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Stratigraphy and Facies of Sediments and Low-Grade Metasediments in the Shackleton Range, Antarctica

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Summary: The stratigraphy of the Shackleton Range established by STEPHENSON (1966) and CLARKSON (1972) was revised by results of the German Expedition GEISHA 1987/88. The „Turnpike Bluff Group" does not form a stratigraphic unit. The stratigraphic correlation of its formations is still a matter of discussion. The following four formations are presumed to belong to different units: The Stephenson Bastion Formation and Wyeth Heights Formation are probably of Late Precambrian age. The Late Precambrian Watts Needle Formation, which lies unconformably on the Read Group, is an independant unit which has to be separated from the „Turnpike Bluff Group". The Mount Wegener Formation has been thrusted over the Watts Needle Formation. Early Cambrian fossils *(Oldhamia sp., Epiphyton sp., Botomaella (?) sp.* and echinoderms) were found in the Mt. Wegener Formation in the Read Mountains.

The Middle Cambrian trilobite shales on Mount Provender, which form the Haskard Highlands Formation, are possibly in faulted contact with the basement complex (Pioneers and Stratton Groups). They are overlain by the Blaiklock Glacier Group, for which an Ordovician age is indicated by trilobite tracks and trails, low inclination of the paleomagnetic field and the similarity to the basal units of the Table Mountain Quartzite in South Africa.

The Watts Needle Formation represents epicontinental shelf sediments, the Mount Wegener Formation was deposited in a (continental) back-arc environment, and the Blaiklock Glacier Group is a typical molasse sediment of the Ross Orogen.

Zusammenfassung: Die Stratigraphie der Shackleton Range, die von STEPHENSON (1966) und CLARKSON (1972) aufgestellt worden war, konnte durch Ergebnisse der deutschen Expedition „GEISHA" 1987/88 revidiert werden. Die „Turnpike Bluff Gruppe" bildet keine stratigraphische Einheit, die Korrelation ihrer Formationen bleibt unklar. Wahrscheinlich gehören ihre vier Formationen zu verschiedenen Einheiten: Die Stephenson-Bastion- und Wyeth-Heights-Formationen sind wahrscheinlich präkambrisch. Die spätpräkambrische Watts-Needle-Formation ist als selbstständige Einheit völlig abzutrennen; sie liegt diskordant der Read-Gruppe auf. Ihr Hangendes bildet, getrennt durch eine Überschiebung, die Mount-Wegener-Formation. Unterkambrische Fossilien *(Oldhamia sp., Epiphyton sp., Botomaella(?) sp.* und Echinodermen) wurden in der Mount-Wegener-Formation in den Read-Mountains gefunden.

Mittelkambrische Trilobitenschiefer der Haskard-Highlands-Formation liegen am Mount-Provender vermutlich mit gestörtem Kontakt auf dem Basement Komplex auf. Sie werden von der Blaiklock-Glacier-Gruppe überlagert. Ein ordovizisches Alter dieser Gruppe ist aufgrund von Trilobitenspuren, geringer Inklination des paläomagnetischen Feldes und der Ähnlichkeit zu basalen Einheiten der Tafelberg-Gruppe in Südafrika wahrscheinlich.

Faziell repräsentiert die Watts-Needle-Formation eine epikontinentale Schelfsedimentation; die Mount-Wegener-Formation dürfte in einem intrakontinentalen Back-arc-basin abgelagert worden sein, während die Blaiklock-Glacier-Gruppe ein typisches Molassesediment des Ross-Orogens darstellt.

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1. INTRODUCTION

The Shackleton Range is located east of the Filchner Ice Shelf at the margin of the East Antarctic Shield, continuing the morphological trend of the Transantarctic Mountains towards the Weddell Sea (Fig. 1). It comprises Precambrian igneous and metamorphic basement rocks overlain by Late Precambrian sediments, very low-grade to low-grade metamorphic Early Phanerozoic slates and phyllites, Middle Cambrian trilobite shales and post-orogenic Phanerozoic red beds. The basic stratigraphy of the rocks of the Shackleton Range was established by STEPHENSON (1966), CLARKSON (1972, 1982a, 1983) and CLARKSON &WYETH (1983). Besides these British authors, geologists from the Soviet Union and East Germany earned recognition for their papers on the Shackleton Range. The present state of knowledge is summarized in Fig. 2a.

According to the results of structural work (BUGGISCH et al. this vol.), the Shackleton Range is composed of three different tectono-stratigraphic units (Fig. 3):

(i) the East Antarctic craton, consisting of igneous and metamorphic rocks of the Read Group and its autochthonous Late Precambrian sedimentary cover (Watts Needle Formation);
(ii) the allochthonous nappe unit formed of metasediments of the former Turnpike Bluff Group (i.e. Stephenson Bastion Formation, Wyeth Heights Formation, and Mount Wegener Formation);
(iii) the northern belt, consisting of basement rocks of the Pioneers Group and Stratton Group and their autochthonous sedimentary cover of the Ordovician(?) Blaiklock Glacier Group. The nature of the Middle Cambrian trilobite shales at Mount Provender (Haskard Highlands Formation) within this belt is still unclear (autochthonous, erratic, or allochthonous?).

Therefore, the stratigraphy of the metasediments of the Shackleton Range will be dealt with in this paper in the order of their tectono-stratigraphic position (Fig. 2b). This paper is based on field work carried out by W. Buggisch and G. Kleinschmidt during the German GEISHA Expedition in the Shackleton Range during the austral summer of 1987/88. The sedimentary petrography is discussed by W. Buggisch, the palaeomagnetic investigations by J. Pohl, K/Ar analyses by H. Kreuzer, and Rb/Sr analyses by A. Höhndorf. The paper focusses on the stratigraphy and facies of the unmetamorphosed to low-grade metamorphic sedimentary cover.

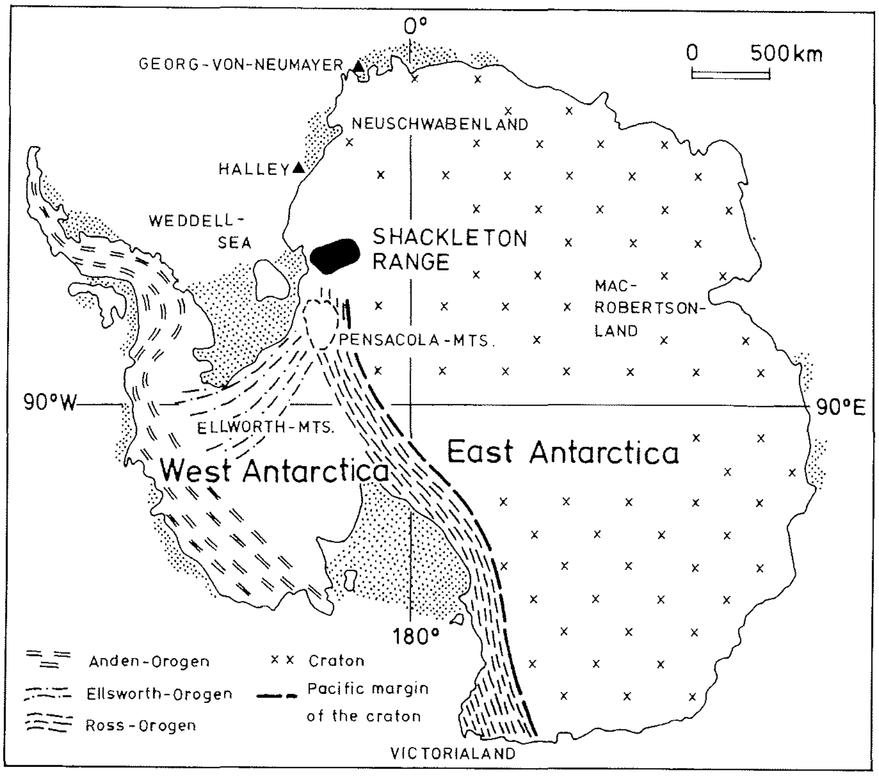


Fig. 1: Location map of the Shackleton Range, Antarctica (after KLEINSCHMIDT 1989).

Abb. 1: Die Lage der Shackleton Range in der Antarktis (nach KLEINSCHMIDT 1989).

	CLARKSON 1972-1983		MARSH 1983	PAECH 1986
PERMIAN				Blaiklock Group
ORDOVICIAN			Blaiklock Glacier Group	
CAMBRIAN	Blaiklock Glacier Group	Otter Highland Fm. intermediate strata Mt. Provender Fm.	Turnpike Bluff Group	pelites and siltstones
LATE PRECAMBRIAN	Turnpike Bluff Group	Wyeth Heights Fm. Stephenson Bastion Flett Crags Fm. Mt. Wegener Fm.	Watts Needle Fm.	Turnpike Bluff Group
PRECAMBRIAN	Shackleton Range Metamorphic Complex		Basement Complex	Basement Complex

Fig. 2a: Stratigraphy of the Shackleton Range according to data from the literature.

Abb. 2a: Die Stratigraphie der Shackleton Range nach den bisherigen Literaturangaben.

Reference is made to methods (e.g. K/Ar), maps (e.g. the Read Mountains) and results described in other papers in this volume, (e.g. BUGGISCH et al. 1994, KLEINSCHMIDT & BUGGISCH 1994).

2. THE SHACKLETON RANGE METAMORPHIC COMPLEX

The Precambrian „Shackleton Range Metamorphic Complex“ (CLARKSON 1982a) can be divided into the Read Group in the southeast and into the Pioneers and Stratton Groups in the north (Fig. 4).

The Read Group falls in the early part of the Late Precambrian. No younger dates were obtained from the metamorphic basement of the Read Mountains. The basement rocks are unconformably overlain by Late Precambrian sediments of the Watts Needle Formation.
In contrast, the Precambrian basement of the Pioneers and Stratton Groups was strongly affected and rejuvenated during the Ross Orogeny. It is unconformably overlain by red beds belonging to the Ordovician Blaiklock Glacier Group. The Pioneer and Stratton Groups differ from the Read Group in their metamorphic history and plate tectonic setting (BUGGISCH et al. 1994, KLEINSCHMIDT & BUGGISCH 1994).

	South		North	new evidence from
JURASSIC	tuffaceous pelites and arenites			K-Ar
ORDOVICIAN		deformation	Blaiklock Glacier Group	Palaeomagnetism trace fossils
CAMBRIAN UPPER				K-Ar
CAMBRIAN MIDDLE			Haskard Highlands Fm.	
CAMBRIAN LOWER		Mt. Wegener Formation	?	Rb-Sr K-Ar
LATE PRECAMBRIAN	Watts Needle Formation	Stephenson Bastion + Wyeth Heights Formations		K-Ar and Rb-Sr
PRECAMBRIAN	Read Group		Stratton and Pioneers Groups	

Fig. 2b: Revised stratigraphy of the Shackleton Range.

Abb. 2b: Revidierte Stratigraphie der Shackleton Range.

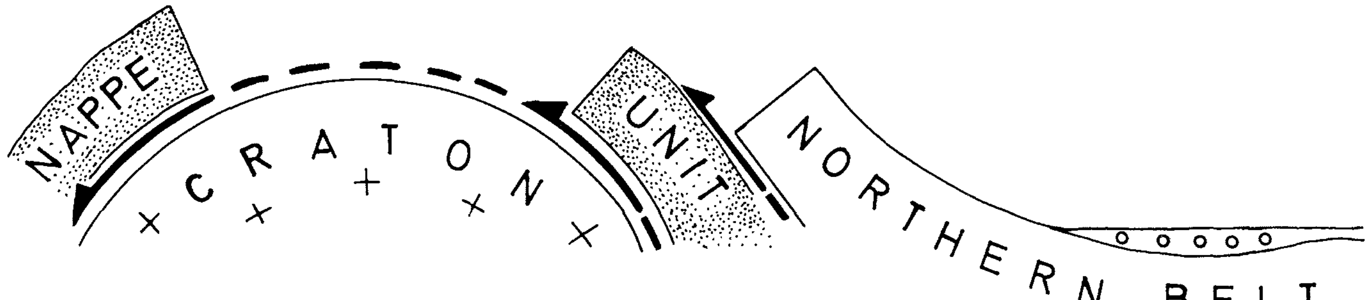


Fig. 3: The structure of the Shackleton Range.

