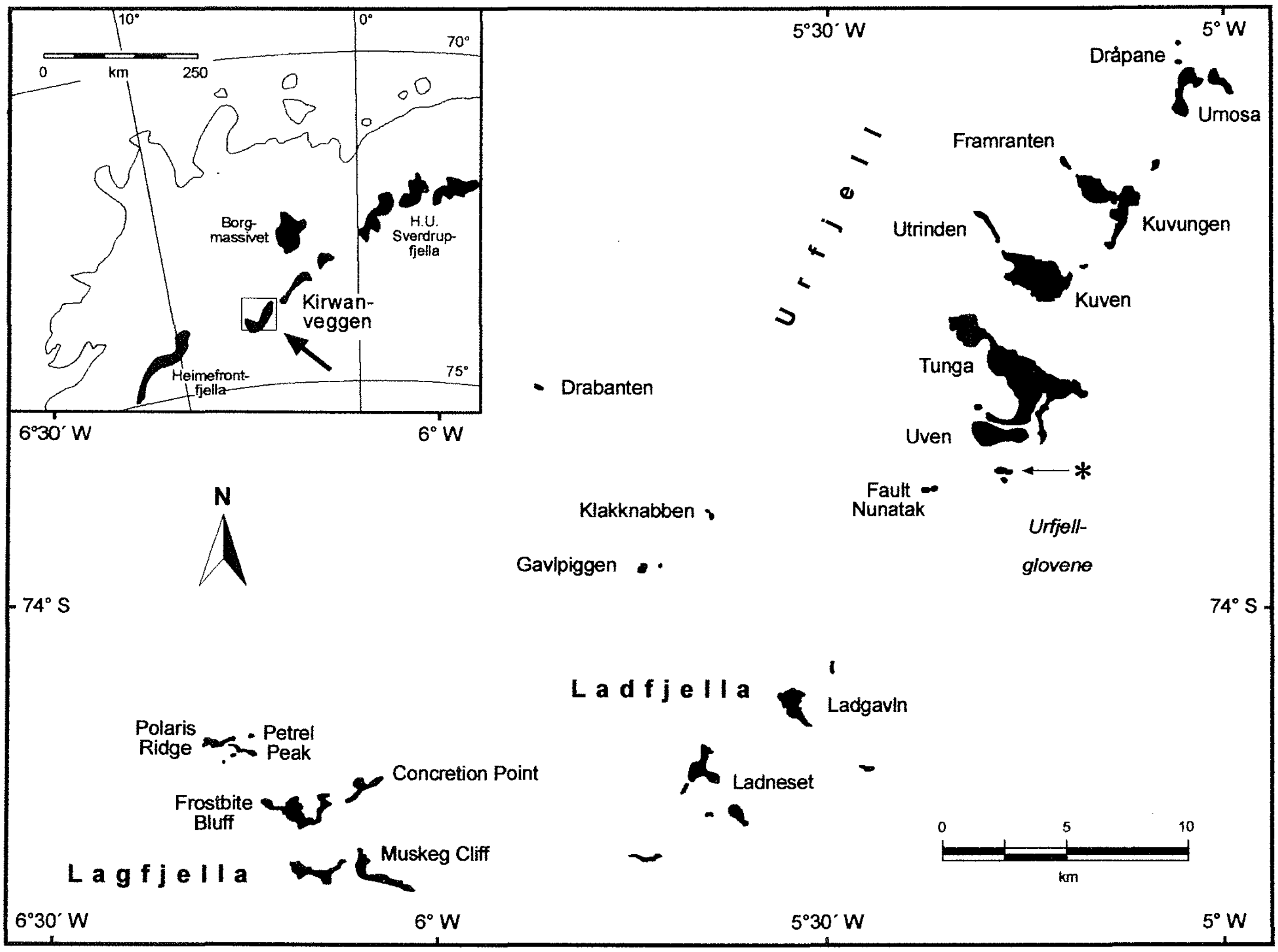

Fig. 2: Southern Kirwanveggen, localities mentioned in the text. * = nunataks between Uven and Urfjellglovene.

Abb. 2: Kirwanveggen-Süd mit allen im Text genannten Lokalitäten. * = Nunatakker zwischen Uven und Urfjellglovene.

FIELD RESULTS

During the field season 1997/98, we studied the following gently SSW-dipping rock sequence of southern Kirwanveggen (SW to NE, i.e. structural top to the structural bottom; Fig. 3):

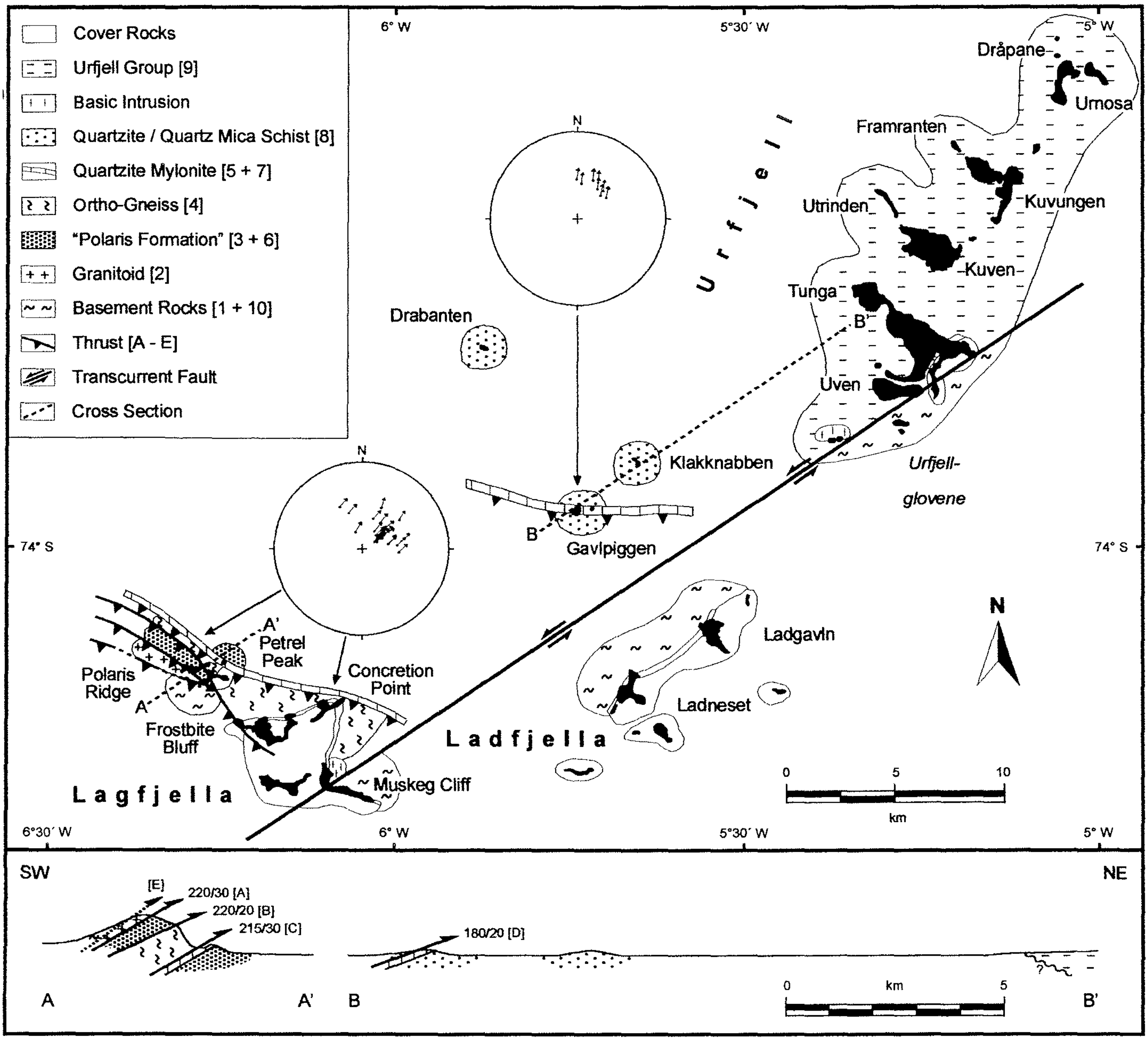

Fig. 3: Geological sketch map of southern Kirwanveggen and schematic SW-NE running cross section (note different scales). Numbers and letters in () refer to the units and structures described in the text. Added: 2 „Hoeppener diagrams" (Hoeppener 1955) showing variation of thrust directions in southern Kirwanveggen.