Abb. 3: Das tektonische Bauprinzip der Shackleton Range.

3. AUTOCHTHONOUS SEDIMENTS ON THE EAST-ANTARCTIC CRATON: THE WATTS NEEDLE FORMATION

The Watts Needle Formation was first described as the basal unit of the Mount Wegener Formation („Turnpike Bluff Group") by Clarkson (1972, 1982b) and later formally established as a separate formation by Marsh (1983a). Nevertheless, most authors regarded the Watts Needle Formation as the lower part of the „Turnpike Bluff Group". In agreement with Grikurov & Dibner (1979) and Marsh (1983a), we can demonstrate that the Watts Needle Formation is an independent formation, tectonically and paleogeographically distinct from the Mount Wegener Formation (see also Buggisch et al.).

The Watts Needle Formation is exposed in only five isolated outcrops: in the Du Toit Nunataks (Marsh 1983a), at Watts Needle, Werner Höhe (east of Watts Needle), Nicol Crags, and Mont. Wegener (NW and N slopes). The last four exposures were examined during the GEISHA Expedition (Fig. 5). As a result, the Watts Needle Formation was divided into three members: from bottom to top, the „Sandstone Member", the „Carbonate Member" and the „Shale Member" (Fig. 6).

3.1 *The Sandstone Member*

The Sandstone Member of the Watts Needle Formation rests unconformably on the deeply weathered and peneplained Read Group (Clarkson 1982a, Paech 1982, Marsh 1983a). Intense Late Precambrian chemical weathering led to oxidation of biotite, decomposition of feldspar, new growth of illite, kaolinite and iron oxides in the top the crystalline basement rocks and resulted in the formation of grus and soil. The surface of unconformity is exposed at Nicol Crags (Fig. 7). It has a relief of a few meters, the hollow apparently filled with continental redbed deposits: red mudstones and siltstones and red (and green) sandstones and conglomerates. Broken quartz grains typical of those found in soils demonstrate a terrestrial environment (Fig. 8). The components of the basal sandstones are derived from the underlying weathered crystalline basement. In the field, the sandstones have the appearance of arkoses; but quantitative analyses of thin sections (Fig. 9) show that the feldspar is strongly weathered and it makes up only < 5 % (usually < 2 %). On the basis of the low content of feldspar and unstable rock fragments, the basal sandstones should be classified as quartz wakkes (Pettijohn et al. 1973).

The basal sandstones, which are several centimeters to a few meters thick, grade up into very clean quartz arenites, 20-25 m

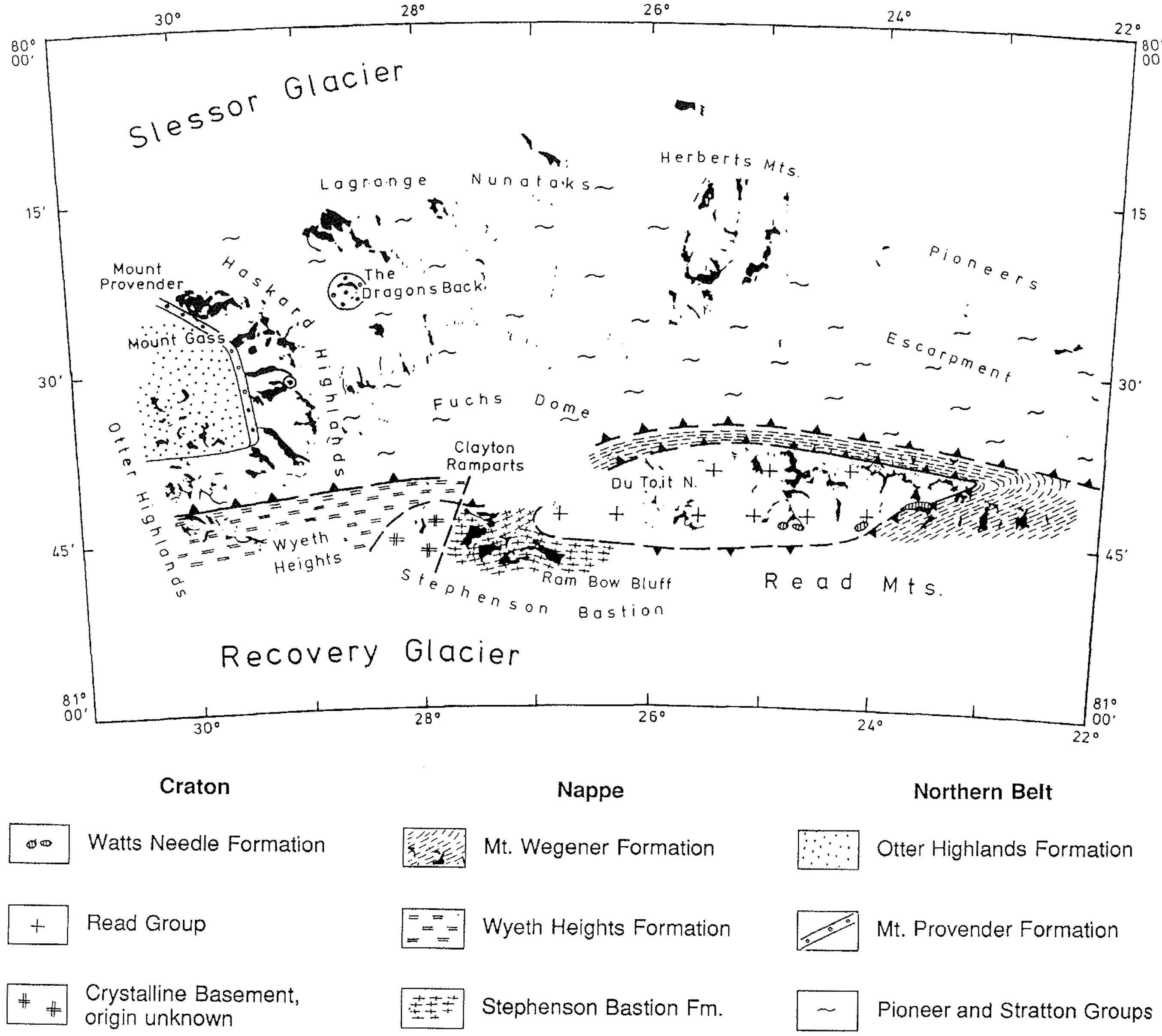


Fig. 4: Geological outline map of the Shackleton Range. < Correction during proof: Pioneers Group.

Abb. 4: Geologische Übersichtskarte der Shackleton Range. ` Richtigstellung bei Korrektur: Pioneers Group.

thick containing 96-100 % quartz (Figs. 8 and 9). The high degree of maturity of the well sorted quartz arenite is also documented by the fact that only stable heavy minerals (green, brown and blue tourmaline and zircon) are present. The well-rounded quartz grains are cemented by homoaxial quartz overgrowth. The boundary between the detrital core and the overgrowth is sometimes marked by a coating of the original detrital dust (Fig. 8). In contrast to PAECH et al. (1987), who „considered (the quartzites) to be of aeolian origin", we interpret the mean grain sizes (0.5-1 mm), the crossbedding, slumps and water-escape structures as indicating deposition in a coastal environment. According to the crossbedding, sediment transport was towards the north during the deposition of the quartz arenites (Fig. 5).

3.2 *The Carbonate Member*

The transitional beds between the Sandstone Member and the Carbonate Member consist of calcite-cemented coarse-grained sandstones and sandy limestones with a total thickness of about 1 m. The overlying Carbonate Member is highly deformed and partly mylonitized at Watts Needle and Werner Höhe on account of the thrusting of the Mount Wegener Nappe on top of it. It is completely exposed only at the northwestern corner of Mount Wegener, where the laminated marls and the well-bedded limestones reach a maximum thickness of about 60 m.

The platy and laminated marls, which have undergone intense pressure solution, were probably precipitated with the aid of microbial mats. Bird's-eyes and desiccation cracks document an intratidal to supratidal depositional environment. LLH to SH

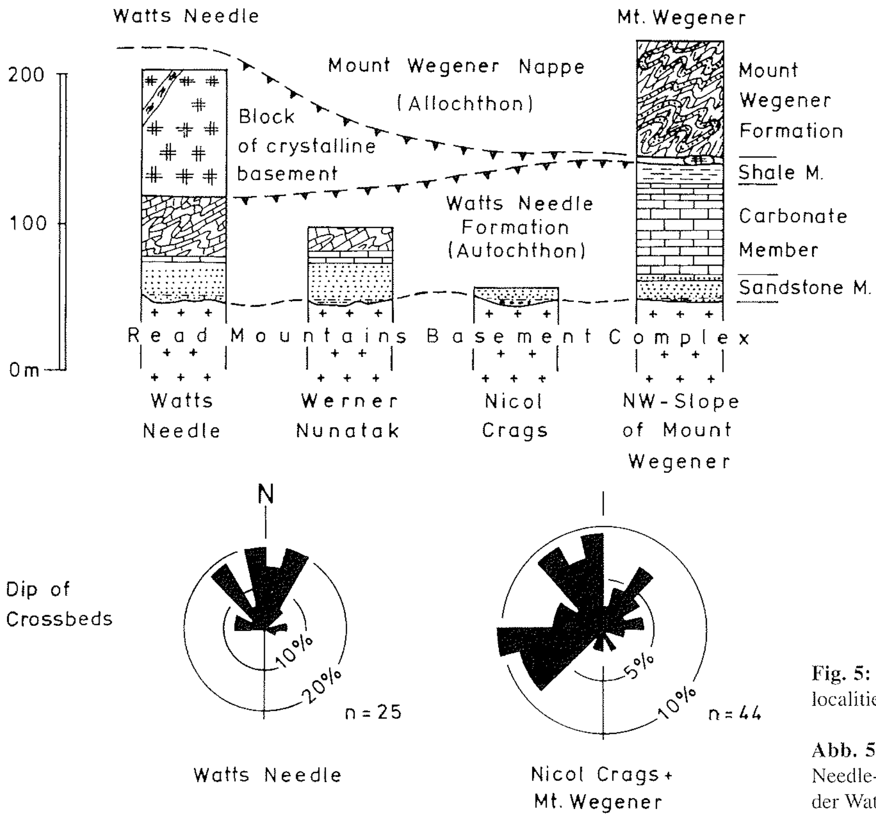


Fig. 5: Correlation of the Watts Needle Formation from different localities and dipp of cross beds.

Abb. 5: Korrelation der verschiedenen Vorkommen der Watts-Needle-Formation und Einfallen von Schrägschichtungskörpern in der Watts-Needle-Formation.

stromatolites are also present. Intrasparites and oosparites are intercalated between the laminites and stromatolites. Reworked microbial mud chips and stromatolites are the most prominent components of the intrasparites, which were deposited in tidal channels (Fig. 10). Graded oosparites with erosional bases may be interpreted as tempestites. Ooids and intraclasts occasionally accumulated in ripples or megaripples giving evidence of high current velocity. All observed sedimentological features are consistent with sedimentation of the carbonates in a subtidal (shallow-marine), intertidal, and supratidal environment of a wide tidal flat.

3.3 *The Shale Member*

The uppermost part of the Watts Needle Formation consists of about 12 m of green shales containing lenses (2.5 by 20 cm) of carbonates with cone-in-cone structures. The shales were probably deposited in a subtidal environment. The Shale Member is truncated by the basal thrust of the Mount Wegener Nappe.

The Watts Needle Formation represents a transgressive sequence of continental basal red beds, beach sands, supratidal to subtidal carbonate-tidal-flat deposits and subtidal shales laid down on a passive continental margin.

3.4 *The age of the Watts Needle Formation*

Stromatolites (Golovanov et al. 1979) and acritarchs (Weber 1989) suggest that the age of the Watts Needle Formation is Late Precambrian (Riphean). This age is corroborated by a single Rb/Sr analysis of a purple shale, which yielded a model age of 720 Ma (Pankhurst et al. 1983).

Our Rb/Sr analyses resulted in two errorchrons (Fig. 11): siltstones and quartz wackes from the base of the Sandstone Member yield a date of 680 ± 14 Ma (IR = 0.726 ± 0.002), pelites from the Shale Member 584 ± 18 Ma (IR = 0.708 ± 0.0024). K/Ar dates of the 2-6 μm fractions range between 800 and 520 Ma (see Buggisch et al. 1994).

Errorchrons with high MSWD values are common for sediments with detrital components because the Sr isotopic composition may not be completely homogenized during deposition and diagenesis of the sediments. If we assume that the scattering of points in the isochron diagram results from a random variation in the initial ratios (IR) of Sr, then the slope of the regression line gives an estimate of the time of deposition/diagenesis of the sediments. The IR of 0.726 for the siltstones and quartz wakkes proves that the Sr is at least partly of detrital origin. Because we cannot exclude that there is a correlation between $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ in the detrital component, the isochron date of 680 Ma is regarded as a maximum estimate of the deposition time. The IR of 0.708 of the pelites corresponds to the value of the marine Sr at the Proterozoic/Cambrian transition (0.709, Faure 1986 p. 192). We may therefore conclude that the Sr of the pelites is of marine origin; the isochron date of 580 Ma can then be interpreted as the time of deposition of the Shale Member.

It is still a matter of discussion whether the Watts Needle Formation is of the same age as the Stephenson Bastion Formation (Paech et al. 1987, Weber 1989). According to our interpretation, the Watts Needle Formation is younger than the Stephenson Bastion Formation.

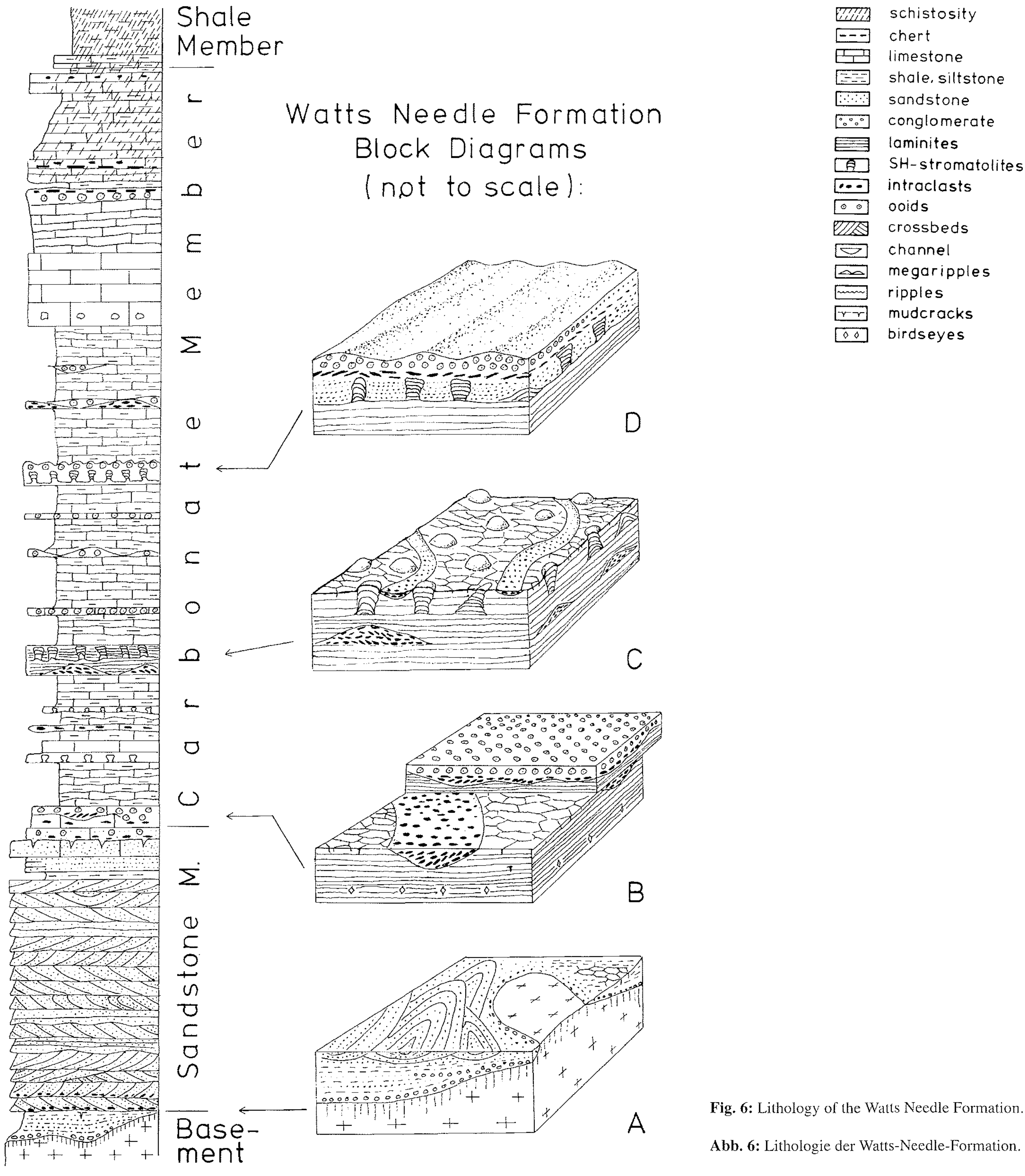


Fig. 6: Lithology of the Watts Needle Formation.

Abb. 6: Lithologie der Watts-Needle-Formation.

4. ALLOCHTHONOUS METASEDIMENTS OF THE NAPPE UNIT: THE „TURNPIKE BLUFF GROUP"

The „Turnpike Bluff Group", which was established by CLARKSON (1972), is exposed in the Read Mountains, at Stephenson Bastion and in the southern Otter Highlands where the type locality - the Turnpike Bluff - is located. It was subdivided by CLARKSON (1972, 1983) into four formations (Fig. 2a). On the basis of the sedimentological identity of the Mount Wegener Formation and the Flett Crags Formation of the „Turnpike Bluff Group", and because they belong to the same tectonic unit (Mount Wegener Nappe), the term „Flett Crags Formation" should be deleted. The „Flett Crags Formation" is the low-

Fig. 7: Transgression of the Watts Needle Formation over the Read Group at Nicols Crags.

Abb. 7: Diskordante Auflagerung von Quarzwacken der Watts-Needle-Formation über dem Kristallin der Read-Gruppe.

grade metamorphic part of the Mount Wegener Formation in the northern Read Mountains. The Mount Wegener Formation, the Stephenson Bastion Formation and the Wyeth Heights Formation are geographically separated and they differ in sedimentology and in modal composition (see Fig. 31). These terms are, therefore, applied in this paper. We do not agree with CLARKSON (1983) that the Watts Needle Formation belongs to the Mount Wegener Formation. No sedimentary contact has been observed between the Mount Wegener Formation and older rocks. It is more probable that the Mount Wegener Formation is allochthonous and separated by a thrust from the underlying Read Group and its sedimentary cover, the Watts Needle Formation. The age of the „Turnpike Bluff Group" is not very well established, due to a lack of fossils. Many authors have adopted a Late Precambrian age (CLARKSON 1972, 1983; PAECH 1982, 1986; PAECH et al. 1987) because of the supposed continuity between the Watts Needle Formation and the Mount Wegener Formation. The age relation between the different formations of the „Turnpike Bluff Group" remains unclear, but K/Ar and Rb/Sr dates from the Stephenson Bastion Formation suggest a minimum age of more than 1000 Ma, whereas fossils show the Mount Wegener Formation to be of Early Cambrian age. Therefore, the term „Turnpike Bluff Group" should also be deleted or restricted to include only the Stephenson Bastion Formation and Wyeth Heights Formation. It is not used in this paper.

4.1 *The Stephenson Bastion Formation*

This formation is exposed in a syncline at Stephenson Bastion with an overturned, steeply dipping northern limb at Clayton Ramparts in the north and relatively flat-lying, gently folded sandstones and siltstones at Ram Bow Bluff in the South. The lowermost beds exposed at Clayton Ramparts contain conglomerates. These consist of quartz and polycrystalline quartz pebbles which are extensively recrystallized and feldspar (mostly microcline) in a fine-grained matrix.

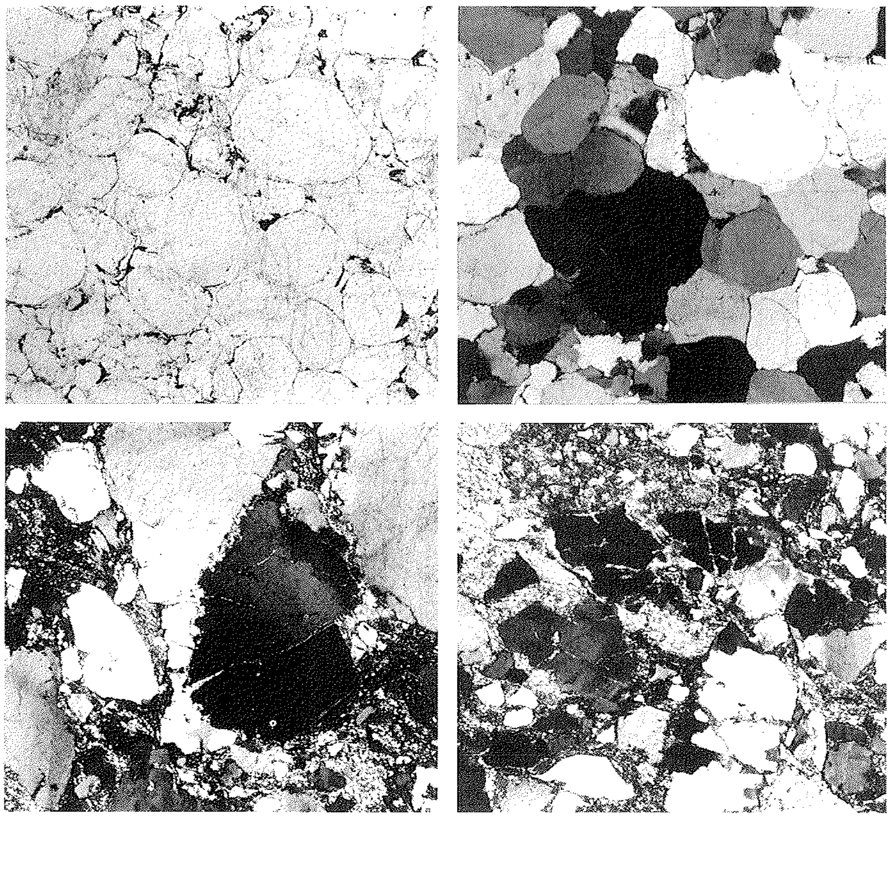
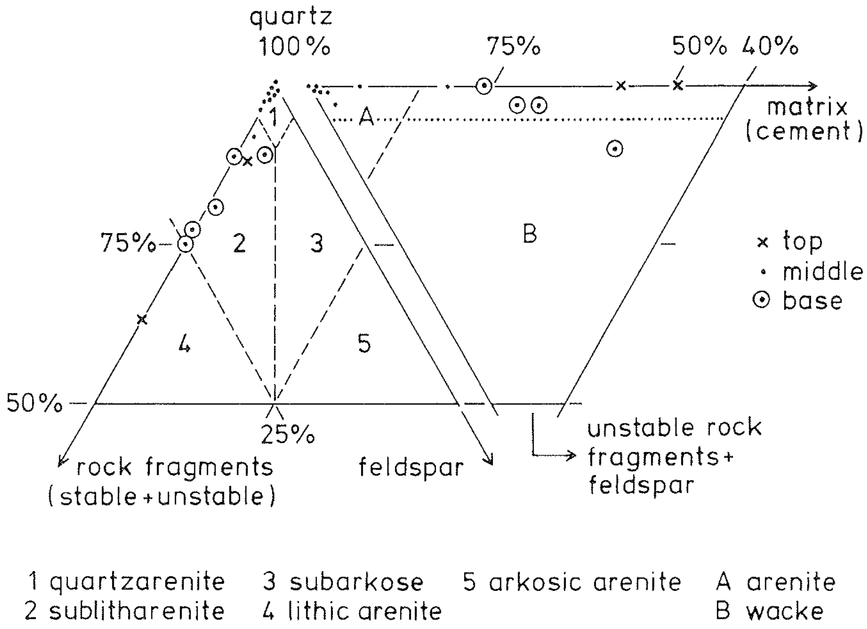


Fig. 8: Thin sections of the Watts Needle Formation (Sandstone Member). a and b = base of the Sandstone Member with broken quartz grains (similar to those in soils) in quartz wackes (crossed polars, x7.5). c and d = quartz arenite with almost no undulose extinction, quartz grains with syntaxial quartz cement (c = plane polarized light, d = crossed polars, x20).