Abb. 3: Schematische geologische Karte Südkirwanveggens und zugehöriges SW-NE-Profil (in unterschiedlichem Maßstab). Die Ziffern bzw. Buchstaben in () beziehen sich auf die im Text beschriebenen Einheiten und Strukturen. Hinzugefügt: 2 Hoeppener-Diagramme (Hoeppener 1955) der Ueberschiebungsrichtungen im südlichen Kirwanveggen.

(1) Migmatic gneisses are exposed only at a tiny nunatak (74° 04' 11"S / 06° 21' 08"W), 1 km south of Petrel Peak/Polaris Ridge. It is the southernmost occurrence of basement in Kirwanveggen at all.

(2) A sheet of granitoid forms the western part of Polaris Ridge. The granitoid is >20 m thick, massive in the centre, gneissic towards the rims.

(3) Mica schists (mainly biotite schists) dominate the upper part, greenschists dominate the lower part of an apparent low-grade, but prograde unit with a minimum thickness of 100-150 m. The greenschists are intercalated by quartzite layers up to 20 cm thick (Fig. 4). This prograde unit consisting of meta-pelites, meta-psammites and meta-basalts is unique in western DML and called the „Polaris Formation". The Polaris Formation forms the medium level of entire Polaris Ridge.

Fig. 4: Main rock types of Polaris Formation, southernmost Kirwanveggen: interlayering of amphibole bearing greenschist (top and bottom) and quartzite (centre).

Abb. 4: Hauptgesteine der Polaris Formation, südlichster Kirwanveggen. Wechsellagerung von amphibolführendem Grünschiefer (oben und unten) und Quarzit (Mitte).

(4) Flesh-coloured ortho-gneisses form the lower parts of eastern Polaris Ridge (i.e. Petrel Peak), Concretion Point and Frostbite Bluff and a group of small nunataks immediately north of Polaris Ridge. Their footwall is not exposed, since their thickness may be much larger than the exposed 250 m. The ortho-gneisses are mylonitized, especially the upper 80-140 m.

(5) At least 15 m thick quartzite mylonites with intercalated mica schists are cropping out 1.5 km north of Polaris Ridge at the southern end of a small nunatak at 74° 02' 38"S / 06° 18' 09"W.

(6) The central and northern parts of the same small nunatak at 74° 02' 38"S / 06° 18' 09"W show an at least 40 m thick sequence of greenschists to amphibolites and intercalated mica schists resembling unit (3). This situation is therefore interpreted as a repetition of the Polaris Formation.

(7) The quartzite mylonites of Gavlpiggen (73° 58' 24"S / 005° 47' 17"W) follow to the NNE after a 12 km wide ice-covered gap of outcrops. The strongly foliated rocks show an exposed thickness of about 220 m and resemble unit (5).

(8) An alternation of quartzites and quartz mica schists at Drabanten (73° 53' 52"S / 005° 54' 46''W) and Klakknabben (73° 57' 12"S / 005° 42'W) is the lowermost unit of the section. The quartzites and quartz-schists respectively form layers from several dm up to a few m in thickness. Especially at Klakknabben, the alternating sequence is partly mixed up with slivers of mylonitized basement rocks.

(9) Approximately 10 km north-east of Klakknabben the conglomerates, quartzites and sandstones of the Urfjell Group (AUCAMP et al. 1972) are following. The contact to the metamorphosed units mentioned before is not exposed. But the contrast of strong deformation in the metamorphosed units and of the Urfjell Group showing no penetrative deformation and metamorphism requires an unconformable contact, which, of course, might be tectonically overprinted.

(10) The southeast of Kirwanveggen contrasts with the section between Polaris Ridge, Gavlpiggen, Drabanten / Klakknabben and main Urfjell: The basement at eastern Lagfjella (= Muskeg Cliff), Ladfjella and between Uven and Urfjellglovene, consists of migmatic, apparently high-grade metamorphic rocks and intermediate to basic magmatic rock types resembling those from H.U. Sverdrupfjella, northern and central Kirwanveggen. Thus, only this part of southern Kirwanveggen (between Muskeg Cliff and Urfjellglovene) plus unit (1) may be included in the Sverdrupfjella Group *sensu strictu*.

STRUCTURE

Remark: All structural data are noted according to the Clar method, i.e. dip direction (plunge direction resp.) in front of slash, dip (plunge resp.) behind.

Southernmost Kirwanveggen between Lagfjella and Urfjell is dominated structurally by a NW-SE to W-E running, south-west to south dipping mylonitic thrust system (Fig. 3). Four major thrust zones are provable in the field:

(A) A mylonitic thrust zone, 5 to 10 m thick, with the attitude of 220/30, separates the units (2) and (3). It is made up mainly of mylonitized granitoid (unit (2)) and in places of mylonitized schists (unit (3)). The mylonitic stretching lineation is 235/25, the tectonic transport direction towards 55°, indicated by S-C- and book-shelf structures and σ-objects.

(B) The most prominent mylonitic thrust is called „Polaris Thrust" (Fig. 5). It is mappable from north of central Polaris Ridge to its eastern end, continuing (but being slightly offset) at Frostbite Bluff, thus extending for more than 8 km. The Polaris Thrust is approximately 80 to 140 m in thickness. Its tectonic data are: thrust plane 220/20; stretching lineation 230/15; tectonic transport 50°, proven by σ-objects and mica fish.

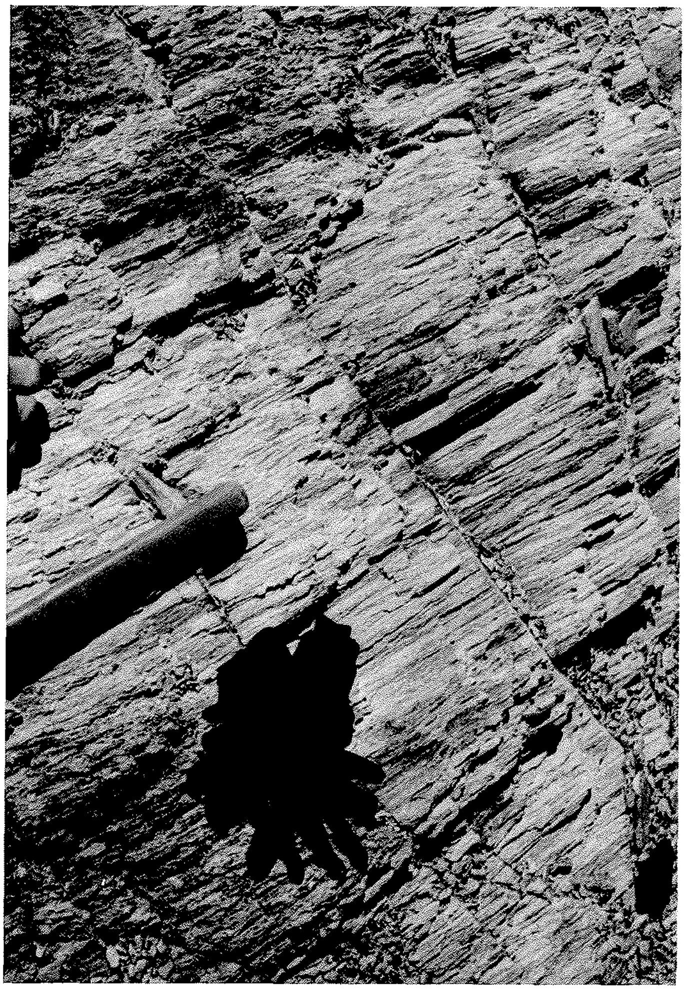

Fig. 5: Polaris Thrust: mylonitized ortho-gneiss from Petrel Peak, southernmost Kirwanveggen, showing strong stretching lineation. NE to the right.

Abb. 5: Polaris Thrust: Mylonitischer Gneis mit deutlichem Streckungslinear. Petrel Peak, südlichster Kirwanveggen. Rechte Bildseite = NE.

(C) The third main thrust is indicated by the quartzite mylonite (5) at the southern end of the small nunatak at 74° 02' 38"S / 006° 18' 09"W. This thrust (thrust plane = 215/30) parallels Polaris Thrust about 1.5 km to the north of it.