Abb. 8: Dünnschliffe aus der Watts-Needle-Formation (Sandstein-Member). a und b = Quarzwacken von der Basis des Sandstein-Members mit pedogen (?) zerbrochenen Quarzklasten (gekreuzte Nicols, 7,5-fach). c und d = Quarzsandstein; die Körner zeigen fast keine undulöse Auslöschung und sind von syntaxialem Quarzzement überwachsen (c = einfach polarisiertes Licht, d = gekreuzte Nicols, 20-fach).

Fig. 9: Modal composition of sandstones of the Watts Needle Formation. Classification of terrigeneous sandstones according to PETTIJOHN et al. 1973.
Left triangle: Quartz = monocrystalline quartz grains, rock fragments (stable and unstable) = polycrystalline quartz + mica + heavy minerals + composite rock fragments, feldspar = monocrystalline grains of feldspar, 1 = quartz arenite, 2 = sublithic arenite, 3 = subarkose, 4 = lithic arenite, 5 = arkosic arenite.
Right triangle: Quartz = monocrystalline + polycrystalline quartz, Matrix = fine-grained matrix + cement, unstable rock fragments + feldspar = composite rock fragments + mica + heavy minerals + feldspar, A = arenites, B = wackes.
Dashed line = boundary between quartz wackes (above) and arkosic wackes + feldspathic or lithic greywakkes (below).

Abb. 9: Modaler Bestand von Sandsteinen der Watts-Needle-Formation. Klassifikation der Sandsteine nach PETTIJOHN et al. 1973.
Linkes Dreiecksdiagramm: Quarz = monokristalline Quarzkörner, stabile und instabile Gesteinsbruchstücke = polykristalline Quarzkörner + Glimmer + Schwermineralien + zusammengesetzte (polymineralische) Gesteinsbruchstücke, Feldspat = monokristalline Feldspatkörner, 1 = Quarzsandstein, 2 = sublithischer Sandstein, 3 = Subarkose, 4 = lithischer Sandstein, 5 = Arkose.



Rechtes Dreiecksdiagramm: Quarz = mono- und polykristalline Quarzkörner; Matrix = feinkörnige Matrix + Zement, instabile Gesteinsbruchstücke + Feldspat = zusammengesetzte Gesteinsbruchstücke + Glimmer + Schwermineralien + Feldspat. A = Sandsteine, B = Wacken.
Punktierte Linie = Grenze zwischen Quarzwacken (oben) und Arkosen + Grauwacken mit Feldspäten und Gesteinsbruchstücken (unten).

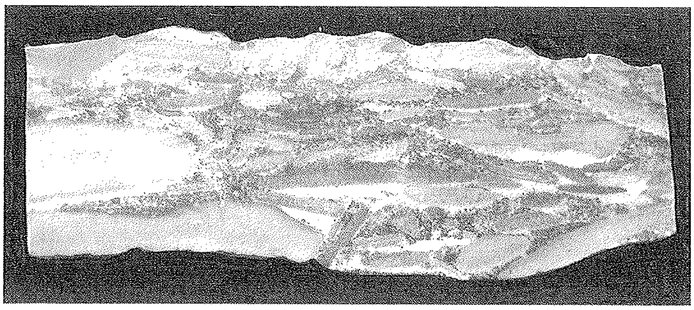


Fig. 10: Rudstone with reworked mud pebbles, intraclasts and ooids at the base of a tidal channel in the Carbonate Member of the Watts Needle Formation (polished section, width about 10 cm).

Abb. 10: Rudstone (Kalkkonglomerat) mit aufgearbeiteten Tongeröllen, Intraklasten und Ooiden an der Basis eines Priels im Karbonat-Member der Watts-Needle-Formation (Anschliff, Bildbreite ca. 10 cm).

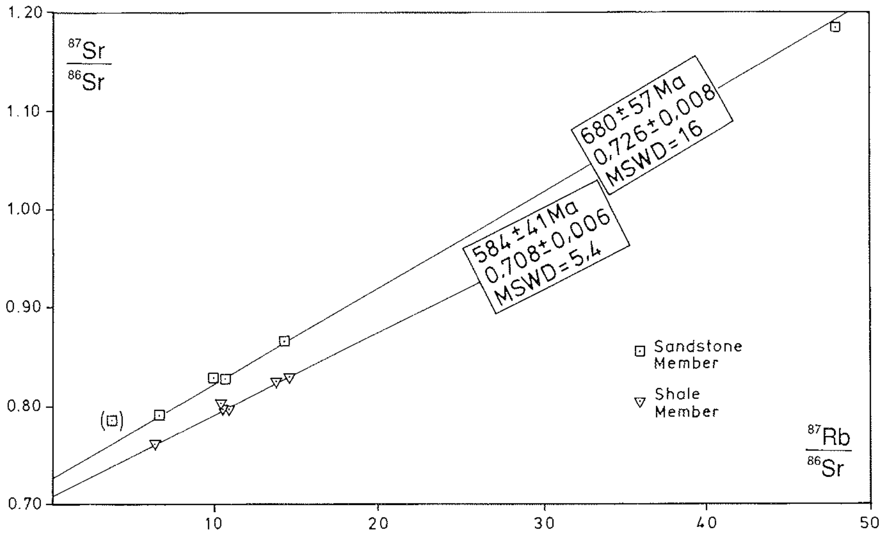


Fig. 11: Rb/Sr whole-rock errorchrons of quartz wackes, siltstones and slates of the Watts Needle Formation.

Abb. 11: Rb/Sr-Gesamtgesteins-Errorchronen von Quarzwacken, Silt- und Tonsteinen der Watts-Needle-Formation.

The conglomerates are interbedded with and overlain by slates and siltstones which grade up into sandstones. The upper part of the Stephenson Bastion Formation at Ram Bow Bluff is much less deformed. It was described by CLARKSON (1983) as a „thick (about 600 m) sequence of sub-horizontal quartzites with some slaty horizons". The fine-grained sandstones are crossbedded or laminated and show parting lineation. Flute casts and crossbedding (Fig. 12) indicate a paleocurrent direction from northwest to southeast. Convolute bedding is very common.

Modal analysis of thin sections revealed about 10-20 % feldspar and 8-22 % (mostly stable) rock fragments in the sand fraction. The matrix or cement make up about 30-55 %. The conglomerates and sandstones are classified as feldspathic to lithic greywackes on the basis of their modal compositions. They differ from the conglomerates and sandstones of the Mount Wegener Formation by the low content of feldspar and the predominance of microcline over other types of feldspar (Fig. 13).

WEBER (1989) described some poorly preserved acritarchs from Mt. Greenfield and correlated them with abundant and well preserved Riphean acritarchs from the Watts Needle Formation at Nicol Crags and Mount Wegener.

K/Ar dating of the 2-6 µm fractions of low- to very low-grade metasiltstones from Clayton Ramparts and Ram Bow Bluff yielded dates between 940 and 1050 Ma (BUGGISCH et al. 1994), which may represent a minimum age for the metamorphism (or diagenesis) of the Stephenson Bastion Formation.

Rb/Sr data from whole rock samples from Ram Bow Bluff define an isochron corresponding to an age of 1251 ± 24 Ma (2s) with an initial ratio IR = 0.7224 ± 0.0032 (Fig. 14). The samples from Clayton Ramparts seem to lie along the correlation line of the Ram Bow Bluff samples; yet, their scatter is too large to allow interpretation as an isochron (Fig. 14).

In the mixing diagram of $^{87}Sr/^{86}Sr$ at 1250 Ma BP versus $1/^{86}Sr$ (Fig. 14a), four samples from Clayton Rampart show a linear

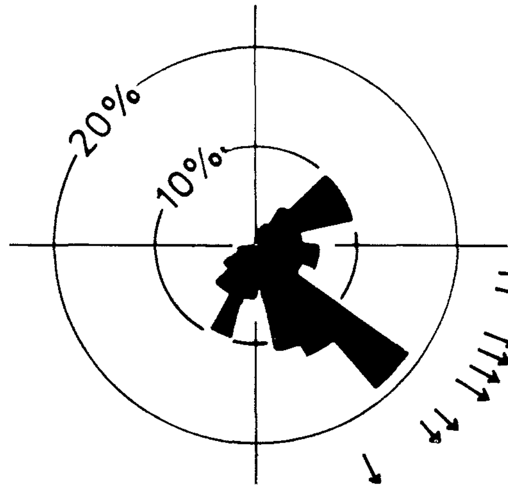


Fig. 12: Dip of crossbeds at Ram Bow Bluff (Stephenson Bastion); arrows = current direction of flute casts.

Abb. 12: Einfallsrichtung von Schrägschichtungskörpern am Ram Bow Bluff (Stephenson Bastion). Pfeile = Strömungsrichtung aufgrund von Strömungsmarken.

arrangement. When interpreted as a mixing line this linear correlation indicates mixing of two components with different $^{87}Sr/^{86}Sr$ ratios about 1250 Ma BP. This could be attributed to mixing during sedimentation. The samples from Ram Bow Bluff show more uniform $^{87}Sr/^{86}Sr$ ratios in the time-corrected mixing diagram (Fig. 14a). The rather homogeneous Sr isotopic composition of these samples at 1250 Ma BP could be due to different processes: (1) Mechanical mixing of rock fragments from a single source rock without mobilization of Rb or Sr. In this case, the initial ratios are inherited from the source rock and the isochron age would reflect the age of the source material. (2) The Sr isotopic composition was homogenized during deposition and diagenesis of the sediments and, therefore, the isochron yields the deposition age. Because of the fine-grained nature of the sediments we prefer the latter interpretation.

The Rb/Sr analyses on the 0.6-2 µm and 2-6 µm fractions of

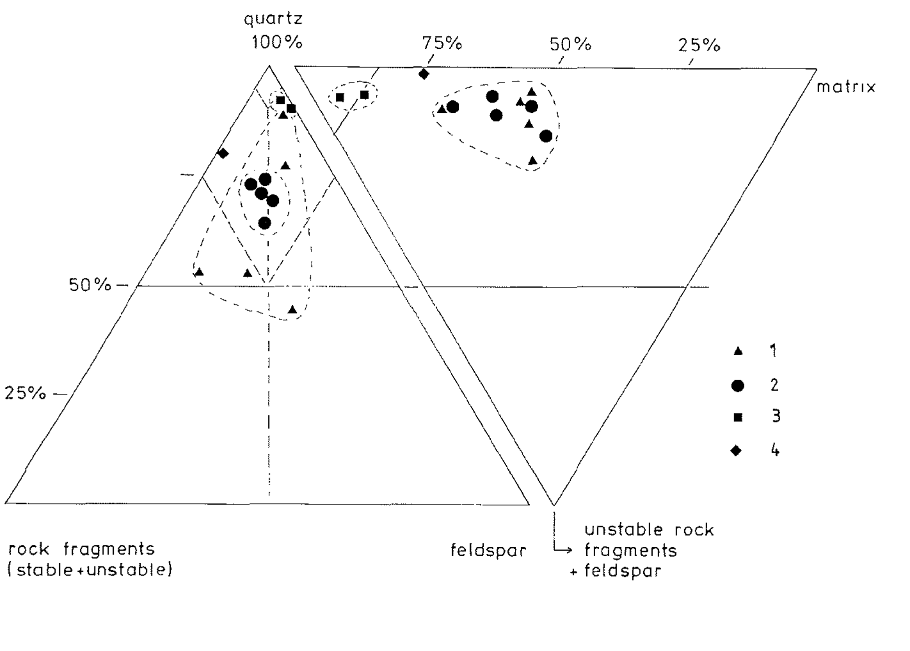


Fig. 13: Modal composition of sandstones from the Stephenson Bastion Formation (1 = Clayton Ramparts, 2 = Ram Bow Bluff) and the Wyeth Heights Formation (3 = Wyeth Heights, 4 = low-grade meta-arenite from the southern Otter Highlands).

Abb. 13: Modalbestand von Sandsteinen der Stephenson-Bastion-Formation (1 = Clayton Ramparts, 2 = Ram Bow Bluff) und der Wyeth-Hights-Formation (3 = Wyeth Hights, 4 = niedriggradige Metasandsteine aus den südlichen Otter Highlands).

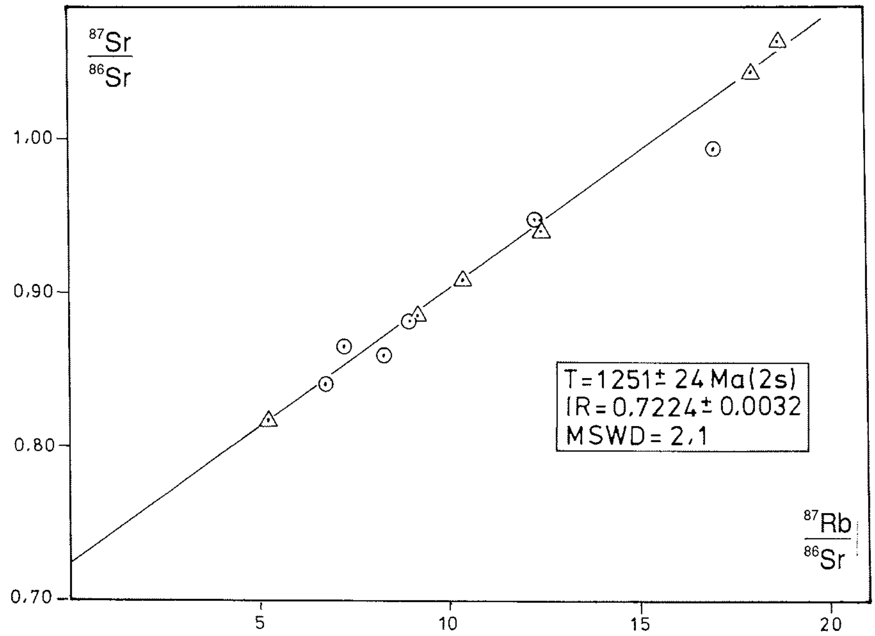


Fig. 14: Rb/Sr whole-rock isochron diagram for siltstones from Ram Bow Bluff (triangles) and Clayton Ramparts (circles).

Abb. 14: Rb/Sr Gesamtgesteinsisochronen für Siltsteine von Ram Bow Bluff (Dreiecke) und Clayton Ramparts (Kreise).

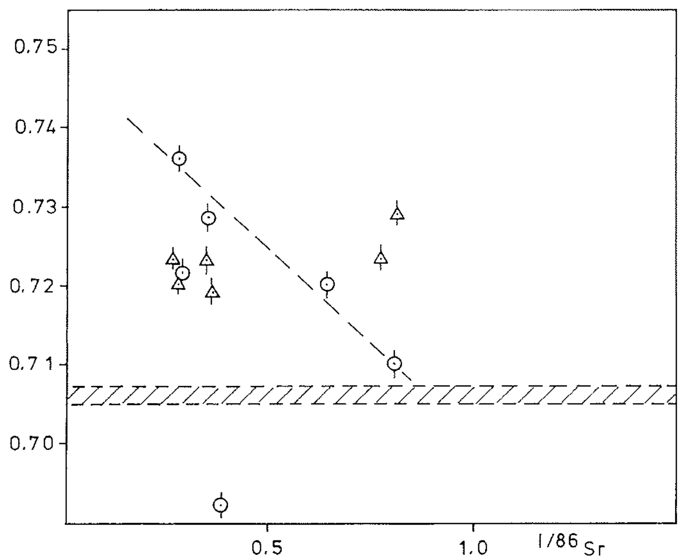


Fig. 14a: Time-corrected mixing diagram of samples from Ram Bow Bluff (triangles) and Clayton Ramparts (circles).

Abb. 14a: Zeitkorrigiertes Mischungsdiagramm fur Proben von Ram Bow Bluff (Dreiecke) und Clayton Ramparts (Kreise).

some samples reveal a later disturbance of the Rb-Sr systems, particularly of the finer fractions. All but one of these samples are below the 1250 Ma isochron, indicating a later increase of the Rb/Sr ratios (Fig. 14b). The disturbance occurred later than about 1170 Ma, as estimated from the data from sample 226 (0.6-2 µm), which yielded the youngest model age, assuming a Sr initial ratio of 0.72. K/Ar dates on the same fractions between 860 Ma and 1050 Ma point to a later disturbance, too.

From the initial ratio of 0.7224 we may conclude that the source rocks are not much older than the deposition age of the sediments. If the Sr in the sediments is of detrital origin only and assuming a mean $^{87}Rb/^{86}Sr$ ratio of 10 for the source rock then the maximum age of the source rock would be about 1.4 Ga. Because there is no known rock unit of this age in the Shackleton Range, the provenance of the sediments remains unclear.

From the isotopic dates we conclude that the Stephenson Bastion Formation was probably deposited about 1250 Ma ago and metamorphosed under very low-grade conditions in Late Precambrian times (>1000 Ma).

4.2 *The Wyeth Heights Formation*

The Wyeth Heights Formation is exposed in the southern Otter Highlands, where the Pioneers and Stratton Groups are thrust over the metasediments of this formation. Close to the thrust, the Wyeth Heights Formation consists of slates showing multiple deformation as well as extensively recrystallized sandstones and siltstones.

Towards the South, a sequence of sandstones several meters thick forms the plateau of Wyeth Heights. These sandstones are mainly composed of quartz. The feldspar content (mostly microcline) is in the range of 5-10 %, and the amount of matrix is about 10 %. According to the modal composition the sandstones are quartz arenites to subarkoses (Fig. 13).

The age of the Wyeth Heights Formation is unknown because of a lack of fossils. However this formation is tentatively correlated with the Stephenson Bastion Formation on the basis of their lithological similarity, in spite of the fact that the first was metamorphosed during the Ross Orogeny (BUGGISCH et al. 1994). Rb/Sr analyses yielded scattered data which do not fit to a unique isochron. Two possible, but rather speculative two-point „isochrons" could be constructed (Fig. 15): One indicates a date of about 1150 Ma with an initial ratio of 0.728, and the other a date of about 1015 Ma with an initial ratio of 0.708. These dates, however, cannot be considered as reliable age information.

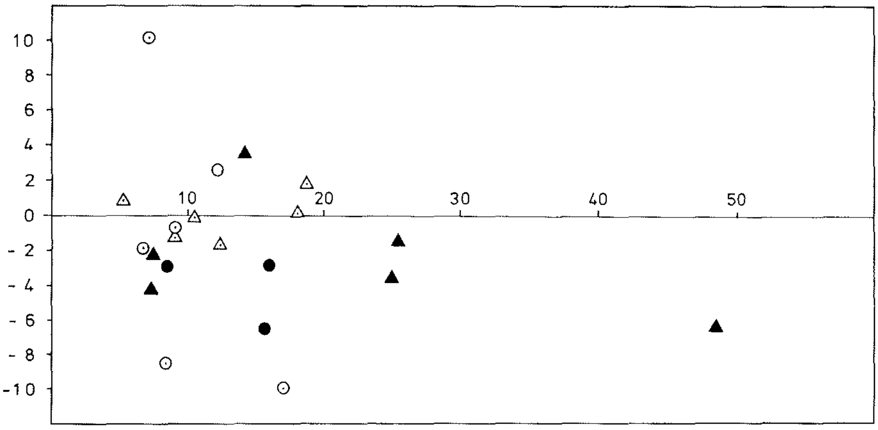


Fig. 14b: Weighted deviations of samples from Stephenson Bastion Formation from the 1250-Ma isochron (Fig. 14), circles = Clayton Ramparts, triangles = Ram Bow Bluff, solid symbols = fine fractions, open symbols = whole-rock samples.

Abb. 14b: Abweichung der Proben aus der Stephenson-Bastion-Formation von der 1250 Ma Isochrone (Abb. 14). Kreise = Clayton Ramparts, Dreiecke = Ram Bow Bluff, ausgefüllte Symbole = feine Korngrößenfraktionen, offene Symbole = Gesamtgesteinsproben.

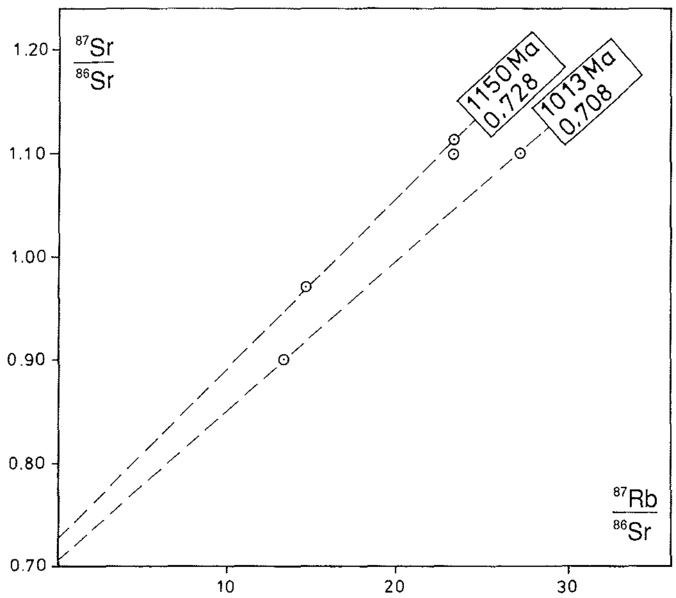


Fig. 15: Rb/Sr whole-rock errorchrons on schists of the Wyeth Heights Formation.

Abb. 15: Rb/Sr Gesamtgesteins-Errorchrone von Schiefern der Wyeth-Hights-Formation.

A continuous lateral increase in maturity is observed from lithic and feldspathic greywackes in the Stephenson Bastion Formation to well rounded quartzose and feldspathic arenites in the Wyeth Heights Formation (see Fig. 31), which indicates a more shallow-water environment to the west (higher degree of roundness, better sorting, higher maturity). On the other hand, a correlation of the Wyeth Heights Formation with the Lower Cambrian Mount Wegener Formation cannot be totally excluded.