(D) The quartzite mylonite from Gavlpiggen (unit (7)) indicates the northernmost thrust of the system. Its attitude is 180/20 to 180/35 (s = thrust plane), the stretching lineation 185/15 to 190/30. The tectonic transport is directed towards 10°, shown by σ-objects, mica fish and sheath folds (varying B-axes: 100/05 - 275/10 - 215/35).

(E) Another inferred thrust may complete the system in the south (south of Polaris Ridge) presumably separating the migmatic gneiss (unit (1)) dipping 20° towards 220°, and the granitoid (unit (2)) dipping 20° towards 230°.

This thrust system and nearly all units mentioned (units (1)-(9)) are cut off to the SE by a SW-NE trending fault (Fig. 3), eastward of which the migmatites of the Sverdrupfjella Group (unit (10)) are following. The fault comprises westward dipping normal, sinistral strike-slip and compressive components (transpression), indicated by slickensides and Riedel shears in particular at the group of nunataks between Uven and Urfjellglovene. This kinetics may cause the slight compressive deformation of the Urfjell Group reaching tilting, bending, kink folding combined with detachments and even inversion near the fault. A sinistral strike-slip faulting as stated by Moyes et al. (1997) cannot be confirmed; all points in question have been re-examined.

The fault may belong to a major fault system, as it parallels the Pencksökket-Jutulstraumen-graben (Grantham & Hunter 1991, Jacobs & Lisker 1999) and the dextral shear zone in the Heimefrontfjella (Jacobs et al. 1996).

The structural pattern resulting from the intersection of the E-W striking thrust system and the SW-NE running faulting is obviously reflected by aeromagnetic anomalies in Dronning Maud Land (Corner 1994, Golynsky & Aleshkova in press, Fig. 6).

Some additional structural data will be just listed:
average attitude of the Polaris Formation (units (3), (6)), 220/35;
average attitude of the ortho-gneis (unit (4)), 210/25;
average attitude of unit (8), 190/25, but varying, especially at Klakknabben between 175/50 and 280/60. The variation is due to subsequent folding (B ≈ 220/35) kinking and some brittle deformation.

PETROLOGY AND GEOCHEMISTRY

The most important rock types of the section are:
- the granitoid (unit (2)),
- the Polaris Formation, especially the amphibole bearing greenschist (units (3) and (6)),
- the mylonitic ortho-gneiss (unit (4)),
- the quartzite mylonites (units (5) and (7)),
- the quartzites / quartz mica schists alternation (unit (8)) and
- the Urfjell Group.

The granitoid (2) with its massive inner part and its gneissic rims is clearly metamorphosed. The main constituents are quartz, K-feldspar, plagioclase, biotite and zoned garnet, additionally white mica and apatite. The metamorphic peak temperature is estimated at slightly over 500 °C by means of several garnet-biotite geothermometers. Geochemically, the granitoid plots in the "quartz syenite" field, using the R_1R_2-diagram by De la Roche et al. (1980) (Fig. 7, Tab. 1).

The greenschists of the Polaris Formation (units (3) and (6); Fig. 4) consist of amphibole and plagioclase, some epidote, and a little bit quartz and calcite. The amphibole varies between actinolite, actinolitic hornblende, and magnesio-hornblende (acc. to Leake 1978) and the plagioclase between $An_{0.7}$ and $An_{5.1}$ with a mean of $An_{2.7}$. Compositions of both amphibole and plagioclase indicate that amphibolite facies conditions have not been reached. Some of the amphiboles stand out of the matrix by size and their pseudotetragonal shape. They seem to be pseudo-

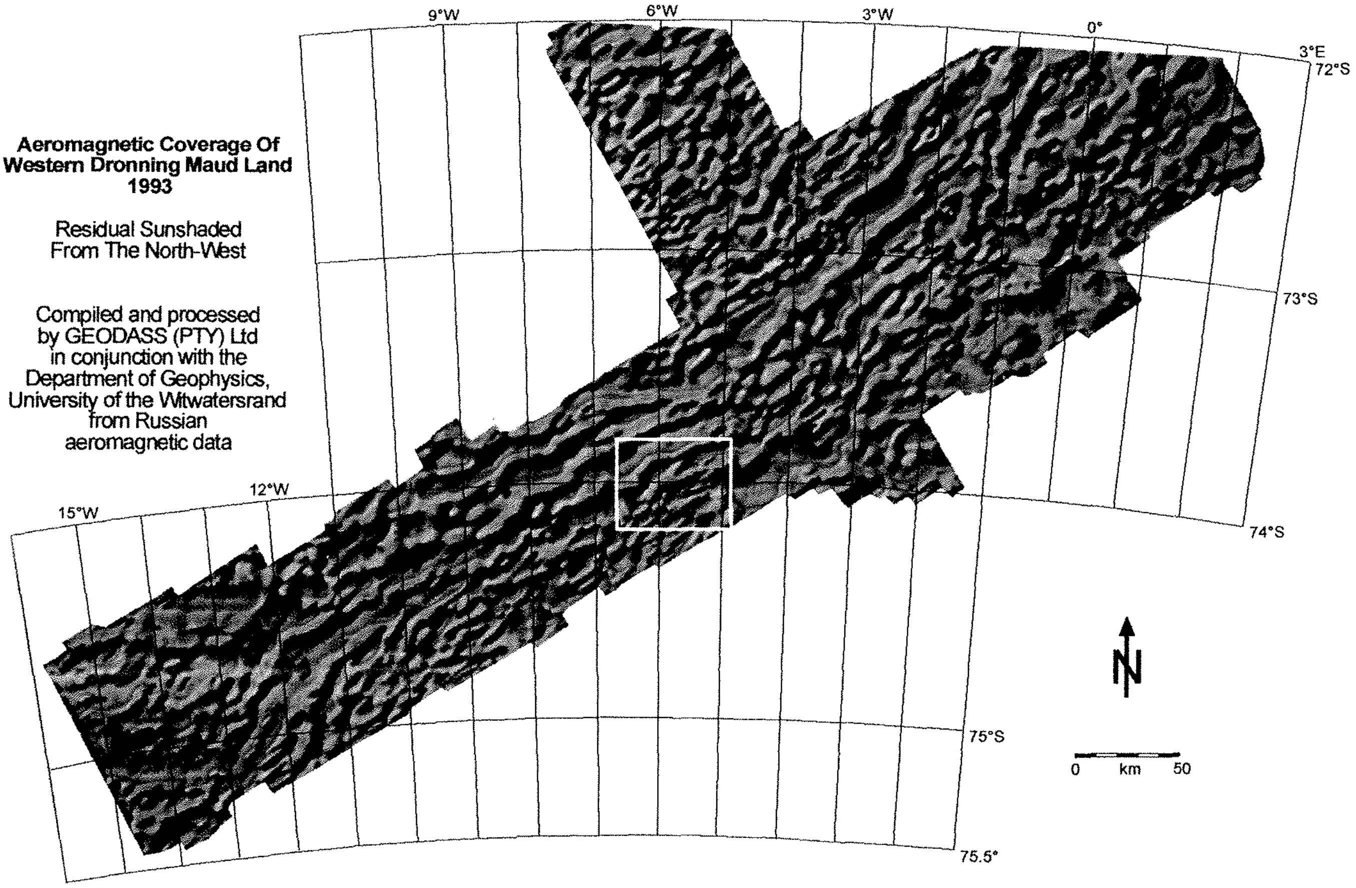

Fig. 6: Black-and-white copy of B. Corner's (1994) aeromagnetic map between 16 °W, 3 °E, 72 °S, and 75.5 °S (using Russian data of Golynsky & Aleshkova 2000). Two sets of linear elements are discernible: (a) E-W trending, (b) SW-NE trending. Marked: southern Kirwanveggen.

Abb. 6: Aeromagnetische Karte zwischen 16 °W, 3 °E, 72 °S und 75,5 °S (nach Corner 1994, unter Verwendung der Daten von Golynsky & Aleshkova 2000). Zu erkennen sind E-W verlaufende und SW-NE verlaufende lineare Elemente. Markierter Ausschnitt = Kirwanveggen-Süd.