4.3 *The Mount Wegener Formation*

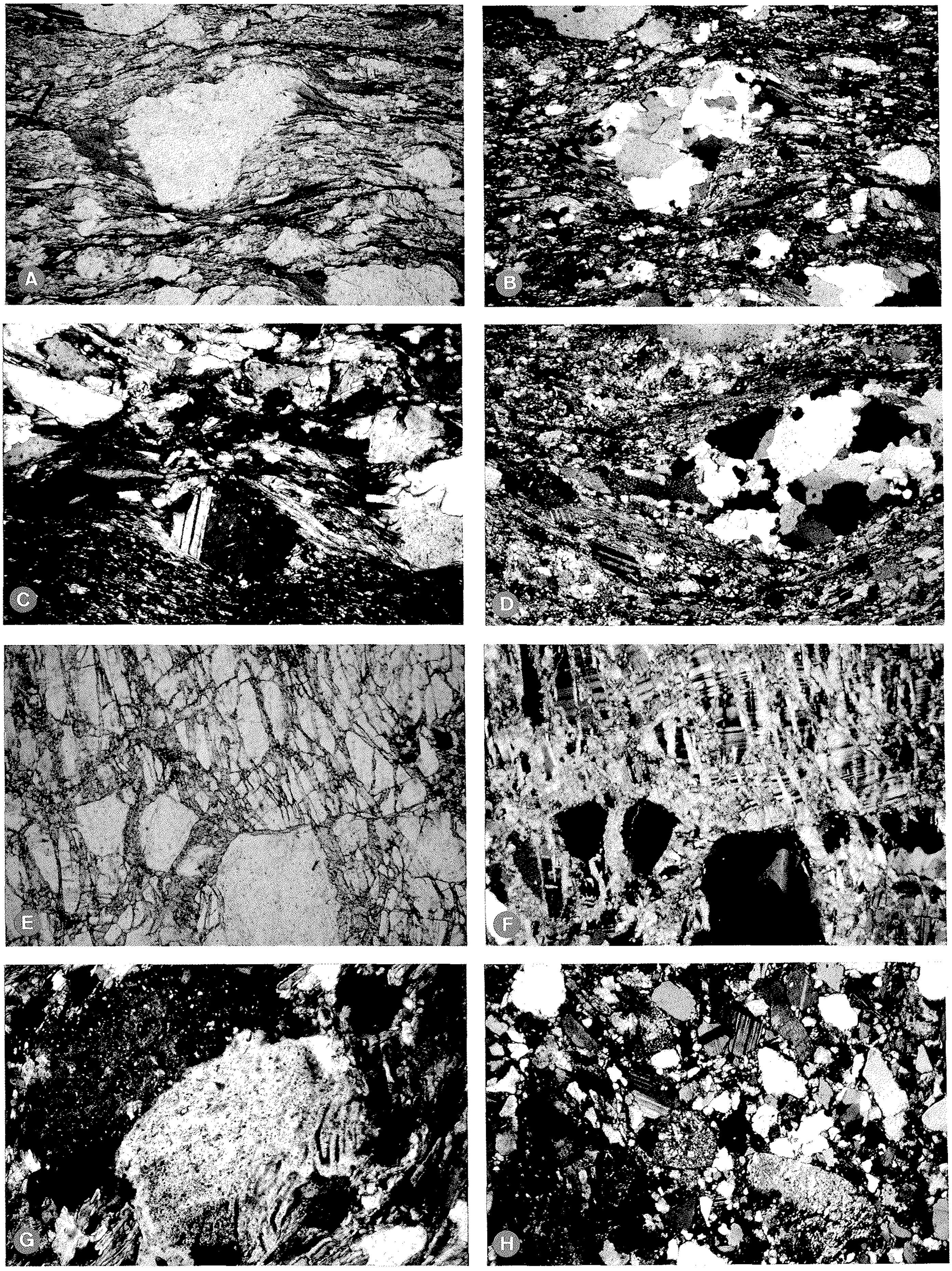
The Mount Wegener Formation forms the Mount Wegener Nappe and is exposed in the Read Mountains, where it frames the window of the Read Group. It consists mainly of metasediments showing multiple folding, very low-grade metamorphic slates and low-grade (quartz-biotite) schists and intercalated meta-conglomerates and sandstones. The metamorphic grade increases continuously from SE to NW (formerly Flett Crags Formation).

The dark grey and green slates are seen in thin section to be banded layers of dark, fine-grained mudstones and argillaceous siltstones consisting of detrital quartz, white mica, chlorite, biotite and feldspar (Clarkson 1983). The matrix is largely recrystallized to illite/sericite, chlorite, and quartz. Due to the increasing grade of metamorphism towards the north, new biotite and quartz constitute the most common constituents of the equivalent schists north of the Read Window.

Sandstones a few centimeters to half a meter thick are interbedded with the shales and siltstones. The bases of the sandstone layers are usually distinct; signs of erosion and flute casts at the base were observed but are not very common. Thick, coarsegrained sandstones and conglomerates often show graded bedding.

The sandstones consist of detrital quartz, polycrystalline quartz, feldspar (mostly plagioclase, some perthite and microcline), white mica, biotite, and unstable rock fragments in a matrix of illite/sericite, chlorite, biotite (in the low-grade metamorphic rocks) or a cement of quartz and calcite (Fig. 16). Due to the very low- to low-grade metamorphism, the feldspars are completely altered to albite. Nevertheless, the large amount of calcite may be at least partly derived from the anorthite component of the original plagioclase. The accessory minerals include zircon, epidote, sphene, ilmenite and hematite (Clarkson 1983). According to the modal composition (Fig. 17), the sandstones are feldspathic greywackes.

The conglomerates with components up to one centimeter across are composed of clasts of quartz, polycrystalline quartz, feldspar, chert and fragments of sandstones, limestones and volcaniclastic rocks (Figs. 18 and 19). The sandy matrix of the conglomerates corresponds to the sandstones of the Mount Wegener Formation. In the metaconglomerates of the northern Read Mountains, limestone clasts are extremely stretched, quartz is recrystallized and feldspar has suffered brittle deformation (Fig. 16). In contrast, clasts can still be identified in the very low-grade meta-conglomerates of the Oldhamia Terrace, Truman Terraces and Swinerton Ledge in the southern Read Mountains. The limestone clasts are composed of dolosparites, laminites, pelsparites, oosparites, cortoids, ooids, reworked cement fragments (Fig. 19), *Epiphyton* sparites, problematica (fragment of an archaeocyathid(?), and echinoderms(?)) (Fig. 18).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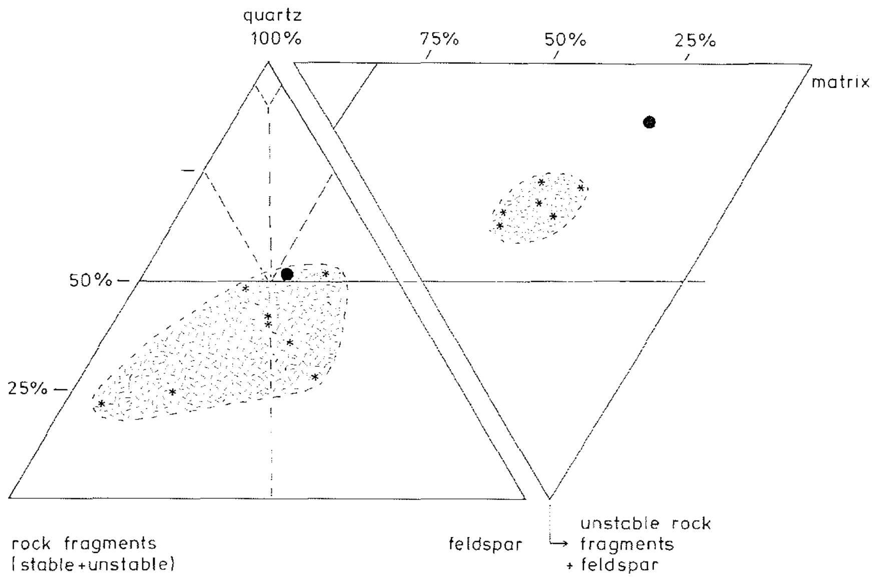

Fig. 17: Modal composition of arenites in the Mount Wegener Formation; asterisk = very low-grade meta-arenites; dot = low-grade meta-arenite with newly formed quartz and biotite.

Abb. 17: Modalbestand der Arenite aus der Mount-Wegener-Formation. Sterne = „very low-grade" Metaarenite, Punkte = grünschieferfazielle Metaarenite mit Neubildung von Quarz und Biotit.

The occurrence of *Oldhamia cf. antiqua* and *Oldhamia cf. radiata* at Oldhamia Terrace demonstrate a Lower Cambrian age for the Mount Wegener Formation (Fig. 20). This age is corroborated by the presence of *Epiphyton sp.,* algae incertae sedis *(Botomaella? sp.* KORDE) and echinoderms(?) (Fig. 18).

Rb/Sr analysis of six samples from the very low-grade slates and on six samples of the low-grade schists of the Mount Wegener Formation resulted in two isochrons corresponding to 561 ± 18 Ma, IR = 0.7113 ± 0.0017 (MSWD = 2.2) and 535 ± 9 Ma, IR = 0.7139 ± 0.00045 (MSWD = 1.8), respectively (Fig. 21a,b).

In the time-corrected mixing diagrams there is no indication of two-component mixing for the analysed samples.

The isochron date of the very low-grade slates is in agreement with the biostratigraphically determined Lower Cambrian age of the Mount Wegener Formation. As mentioned below, the Mount Wegener Formation was deposited in a basinal environment. If we assume that the Sr was isotopically homogenized during deposition then the isochron date of the nearly unmetamorphosed slates could be interpreted as the time of deposition.

The slightly, but significantly younger isochron date of the metamorphic schists possibly resulted from the metamorphism which caused partial loss of radiogenic strontium. It is still an open question whether the isochron gives the age of the metamorphism or is only a disturbed isochron contributing no real age information. K/Ar analyses on artificial 2-6 µm fractions of the same samples resulted in consistent dates of about 490 Ma (BUGGISCH et al. 1994).

Oldhamia is typical of a basinal environment. This trace fossil is usually found in flysch or flysch-like sediments. Therefore, the sediments of the Mount Wegener Formation were probably deposited in a relatively deep basin. Graded bedding and occasional flute casts agree with this interpretation. The limestone clasts are derived from a shallow-water environment. The large amount of feldspar (plagioclase) and the occurrence of volcaniclasts and unstable heavy minerals is consistent with a (intracontinental?) back-arc environment.

5. SEDIMENTS OF THE NORTHERN BELT

5.1 *The Haskard Highlands Formation*

South of Mount Provender, fossiliferous shales and calcareous siltstones were found to contain obolid brachiopods (THOMSON 1972) and Middle Cambrian trilobites (SOLOVIEV & GRIKUROV 1979).

The open marine trilobite shales were deposited in a low-energy environment, while the brachiopod-bearing siltstones with fragmented shell accumulations point to periodical current action and reworking (CLARKSON et al. 1979). Although no clea-

Fig. 16: Thin sections of arenites from the Mount Wegener Formation. A - D = Meta-arenite from the Mount Wegener Formation north of Read Window (formerly Flett Crags Formation). Clasts consist of polycrystalline quartz and feldspar. Quartz is strongly recrystallized. Beards of quartz and biotite in s_1. A = plane polarized light; B = crossed polars; C = crossed polars, x20; D = crossed polars, x10.
E - F = Brittle deformation of feldspar (microcline). Cracks are filled with calcite; E = plane polarized light; F = crossed polars, x20. G = Clast with granophyric texture; crossed polars, x20. H = Feldspathic arenite from Truman Terraces; crossed polars, x10.

Abb. 16: Dünnschliffe von Areniten der Mount-Wegener-Formation. A - D = Metaarenite aus der Mount-Wegener-Formation nördlich des Read-Fensters (ehemals Flett-Crags-Formation). Die Klasten bestehen aus (polykristallinem) Quarz und Feldspat. Quarz ist stark rekristallisiert. Faserbärte in s_1 bestehen aus Quarz und Biotit: A = einfach polarisiert, B = gekreuzte Nicols, C = gekreuzte Nicols, 20fach, D = gekreuzte Nicols, 10fach.
E - F = Spröddeformierter Feldspat (Mikroklin). Die Brüche sind mit Kalzit verheilt. E = einfach polarisiert, F = gekreuzte Nicols, 20fach. G = Klast mit granophyrischer Textur, gekreuzte Nicols, 20fach. H = Feldspathaltiger Arenit von der Truman Terrasse, gekreuzte Nicols, 10fach.

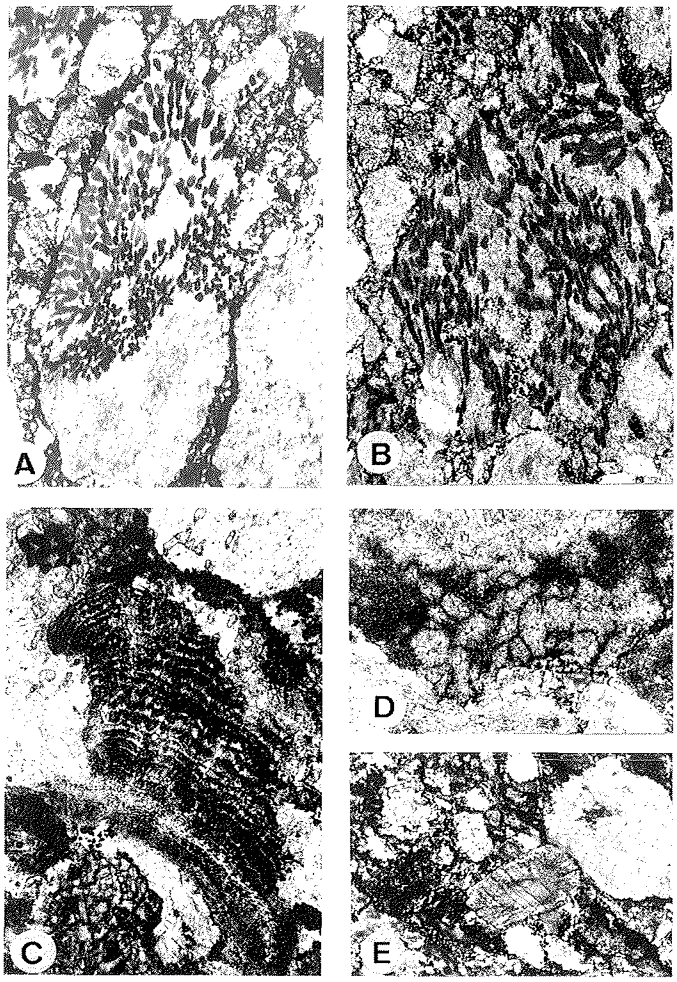

Fig. 18: Thin sections of carbonate components in conglomerates of the Mount Wegener Formation. a - b = *Epiphyton* sp. (a = x7.5; b = x15). c = *Botomaella* ? sp. (x15). d = Organic structures of unknown origin (fragments of archaeocyathids?), (x15). e = Echinoderm fragment (center) (x7.5).