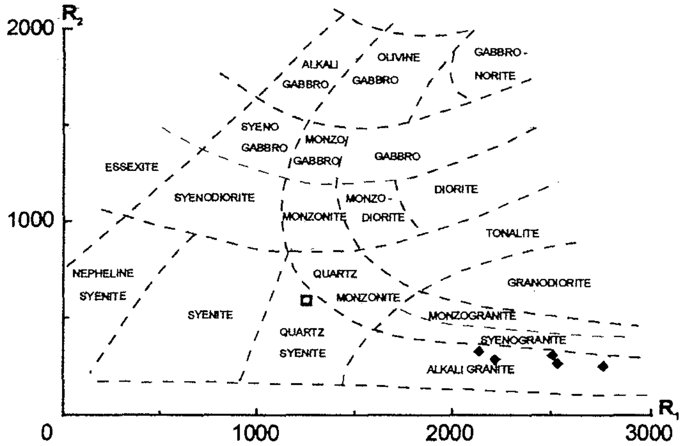

Fig. 7: Plottings of the granitoid (unit [2]) = □ and various ortho-gneisses (unit 5) = ◆ into the R_1R_2-diagram by De la Roche et al. (1980) using XRF-data (Tab. 1). R_1 = 4 Si - 11 (Na+K) - 2 (Fe+Ti), R_2 = 6 Ca + 2 Mg + Al.

Abb. 7: Darstellung des Granitoids (Einheit 2) = □ und der Orthogneis-Varietäten (Einheit 5) = ◆ im R_1R_2-Diagramm nach De la Roche et al. (1980) anhand geochemischer Daten (Tab. 1). R_1 = 4 Si - 11 (Na+K) - 2 (Fe+Ti), R_2 = 6 Ca + 2 Mg + Al.

morphs after pyroxene and may be therefore relics of a basaltic protolith. Modal composition and structure point to prograde metamorphism of high greenschist facies. Because of the rather strong metamorphism, only trace elements such as Ti, Zr, Y, and Nb are considered to be immobile and can be used for geochemical characterization of the former tectonic environment (Cann 1970). Plots of the meta-basalts of the Polaris Formation onto several discriminant diagrams, e.g. those by Pearce & Cann (1973) and Meschede (1988), yielded consistently calc-alcaline volcanic arc basaltic affinities (Fig. 8, Tab. 1).

The mylonitic ortho-gneiss (unit (4)) consists of quartz, microcline perthite, plagioclase, green biotite, white mica, and as accessories zircon and opaque minerals. The rock is rather coarse-grained, K-feldspars are up to 3 cm long. The mylonitic structure is variably developed. Strong mylonitic foliation transitional into L-tectonites dominates towards the hanging wall, i.e. the Polaris Thrust (B). Further down the gneiss partly turns more or less into the granitic protolith. The chemical composition indicates alkali-granite (Fig. 7).

Petrographically, the quartzite mylonites (units (7) and (5)) are pure quartzites, containing few blasts of plagioclase and a small amount of white mica (sericite).

Rock type	Unit	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	(SO_3)	(Cl)	(F)	LOI	Summe
Greenschist	(3)	53.8	0.27	11.7	10.07	0.21	9.93	9.0	2.96	0.4	0.09	<0.01	0.02	0.027	1.2	99.71
Greenschist	(3)	53.2	0.28	12.2	10.17	0.22	10.2	8.4	3.05	0.5	0.09	<0.01	0.02	<0.02	1.5	99.73
Greenschist	(3)	54.6	0.31	13.0	9.79	0.2	9.37	7.2	1.85	1.1	0.10	<0.01	0.01	<0.02	2.1	99.68
Greenschist	(3)	55.6	0.30	13.1	9.28	0.19	8.74	7.3	1.98	1.0	0.09	<0.01	0.02	0.036	2.0	99.70
Granitoid	(2)	64.6	0.37	17.7	4.05	0.1	0.36	2.1	5.77	3.9	0.07	–	–	–	–	99.01
Ortho–gneiss	(4)	75.2	0.15	13.7	1.79	0.02	0.44	0.2	3.92	4.5	0.05	–	–	–	–	99.91
Ortho–gneiss	(4)	77.4	0.15	11.8	1.87	0.01	0.2	0.1	3.70	4.4	0.07	–	–	–	–	99.75
Ortho–gneiss	(4)	72.8	0.31	13.3	3.56	0.05	0.18	0.1	3.90	5.0	0.05	–	–	–	–	99.24
Ortho–gneiss	(4)	76.2	0.11	12.9	1.21	0.01	0.07	0.1	3.61	5.3	0.02	–	–	–	–	99.45
Ortho–gneiss	(4)	72.9	0.22	13.5	3.09	0.07	0.16	0.5	3.90	5.4	0.04	–	–	–	–	99.77

Rock type	Unit	Ba	Bi	Ce	Co	Cr	Cs	Cu	Ga	Hf	La	Mo	Nb	Ni
Greenschist	(3)	179	4	<20	42	610	<5	34	11	<5	<20	24	3	150
Greenschist	(3)	220	5	<20	44	630	<5	39	11	<5	<20	22	4	159
Greenschist	(3)	576	<3	<20	42	359	<5	121	11	<5	<20	25	4	88
Greenschist	(3)	509	<3	<20	50	344	<5	112	13	<5	<20	23	4	84
Granitoid	(2)	5260	–	25	–	<10	–	–	–	–	–14	–	7	<5
Ortho–gneiss	(4)	779	–	25	–	<10	–	–	–	–	–<10	–	11	<5
Ortho–gneiss	(4)	1214	–	35	–	<10	–	–	–	–	15	–	7	<5
Ortho–gneiss	(4)	878	–	161	–	<10	–	–	–	–	96	–	18	<5
Ortho–gneiss	(4)	560	–	77	–	<10	–	–	–	–	40	–	9	<5
Ortho–gneiss	(4)	891	–	89	–	<10	–	–	–	–	63	–	11	<5

Rock type	Unit	Pb	Rb	Sb	Sc	Sn	Sr	Ta	Th	U	V	Y	Zn	Zr
Greenschist	(3)	<4	10	<5	41	<2	139	<5	6	<3	231	8	167	23
Greenschist	(3)	<4	17	<5	44	<2	103	<5	<5	<3	224	8	176	27
Greenschist	(3)	<4	31	<5	43	<2	169	<5	<5	<3	290	7	168	33
Greenschist	(3)	<4	34	9	37	<2	186	<5	5	<3	281	8	161	35
Granitoid	(2)	–	50	–	–	–	430	–	4	–	10	22	–	521
Ortho–gneiss	(4)	–	132	–	–	–	69	–	15	–	5	13	–	136
Ortho–gneiss	(4)	–	93	–	–	–	83	–	13	–	6	14	–	99
Ortho–gneiss	(4)	–	110	–	–	–	68	–	13	–	11	70	–	484
Ortho–gneiss	(4)	–	115	–	–	–	93	–	10	–	<5	60	–	187
Ortho–gneiss	(4)	–	118	–	–	–	87	–	11	–	13	124	–	341

Tab. 1: XRF–data of selected rocks from southern Kirwanveggen.

Tab. 1: RFA–Daten ausgewählter Gesteine Süd–Kirwanveggens.

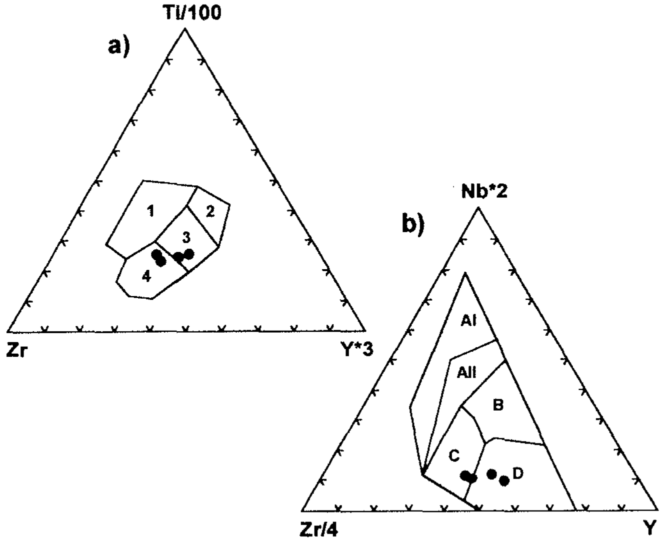

Fig. 8: Positions of amphibole bearing greenschists of the Polaris Formation in: (a) discriminant diagram by PEARCE & CANN (1973), 1 = within-plate basalt; 2+3 = low-potassium tholeiite; 3 = ocean-floor basalt; 3+4 = calc-alcaline-basalt; greenschists of the Polaris Formation (dots): calc-alcaline-basalt.
(b) discriminant diagram by MESCHEDE (1988), AI+AII = within-plate basalts; B = E-type MORB; C = within-plate tholeiite + volcanic arc basalt; D = N-type MORB + volcanic arc basalt; greenschists of the Polaris Formation (dots): volcanic arc basalt.