Abb. 18: Dünnschliffe von Karbonatkomponenten aus Konglomeraten der Mount-Wegener-Formation. a - b = *Epiphyton* sp. (a = 7,5-fach, b = 15fach). c =*Botomaella* ? sp. (15fach). d = Organische Struktur unbekannten Ursprungs (Bruchstück eines Archaeocyathiden ?), 15fach. e = Echinodermen-Fragment (Bildmitte), 7,5-fach.

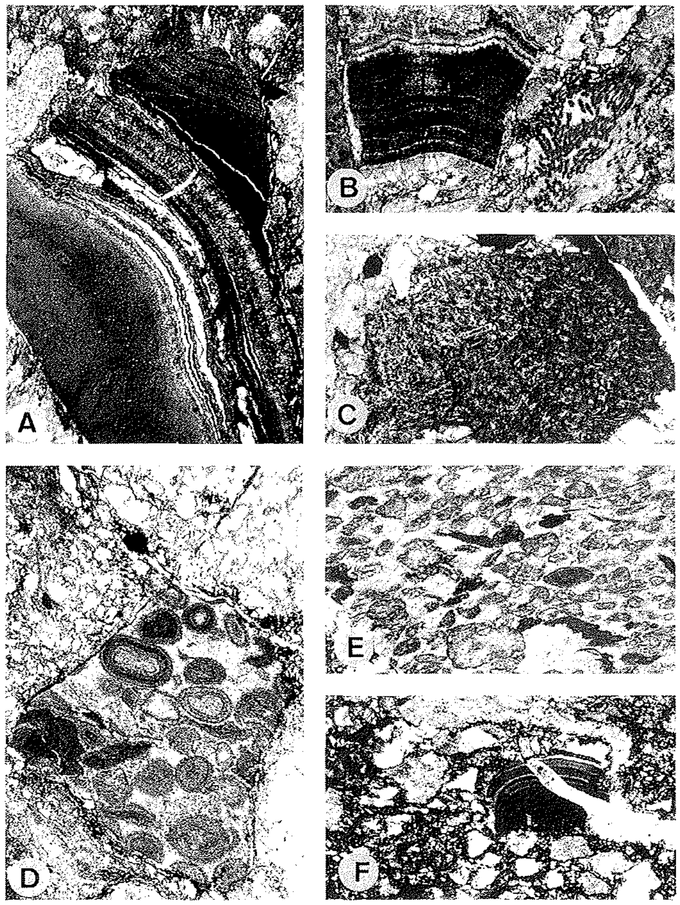

Fig. 19: Thin sections of components in conglomerates of the Mount Wegener Formation. A - B = Fragmented carbonate crusts and cements (x7.5). C = basic volcanic rock fragment (x7.5). D = Clast of oolite (x7.5). E = Clast with deformed ooids (x7.5). F = Fragmented ooid as clast (x7.5).

Abb. 19: Dünnschliffe von Komponenten aus Konglomeraten der Mount-Wegener-Formation. A - B = Zerbrochene Karbonatkruste und Zemente (7,5fach). C = Bruchstück eines basischen Vulkanits (7,5-fach). D = Oolith-Klast (7,5-fach). E = Klast mit deformierten Ooiden (7,5-fach). F = Zerbrochenes Ooid als Klast (7,5-fach).

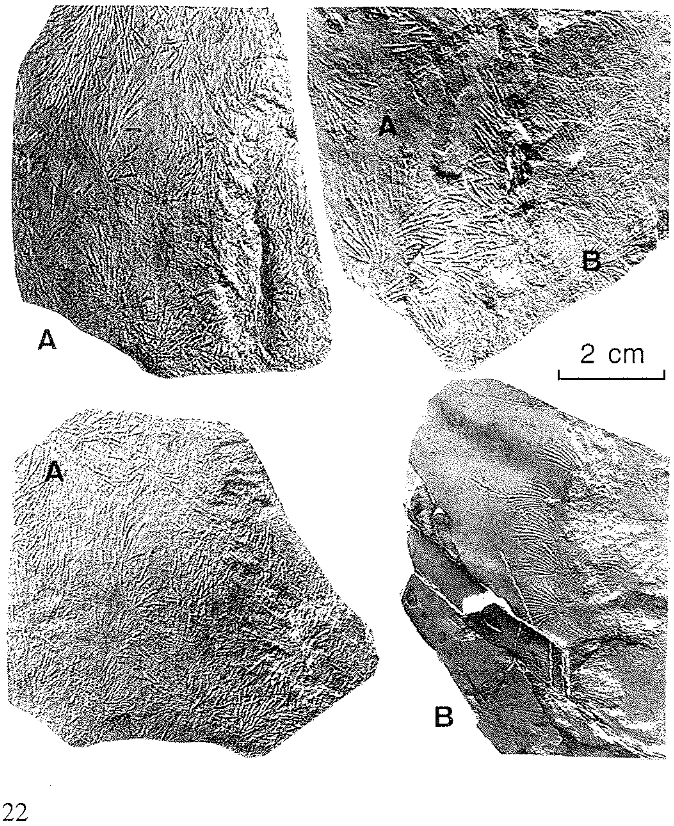

Fig. 20: (a) *Oldhamia radiata* FROBES and (b) O. cf. *antiqua* KINAHAN from the Mount Wegener Formation south of Lapworth Cirque.

Abb. 20: (a) *Oldhamia radiata* FROBES und (b) = O. cf. *antiqua* KINAHAN aus der Mount-Wegener-Formation der Oldhamia-Terrasse südlich Lapworth Cirque.

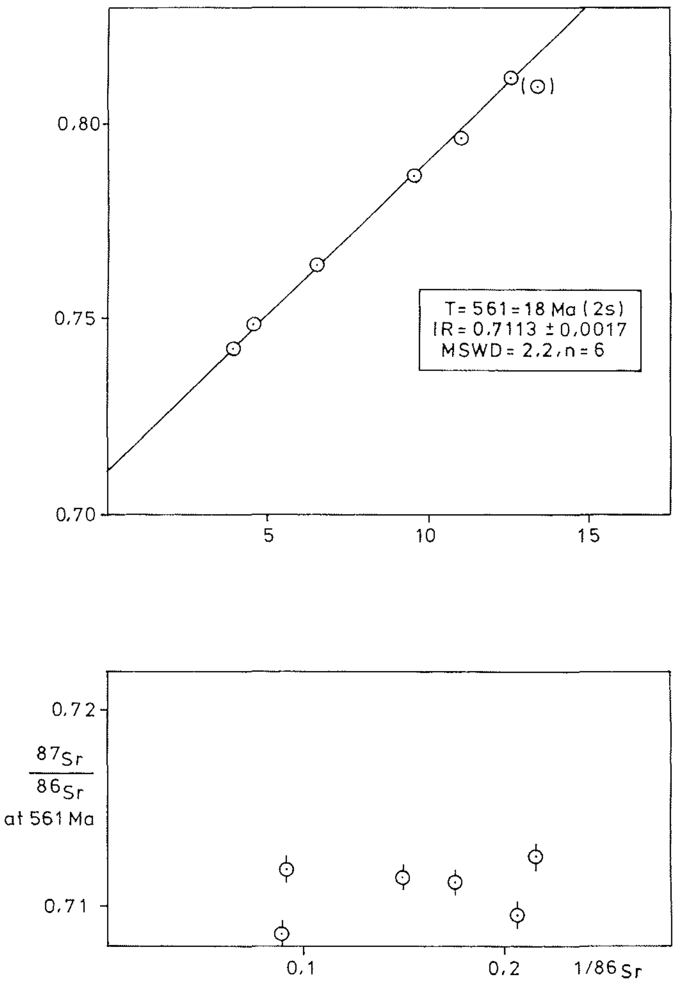

Fig. 21a: Rb/Sr isochron plot for very low-grade slates of the Mount Wegener Formation (upper part); time-corrected mixing diagram (lower part).

Abb. 21a: Rb/Sr-Isochrone für „very low-grade“ Schiefer der Mount-Wegener-Formation (oben); zeitkorrigiertes Mischungsdiagramm (unten).

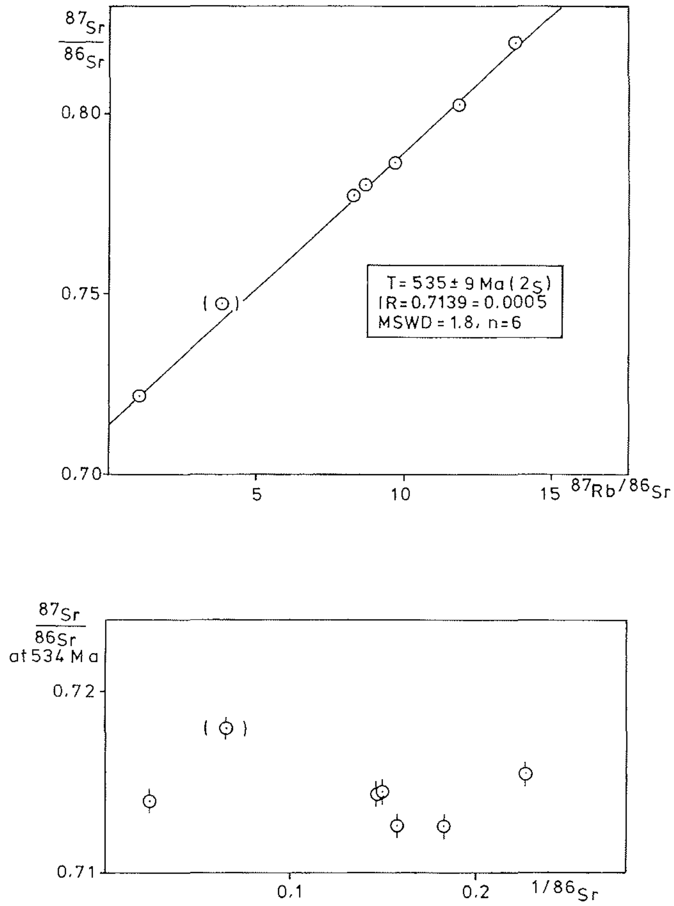

Fig. 21b: Rb/Sr isochron plot for low-grade schists of the Mount Wegener Formation (upper part); time-corrected mixing diagram (lower part).

Abb. 21b: Rb/Sr-Isochrone für niedriggradige Schiefer der Mount-Wegener-Formation (oben); zeitkorrigiertes Mischungsdiagramm (unten).

vage was observed, either in the field or in thin section, the distortion of the fossils indicated that the rock has undergone at least some tectonic deformation (Fig. 22).

The provenance of the shales and siltstones, which have so far been found only as erratics, is a matter of controversy. Most authors agree that the source of the erratics must be very close to the moraine in which the fossiliferous material is found. Stephenson (1966) and Clarkson et al. (1979) suggested that, stratigraphically, the shales and siltstones belong between the Mount Provender Formation and the Otter Highlands Formation of the Blaiklock Glacier Group. Soloviev & Grikurov (1979) and Paech (1986) postulated that the fossiliferous sediments were deposited in pockets on the crystalline basement and below the Mount Provender Formation. These interpretations are inconsistent with three facts:

(i) According to the facies, the trilobite shales were deposited in a low-energy environment, far from any coarse-grained clastic input. Furthermore, the shales must have covered a large depositional area.