Abb. 8: Darstellung amphibolführender Grünschiefer der Polaris-Formation im: (a) Diskriminierungsdiagramm nach PEARCE & CANN (1973), 1 = Within-Plate-Basalt, 2+3 = Niedrig-K-Tholeiit, 3 = Ozeanboden-Basalt, 3+4 = Kalkalkali-Basalt; Grünschiefer der Polaris-Formation (Punkte): Kalkalkali-Basalt.
(b) Diskriminierungsdiagramm nach MESCHEDE (1988), AI+AII = Within-Plate-Basalte, B = Mittelozeanischer-Rücken-Basalt (E-Typ), C = Within-Plate-Tholeiit + Vulkanischer-Bogen-Basalt, D = Mittelozeanischer-Rücken-Basalt (N-Typ), + Vulkanischer-Bogen-Basalt; Grünschiefer der Polaris-Formation (Punkte): Vulkanischer-Bogen-Basalt.

The quartzites of the alternation (unit (8)) at Drabanten and Klakknabben are impure quartzites consisting of quartz (~90 %), white mica (~10 %) and accessories (zircon, ore, apatite), whereas the quartz mica schists consist of ~70 % quartz, ~20 % white mica, ~5 % plagioclase, ~5 % chlorite and accessories (zircon, tourmaline, epidote, ore, calcite). Additionally, the schists are strongly quartz-veined (Fig. 9). There is no indication of retrogressive metamorphism. The alternation is rather regular and the alternating layers are mainly some dm up to 1 or 1.25 m thick. In the field, the quartzites appear relatively light, the schists somewhat darker (Fig. 9). The boundaries of the layers are sharp on the one hand, on the other hand transitional. This is especially visible at the north-eastern corner of Drabanten, where, from top to bottom, quartzites show a sharp contact to their hanging wall. They grade into more and more schistose, quartz-veined rocks. This repeats itself several times. Thus, we got the impression, that the layers represent sedimentary bedding showing grading, inverted in the case of north-eastern Drabanten. Dimension and appearance resemble largely metamorphic turbidites from the north-eastern Shackleton Range. There, graded bedding is well preserved, even if the metamorphic degree is a bit stronger (the schists contain garnet and kyanite) (Kleinschmidt et al., in press, a). But though, the similarity is striking!

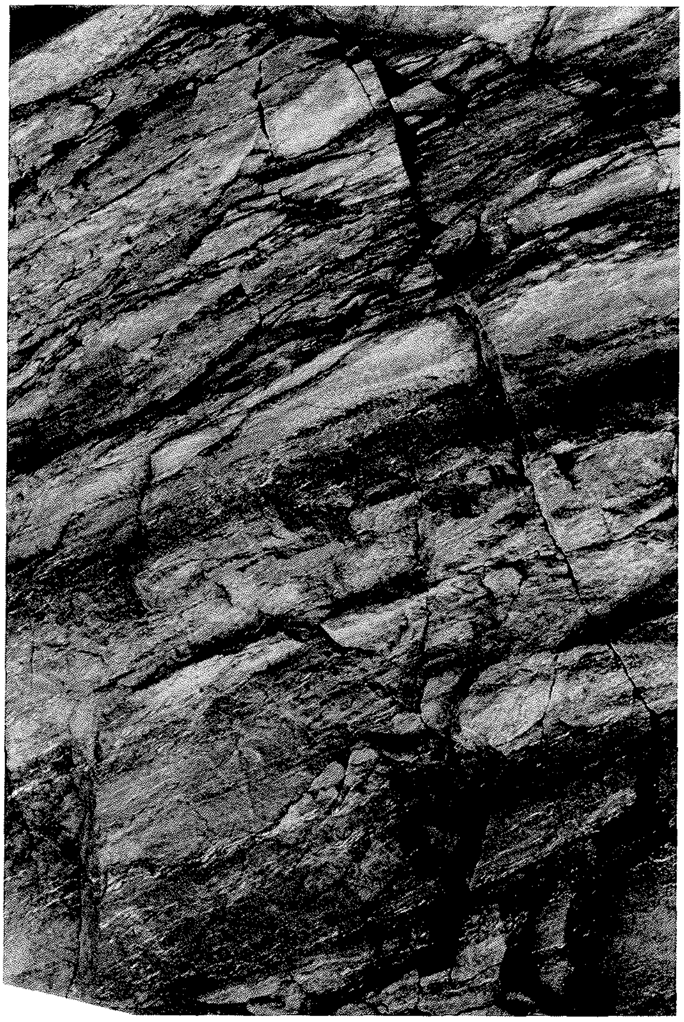

Fig. 9: Probable meta-turbidites from Klakknabben, southern Kirwanveggen: alternation of light, i.e. rather quartzitic, and of darker, i.e. rather micaceous and quartz veined layers. Height of exposure: about 10 m.

Abb. 9: Wechsellagerung von hellen, quarzitischen und dunkleren, glimmerreichen, von Quarzgängen durchzogenen Lagen: vermutlicher Metaturbidit, Klakknabben, Südkirwanveggen. Lange Bildkante ca. 10 m.

The sediments of the Urfjell Group (unit (9)) are mainly sandstones to (sedimentary) quartzites, and less common conglomerates. The psammites consist mainly of quartz grains plus some plagioclase, K-feldspar, detrital white mica, sericite, garnet and other heavy minerals. In layers, the sediments are extremely immature: feldspar is a main constituent, the components are angular, poorly sorted, especially reddish parts contain detrital mica. Lenses of mudstone up to 20 cm long and 7 cm thick occur at Urnosa. In contrast, the pebbles of the conglomerates are well rounded. They vary in diameter between 0.5 and 12 cm with a mean around 2-3 cm. In the order of decreasing abundance, they are made up of vein-quartz, quartzite (inclusive chert?), jasper, basement rocks (mainly augen-gneiss) and shale. Cross-bedding is very common in both the sandstones and the conglomerates and indicates a current direction mainly from NW (Croaker & Whitmore 1998), but as well from SE, provided by a braided-river system (Croaker 1999). The NE Urfjell rocks are grey to yellowish, in parts red to reddish. In particular, the reddish types from Dråpane are similar to the main rocks of the Blaiklock Glacier Group of the Shackleton Range mentioned above.

AGES

The age of the granitoid (unit (2)) is very ambiguous: its undeformed, possibly magmatic biotites yielded a K-Ar cooling-age of 585 ±5 Ma (Tab. 2). This age seems to be related to the metamorphism of the rocks (garnet growth). Pb-Pb age determinations on single zircons using the single grain evaporation technique (Kober 1986) yield ages between 1058 ±18 Ma and 1073 ±35 Ma (Tab. 2). Preliminary results from conventional U-Pb datings on zircons, carried out at the University of Cape Town, yield an almost concordant age of 1085 ±4 Ma and therefore substantiate the Pb-Pb ages from the same locality. Thus, the rock seems to be formed at about 1 to 1.1 Ga (Grenvillian), and overprinted prior to 585 Ma.

The ages of the prograde amphibole bearing greenschists of the Polaris Formation (unit (3)) are of special interest and problematic nature. Up to now, we have the following results: (i) K-Ar ages of amphiboles: 864 ±15 Ma and 993 ±17 Ma (Tab. 2); (ii) Ar-Ar ages of amphiboles: 876 ±7 Ma and 1058 ±7 Ma.

As these ages have to be regarded as cooling ages, we can at least make the point, that the age of metamorphism of the greenschists (and of course their protolith's age) is older than about 1 Ga. Very similar ages are known from the Heimefrontfjella (886 ±19 and 976 ±21 Ma, Jacobs et al. 1996), which are interpreted as Grenvillian cooling ages without any Pan-African influence. But these ages are K-Ar muscovite cooling ages and those should not be compared with our amphibole ages.

Sample	Fraction	K (wt.-%)	rad. Ar (nl/g STP)	rad. Ar (%)	Age (Ma)
Amphiboles from greenschists of the Polaris Formation (unit (3))					
9/1/1	125-63 µm	0.171	8.69	93.6	986 ±16
10/1/3	125-63 µm	0.204	8.76	93.6	862 ±14
Biotites from the granitoid (unit (2))					
8/1/31	125-63 µm	6.074	162.27	99.2	582 ±6
Detrital muscovites from the Urfjell Group (unit (9))					
SH 1A	500-200 µm	7.99	205.2	99.4	563 ±5
SH 1B	500-200 µm	8.42	218.4	99.7	568 ±5
SH 2A	500-200 µm	8.49	225.7	99.4	580 ±5
SH 2B	500-200 µm	8.42	225.0	99.6	583 ±6
SH 3A	500-200 µm	8.41	219.9	99.3	572 ±5
SH 3B	500-200 µm	8.02	209.5	99.6	571 ±5
Sericites from the Urfjell Group (unit (9))					
MC 1	2-0.6 µm	7.249	150.45	97.8	468 ±5
MC 1	0.6-0.2 µm	7.615	151.15	97.5	450 ±5
3/1/1	2-0.6 µm	7.031	143.30	96.3	460 ±5
3/1/1	0.6-0.2 µm	7.264	149.05	96.9	463 ±5
31/12/2	2-0.6 µm	6.458	130.15	91.4	456 ±5

Sample	Grain	No. of ratios	$^{207}Pb/^{206}Pb \pm 2\sigma$	$^{206}Pb/^{208}Pb$	Age (Ma)*
Zircons from the granitoid (unit (2))					
Z 2-2	a	120	0.08215 ±0.00153	3658	1073 ±35
Z 5-2	b	280	0.09451 ±0.00540	7740	1058 ±18

Tab. 2: Relevant data of age determinations in southern Kirwanveggen. * Correction for common lead based on STACY & KRAMERS (1975).

Tab. 2: Daten zur Altersbestimmung im südlichen Kirwanveggen. * Korrektur für gewöhnliches Blei basiert auf STACY & KRAMERS (1975).

CROAKER (1999) determined an ^{40}Ar - ^{39}Ar muscovite age of 549 ±5 Ma from the quartzite mylonite at Gavlpiggen (unit (7)). It is interpreted as cooling age of the mica formed during mylonitisation.

There is a number of ages known from the Urfjell Group (unit (9)). CROAKER (1999) figured out several zircon populations, and his SHRIMP ages yielded peaks at 1050 Ma and 650 Ma; the youngest age came to 554 ±21 Ma. MOYES et al. (1997) produced an Rb-Sr WR age of 531 ±25 from Kuven. We got K-Ar ages of 563 ±5 Ma to 583 ±6 Ma for detrital muscovites from Utrinden and Tunga and K-Ar ages of 450 ±5 Ma to 468 ±5 Ma for newly formed sericite (Ø = 0.2-2 mm) from the same localities (Tab. 2).

An overall consistent interpretation of all of these ages would be: The source rocks of the zircons have a wide range of ages, i.e. they suffered a wide range of events, the youngest of which was 554 Ma ago. Thus, the sedimentation of the Urfjell Group is younger than 554 Ma. The ages of the detrital muscovites indicate a cooling of the source rocks about 560 to 580 Ma ago, and the ages of the sericites mean that the diagenesis of the Urfjell Group happened around 450 to 470 Ma ago.

DISCUSSION AND ATTEMPT AT INTERPRETATION

In summary, southern Kirwanveggen shows several geological characteristics:

- There are 1 to 1.1 Ga old (i.e. Grenvillian) alkali-granitic migmatites (A-types?), probably overprinted during the Pan-African cycle.
- There is evidence for an island arc volcanism (Polaris Formation) older than 1 Ga, weakly progessively metamorphosed earlier than 1 Ga.

- There are at least four thrust zones, showing an age of approx. 550 Ma, where dated.
- There are molasse-type sediments (Urfjell Group) with approx. 450 Ma minimum and approx. 540 Ma maximum ages, indicating a paleocurrent direction mainly from NE to SW, but secondarily as well from SE to NW.
- And there is a metamorphosed turbidite-like sequence of unknown sedimentary and metamorphic age. Unfortunately, the striking similarity with Pan-African related metamophic turbidites from north-eastern Shackleton Range does not justify any correlation.

All that is located at the very south-eastern margin of the remains of the Grenvillian orogen (Maud Belt). This part of the Maud Belt belongs to those places which show a Pan-African overprint. Though the Pan-African overprint in southern Kirwanveggen seems to be more intense and geometrically different. Possible Pan-African thrusting is directed towards NW in the Heimefrontfjella (FIELITZ & SPAETH 1991, JACOBS et al. 1996), towards NW in H.U. Sverdrufjella (GRANTHAM et al. 1995, GROENEWALD et al. 1995) and towards NW in northern Kirwanveggen (WOLMARANS & KENT 1982). The thrust directions of southern Kirwanveggen turn from about 40° in the South to about 0° in the North (Fig. 3). Additionally, southern Kirwanveggan shows the possibly Pan-African related molasse of the Urfjell Group.

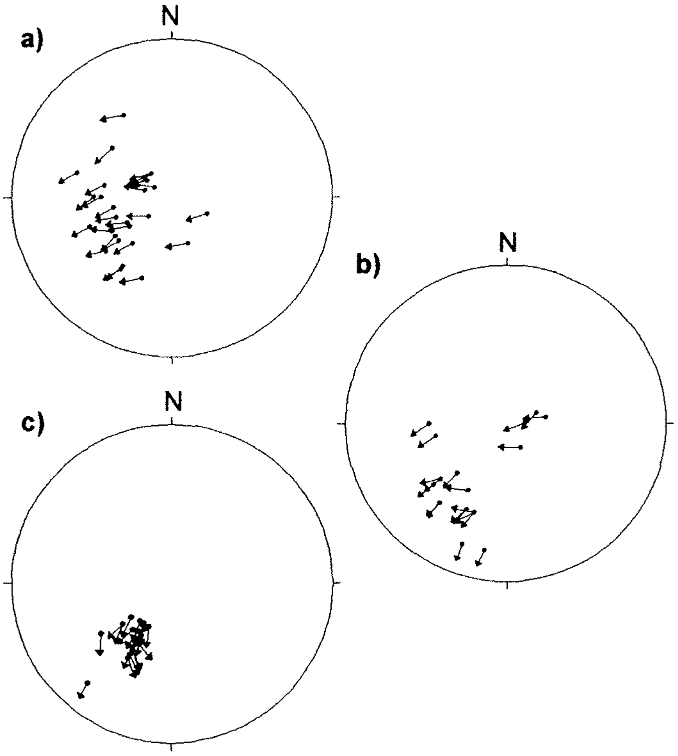

Fig. 10: „Hoeppener diagrams" (HOEPPENER 1955) showing variation of thrust directions in the Shackleton Range: (a) northern Shackleton Range, (b) central Shackleton Range (c) southern Shackleton Range (after KLEINSCHMIDT et al. 1999b).

Abb. 10: Hoeppener-Diagramme (HOEPPENER 1955) der Überschiebungsrichtungen in der Shackleton Range. (a) = nördliche Shackleton Range, (b) zentrale Shackleton Range (c) südliche Shackleton Range (nach KLEINSCHMIDT et al. 1999b).

The Pan-African thrusting in the Shackleton Range also varies systematically (KLEINSCHMIDT et al. in press, b; Fig. 10). Westward directed tectonic transport dominates in the northern Shackleton Range, SW directed in the central part and southward directed in the southern Shackleton Range. This systematic variation of thrust directions in the Shackleton Range is interpreted as product of sinistral transpression. Furthermore, an ophiolitic complex occurs in the Shackleton Range. Its protoliths - oceanic crust - are post-Grenvillian, its deformation and metamorphism is Pan-African (TALARICO et al. 1999).Thus the Shackleton Range is part of a Pan-African orogen due to a transpressional regime and following a suture. The Pan-African orogen is running from the Shackleton Range towards east to north-east and is interpreted to form a part of the suture between West and East Gondwana, the ophiolite may be the southern continuation of the Moçambique Ocean (TESSENSOHN et al. 1999).

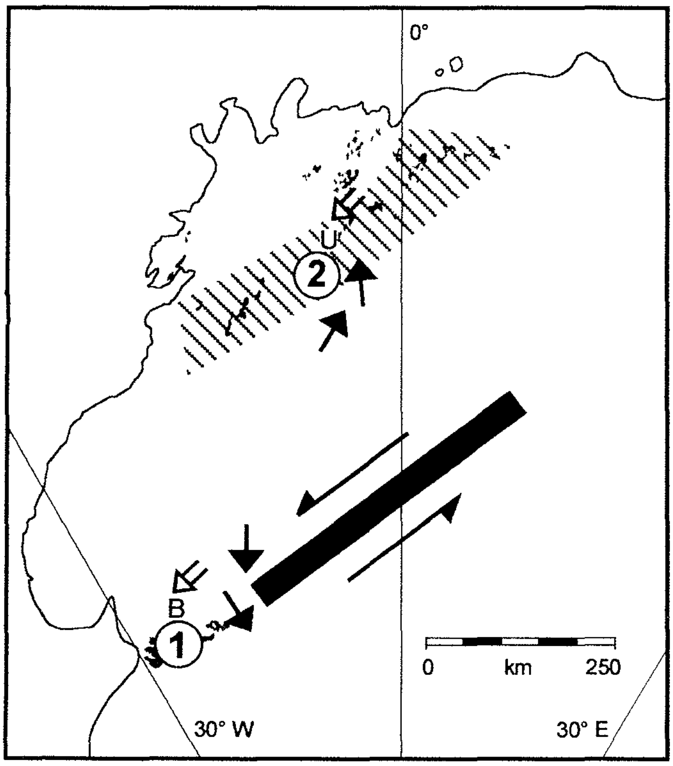

Fig. 11: Schematic orientation of the Pan-African orogen in Antarctica (black). Hatched = Grenvillian belt, (1) = Shackleton Range, (2) = southern Kirwanveggen; long arrows = transpressional regime, short arrows = tectonic transport directions; U, B = molasses: U = Urfjell Group, B = Blaicklock Glacier Group, double arrows = main current directions.

Abb. 11: Schematische Lage des Panafrikanischen Orogens in der Antarktis (schwarzer Streifen). Schraffiert = Grenvillischer Gürtel, (1) = Shackleton Range, (2) = Kirwanveggen Süd, Halbpfeile = Transpressionsregime, Kurzpfeile = Tektonischer Transport, U, B = Molasse: U = Urfjell-Gruppe, B = Blaicklock-Glacier-Gruppe, Doppelpfeile = Hauptschüttungsrichtung,

This Pan-African orogen (and the West-East Gondwana suture) has to pass southern Kirwanveggen at the south to south-east (Fig. 11). This is indicated by the Pan-African effects described, especially by the thrust systems (A-D) and their systematic variation, showing a symmetrical arrangement compared to the Shackleton Range and indicating the same sinistral tranpressional regime. Therefore, the Antarctic Pan-African orogen (and the suture between West-East Gondwana) forms a belt: Shackleton Range - south(east) of Kirwanveggen - easternmost DML, pointing to the areas of Sør Rondane or Lützow-Holmbukta or anywhere in between (Fig. 12). This idea contradicts the reconstruction of the West-East Gondwana boundary in Antarctica in western DML (Shackleton 1996), it matches to some extent a position in central DML (Jacobs et al. 1998), it goes well with the assumptions by Moyes et al. (1993) of eastern Dronning Maud Land or by Grunow et al. (1996), who draw a line directly from the Shackleton Range to the Lützow-Holmbukta based on the results of Shiraishi et al. (1994).

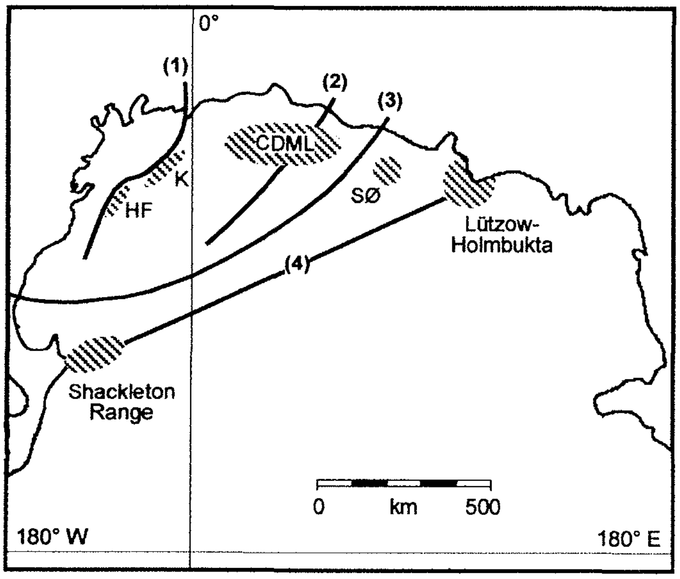

Fig. 12: The West/East Gondwana suture (Pan-African orogen) in Antarctica: (1) according to Shackleton (1996); (2) according to Jacobs et al. (1998); (3) according to Moyes et al. (1993); (4) according to Grunow et al. (1996) and Shiraishi et al. (1994); (3)+(4) this paper.
K = Kirwanveggen, HF = Heimefrontfjella, CDML = central Dronning Maud Land, SØ = Sør Rondane.

Abb. 12: Die West/Ost-Gondwana-Sutur (Panafrikanisches Orogen) in der Antarktis: (1) nach Shackleton (1996), (2) nach Jacobs et al. (1998), (3) nach Moyes et al. 1993, (4) nach Grunow etal. (1996), und Shiraishi et al (1994), (3) + (4) this paper.
K = Kirwanveggen, HF = Heimefrontfjella, CDML = zentrales Dronning Maud Land, SØ = Sør Rondane.

The position of the Pan-African belt close to southern Kirwanveggen and the NE-SW trend of the orogen are supported by the molasse sediments of the Urfjell Group and its current directions (NE-SW, locally SE-NW). As demonstrated in the classical example of the Alps (e.g. Lembke et al 1953, Lembke 1988), molasses show main current directions parallel to the related orogenic belt, but sometimes as alluvial fans transversely. As well, the Pan-African connection Shackleton Range/region south-east of southern Kirwanveggen and its SW-NE trend is supported by the similarity of the Urfjell Group and its current directions to the Ordovician Blaicklock Glacier Group and the current directions mainly of its upper section (NE-SW, e.g. Buggisch et al. 1999).

Our rather speculative model up to now is based mainly on field observations and on first age determinations and a few geochemical analyses. In further substantiation, mainly more geochronological data are required, especially of the Polaris Thrust and of the Polaris Formation. They are in progress.

ACKNOWLEDGMENTS

We are indebted to the following persons and institutions: the South African National Antarctic Program (SANAP) for the invitation to join the South African Earth Sciences Expedition to western Dronning Maud Land 1997/1998; Jan Hattingh and the entire DEA & T (Kaapstad) for logistic support; Warren Johnstone for discussions and for guidance in the field; Kent Larsson for a lot of discussions during the whole expedition, guidance and company in the Polaris Ridge area and for hospitality in his cosy container during a heavy blizzard; the wonderful new station SANAE-IV, its leaders and crew for hospitality; the 22 Eskader for flying us and for cordial hospitality at Grunehogna Station; the Alfred Wegener Institute (Bremerhaven) for logistic support and for transport of equipment and samples; the Neumayer-Station for communication and weather forecasts; the Bundesanstalt für Geowissenschaften und Rohstoffe (Hannover) for various equipment; W. Todt, MPI Mainz, for assistance during Pb-Pb dating; Joachim Jacobs and an anonymus for helpful reviews; and last but not least: the Deutsche Forschungsgemeinschaft (DFG) for financial support (AZ: Kl 429/16-1).

References

Ahlberg, P., Bylund, G. & Larsson, K. (1992): Geological fieldwork in the Kirwanveggen area.- In: O. MELANDER & M. LÖNNROTH CARLSSON (eds.), Swedish Antarctic Research Programme 1991/92 - A cruise report, 13-21, Stockholm.

Aucamp, A.P.H., Wolmerans, G. & Neethling, D.C. (1972): The Urfjell Group, a deformed (?) early Palaeozoic sedimentary sequence, Kirwanveggen, western Dronning Maud Land.- In: R.J. ADIE (ed.), Antarctic Geology and Geophysics, 557-562, Universitetsforlaget, Oslo.

Buggisch, W., Bachtadse, V. & Henjes-Kunst, F. (1999): Lithostratigraphy, facies, geochronology, and palaeomagnetic data of the Blaiklock Glacier Group, Shackleton Range, Antarctica.- Terra Antartica 6: 229-239.

Cann, J.R. (1970): Rb, Sr, Y, Zr and Nb in some ocean floor basaltic rocks.- Earth Planet. Sci. Lett. 10: 7-11.

Corner, B. (1994): Geological evolution of western Dronning Maud Land within a Gondwana framework: geophysics subprogramme.- Final Report to SACAR, 21 pp.

Croaker, M.R.D. (1999): Geological constraints on the evolution of the Urfjell Group, Southern Kirwanveggen, Western Dronning Maud Land, Antarctica.- Unpubl. Master Thesis, School of Geological and Computer Sciences, University of Natal, Durban, RSA, 188 pp.

Croaker, M.R.D. & Whitmore, G.P. (1998): Sedimentology of the Urfjell Group, western Dronning Maud Land Antarctica.- J. African Earth Sci., Addendum to Vol. 27 (1A): 2.

De la Roche, H., Letterier, J., Gandclaude, P. & Marchall, M. (1980): A classification of volcanic and plutonic rocks using R_1R_2-diagramm and major-element analyses – its relationships with current nomenclature.- Chem. Geol. 29: 183-210.

Fielitz, W. & Spaeth, G. (1991): A structural survey of Precambrian rocks, Heimefronfjella, western Neuschwabenland, with special reference to the basic dykes.- In: M.R.A. THOMSON, J.A. CRAME & J.W. THOMSON (eds.), Geological Evolution of Antarctica, 67-72, Cambridge Univ. Pr., Cambridge.

Golynsky, A.V. & Aleshkova, N.D. (2000): Regional magnetic anomalies of the Weddell Sea region.- Polarforschung 68.

Grantham, G.H. & Hunter, D.R (1991): The timing and nature of faulting and jointing ajacent to the Pencksökket, western Dronning Maud Land, Antarctica.- In: M.R.A. THOMSON, J.A. CRAME & J.W. THOMSON (eds.), Geological Evolution of Antarctica, 47-51, Cambridge Univ. Pr., Cambridge.

Grantham, G.H., Jackson, C., Moyes, A.B., Groenewald, P.B., Harris, P.D. Ferrar, G. & Krynauw, J.R. (1995): The tectonothermal evolution of the Kirwanveggen-H.U. Sverdurpfjella areas, Dronning Maud Land, Antarctica.- Precambrian Res. 75: 209-229.

Groenewald, P.B., Moyes, A.B., Grantham, G.H. & Krynauw, J.R. (1995): East Antarctic crustal evolution: geological constraints and modelling in western Dronning Maud Land.- Precambrian Res. 75: 231-250.

Grunow, A., Hanson, R. & Wilson, T. (1996): Were aspects of Pan-African deformation linked to the Iapetus opening?- Geology 24: 1063-1066.

Harris, C., Marsh, J.S., Duncan, A.R. & Erlank, A.J. (1990): The petrogenesis of the Kirwan Basalts of Dronning Maud Land, Antarctica.- J. Petrology 31: 341-369.

Hoeppener, R. (1955): Tektonik im Schiefergebirge.- Geol. Rdsch. 44: 26-58.

Jacobs, J., Bauer, W., Spaeth, G., Thomas, R.J. & Weber, K. (1996): Lithology and structure of the Grenville-aged (~1.1 Ga) basement of Heimefrontfjella (East Antarctica).- Geol. Rdsch. 85: 800-821.

Jacobs, J., Fanning, C.M., Henjes-Kunst, F., Olesch, M. & Paech, H.-J. (1998): Continuation of the Mozambique Belt into East Antarctica: Grenville-age metamorphism and polyphase Pan-African high-grade events in Central Dronning Maud Land.- J. Geology 106: 385-406.

Jacobs, J., Hansen, B.T., Henjes-Kunst, F., Thomas, R.J., Weber, K., Bauer, W., Armstrong, R.A. & Cornell, D.H. (1999): New age constraints on the Proterozoic/Lower Palaeozoic evolution of Heimefrontfjella, East Antarctica, and its bearing on Rodinia/Gondwana correlations.- Terra Antartica 6: 377-389.

Jacobs, J. & Lisker, F. (1999): Post Permian tectono-thermal evolution of western Dronning Maud Land, East Antarctica: an apatite fission-track approach.- Antarctic Sci. 11: 451-460.

Kleinschmidt, G., Tessensohn, F. & Henjes-Kunst, F. (in press, a): Nappetectonics in the central Shackleton Range, Antarctica.- Z. dt. Geol. Ges.

Kleinschmidt, G., Buggisch, W., Läufer, A.L., Helferich, S. & Tessensohn, F. (in press, b): The "Ross orogenic" structures in the Shackleton Range and their meaning for Antarctica.- In: J. GAMBLE, D.N.B. SKINNER & S. HENRYS (Eds.), Antarctica at the Close of a Millennium, Proc. 8th ISAES Wellington NZ, Royal Soc. NZ, Wellington.

Kober, B. (1986): Whole-grain evaporation for $^{207}\text{Pb}/^{206}\text{Pb}$-age-investigations on single zircons using a double-filament thermal ion source.- Contr. Miner. Petrol. 93: 482-490.

Leake, B.E. (1978): Nomenclature of amphiboles.- Miner. Mag. 42: 533-563.

Lembke, K. (1988): Geologie von Bayern I. Das bayrische Voralpenland vor der Eiszeit.- 175 S., Stuttgart (Schweizerbart).

Lembke, K., Engelhardt, W.v. & Füchtbauer, H. (1953): Geologische und sedimentologische Untersuchungen im Westteil der ungefalteten Molasse des süddeutschen Alpenvorlandes.- Beih. Geol. Jb. 11: 110 S.

Meschede, M. (1986): A method of discriminating between different types of mid-ocean-ridge basalts and continental tholeiites with the Nb-Zr-Y diagram.- Chem. Geol. 56: 207-218.

Moyes, A.B., Barton, J.M. & Groenewald, P.B. (1993): Late Proterozoic to Early Paleozoic tectonism in Dronning Maud Land, Antarctica: supercontinental fragmentation and amalgamation.- J. Geol. Soc. London 150: 833-842.

Moyes, A.B., Knoper. M.W. & Harris, P.D. (1997): The age and significance of the Urfjell Group, western Dronning Maud Land.- In: C.A. RICCI (Ed.), The Antarctic Region: Geological Evolution and Progress, 31-36, Terra Antartica Publ., Siena.

Ohta, Y. (Ed.) (1996): Nature enviroment map, H.U. Sverdrupfjella 1:150 000.- Norsk Polarinstitutt Temakart Nr. 18.

Paech, H., Laiba, A.A., Shulyatin, O.G., Aleksashin, N.D. & Traube, V.V. (1991): Contribution to the geology of western Dronning Maud Land: Present knowledge, latest results and unsolved problems.- Z. Geol. Wiss. 19: 127-143.

Pearce, J.A. & Cann, J.R. (1973): Tectonic setting of basic volcanic rocks determined using trace element analyses.- Earth Planet. Sci. Lett. 19: 290-300.

Roots, E.F. (1969): Geology of Queen Maud Land.- In: V.C. BUSHNELL & C. CRADDOCK (eds.), Geologic Maps of Antarctica.- Antarctic Map Folio Series, folio 12, plate VI, Amer. Geogr. Soc., New York.

Shackleton, R.M. (1996): The final collision zone between East and West Gondwana: where is it?- J. African Earth Sci. 23: 271-287.

Shiraishi, K., Ellis, D.J., Hiroi, Y., Fanning, C.M., Motoyoshi, Y. & Nakai, Y. (1994): Cambrian orogenic belt in East Antarctica and Sri Lanka: implications for Gondwana assembly.- J. Geology 102: 47-65.

Stacy, J.S. & Kramers, J.D. (1975): Approximation of terrestrial lead isotope evolution by a two-stage model.- Earth Planet. Sci. Lett. 26: 207-221.

Talarico, F., Henjes-Kunst, F. & Kleinschmidt, G. (1999): An ophiolitic complex in the northern Shackleton Range, Antarctica.- Terra Antartica 6: 293-315.

Tessensohn, F., Kleinschmidt, G., Talarico, F., Buggisch, W., Brommer, A., Henjes-Kunst, F., Kroner, U., Millar, I.L. & Zeh, A. (1999): Ross-age amalgamation of East and West Gondwana: Evidence from the Shackleton Range, East Antarctica.- Terra Antartica 6: 317-325.

Wolmarans, L.G. & Kent, L.E. (1982): Geological investigations in Western Dronning Maud Land, Antarctica – a synthesis.- South African J. Ant. Res., Supplement 2: 1-93, 3 geol. maps 1:250 000.