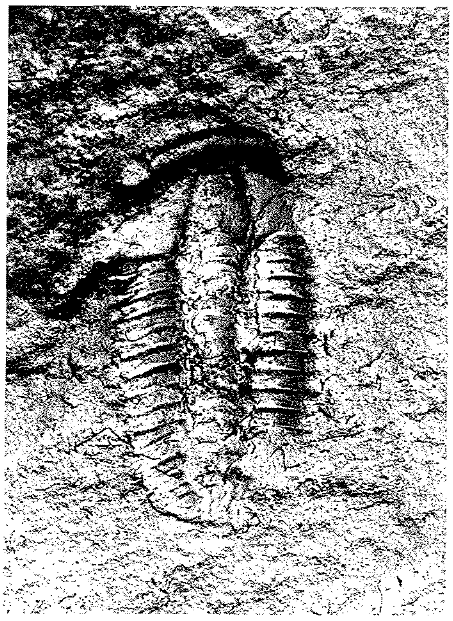

Fig. 22: Distorted trilobite from the Haskard Highlands Formation (x2).

Abb. 22: Tektonisch verzerrter Trilobit aus der Haskard Highlands-Formation (x2).

(ii) Radiometric dates indicate Middle to Late Cambrian or even Ordovician ages for the partly high-grade metamorphic rocks of the Stratton Group immediately below the Haskard Highlands Formation (REX 1972, GREW & HALPERN 1979, PANKHURSTet al. 1983, BUGGISCH et al. 1994). This would not have left enough time for high-grade metamorphism, uplift and formation of a peneplain.
(iii) K/Ar determinations on the 2-6 µm fractions from Middle Cambrian siltstones of the Haskard Highlands Formation gave dates of 455 and 463 Ma, which indicate later, very low-grade metamorphism, which is consistent with the slight distortion of the trilobites (Fig. 22).

We agree that the blocks of the Haskard Highlands Formation are of local origin. Clasts of reworked siltstones and shales occur in the basal Mount Provender Formation at Mount Provender. Although no fossils were found in these clasts, they resemble the trilobite shales and siltstones. Therefore, we favour a position for the Haskard Highlands Formation below the Blaiklock Glacier Group. At The Dragon's Back, Maucher Nunatak, Mount Gass and Wedge Ridge, the Mount Provender Formation rests unconformably on basement rocks. Consequently, it appears that the Haskard Highlands Formation was extensively eroded before deposition of the Blaiklock Glacier Group. The only alternative is that the shales and siltstones of the Haskard Highlands Formation are relics of a tectonic slice which is covered by the postorogenic molasse sediments of the Blaiklock Glacier Group.

5.2 *The Blaiklock Glacier Group*

The Blaiklock Glacier Group is exposed only in the northwestern Shackleton Range. It was first described by STEPHENSON (1966) as „Blaiklock Beds" and later formally renamed as Blaiklock Glacier Group (CLARKSON 1972). The group is divided into two formations: The Mount Provender Formation below and the Otter Highlands Formation above. A comprehensive description was given by CLARKSON & WYETH (1983).

5.2.1 The Mount Provender Formation

The Mount Provender Formation is exposed on the western margin of the Haskard Highlands, on a small nunatak in Stratton Glacier 6 km west of Lister Heights, on a nunatak at the northwestern end of Wedge Ridge and on The Dragon's Back. In contrast to CLARKSON & WYETH (1983), we include two further outcrops: the northwestern part of Wedge Ridge and The Dragon's Back. The definition of the Mount Provender Formation should therefore be amended as follows: The Mount Provender Formation rests unconformably on the Pioneers and Stratton Groups and probably locally on the Haskard Highlands Formation. The contact is complicated by minor faults in most outcrops, but the transgressive nature of this formation is evident. Two sections were studied in detail: at Maucher Nunatak (Figs. 23 and 24) and Mount Gass (Fig. 25). All other known outcrops were examined during short visits.

At Wedge Ridge, Maucher Nunatak and Mount Gass the basal units show considerable and rapid lateral facies variation, which give evidence that the unconformaty has a relief of at least several tens of meters. Typical fanglomerates are exposed at the nunatak at the northwestern end of Wedge Ridge. The boulder beds and the coarse-grained, poorly sorted breccias and conglomerates of local origin represent a typical sequence from gravity slides into fan conglomerates, probably of flash flood origin (Fig. 26). Downslope, these basal units pass into alluvial braided channel sediments, which are exposed at Maucher Nunatak. Coarse-grained conglomerates interbedded with pebbly siltstones are restricted to the bottom few tens of meters in the other outcrops. The typical succession of the upper part of the Mount Provender Formation is exposed in the Mount Gass section (Fig. 25). Intensely bioturbated siltstones and mudstones with mud cracks alternate with crossbedded, medium- to fine-grained sandstones in which convolute bedding is common. Trace fossils are abundant in the upper part. The fact that CLARKSON & WYETH (1983) did not find these obvious fossils was probably due to the differing snow conditions during the expeditions. We found trace fossils at Mount Gass, The Dragon's Back, and the small nunatak west of Lister Heights. Some have been identified as trilobite tracks and trails (Fig. 27), which substantiate the hypothesis of a marine environment for the upper part of the Mount Provender Formation.

The results of microscopic investigation are shown in Figure 28. The sandstones consist of 30-50 % quartz, 10-20 % feldspar and 30-60 % rock fragments. The sandstones are, therefore, lithic arenites. Quartz showing faint undulatory extinction or none at all is more common than stressed quartz; volcanic quartz displaying typical resorption was observed. Untwinned feldspar is more abundant than twinned acid plagioclase. Biotite is strongly altered to chlorite and hematite. Up to 30 % of the rock fragments consist of detrital mica, the other contituents are quartzites, mica schists, heavy minerals and gneisses. The uppermost beds of the Mount Gass section, which form the transition to the Otter Highlands Formation, exhibit modal compositions with up to 40 % feldspar.

According to the trace fossils, the age of the Mount Provender Formation is between Cambrian and Devonian. Permian age, which was inferred by GRIKUROV & DIBNER(1979) and PAECH (1986), is not convincing. The sedimentological similarity between the Mount Provender Formation in Antarctica and the basal units of the Table Mountain Group in South Africa suggests an Ordovician age for the Mount Provender Formation. This is supported by paleomagnetic data.

5.2.2 Palaeomagnetic evidence

Palaeomagnetic measurements were made to obtain additional data on the age of the Blaiklock Glacier Group (Mount Provender Formation). As the samples were originally collected for purely geological purposes and not for palaeomagnetic analysis, only the inclination of the remanent magnetization relative to the bedding plane could be determined. In view of this incom-

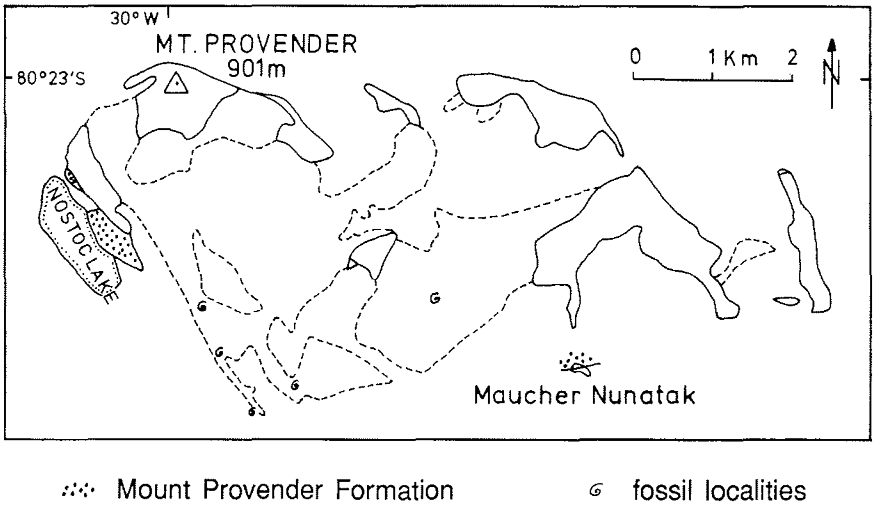

Fig. 23: Geology of the Mount Provender area showing the position of Maucher Nunatak according to Grew & Halpnern (1979). On Grew & Halpnern's map, the positions of the basement and the Mount Provender Formation at Maucher Nunatak are exchanged by mistake.

Abb. 23: Geologie der Region des Mount Provender (nach Grew &Halpnern 1979) mit der Lage des Maucher Nunatak. Auf der Karte von Grew & Halpnern sind die Signaturen von Basement und Mount-Provender-Formation am Maucher Nunatak verwechselt.

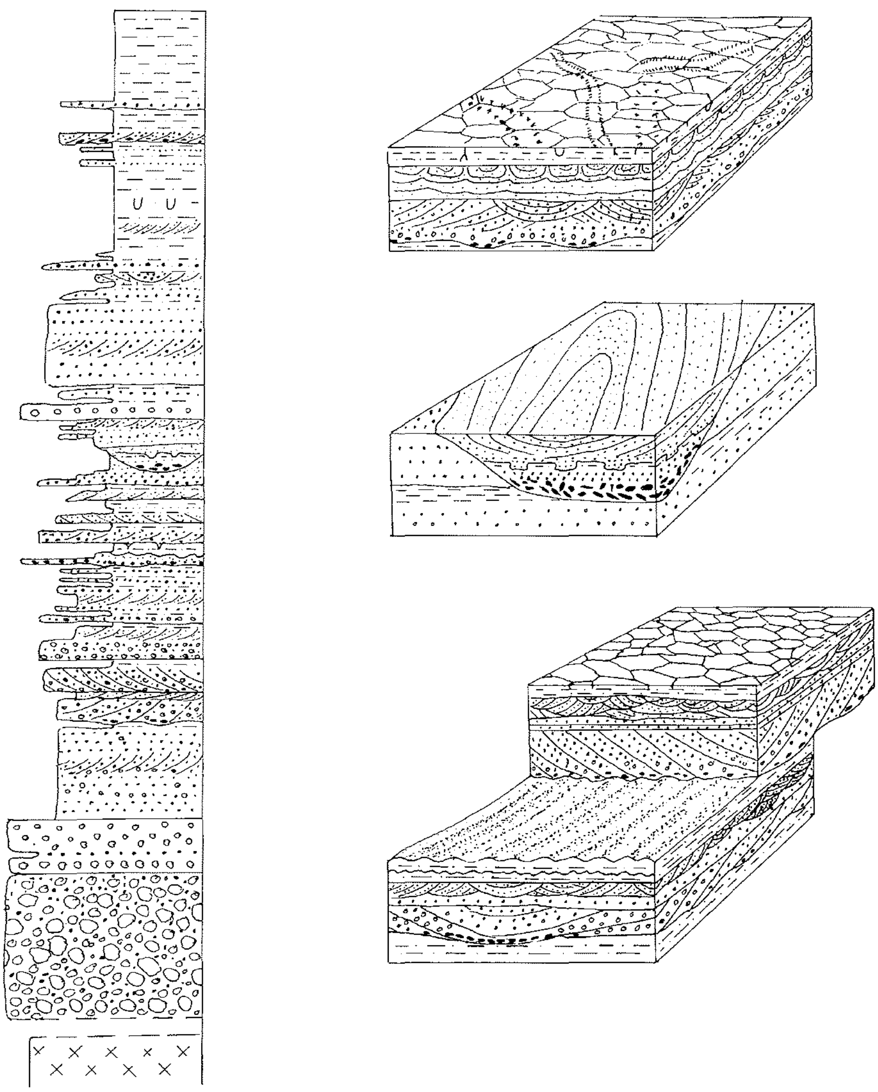

Fig. 24: Sedimentary section of Mount Provender Formation at Maucher Nunatak.

Abb. 24: Säulenprofil der Mount-Provender-Formation am Maucher Nunatak.

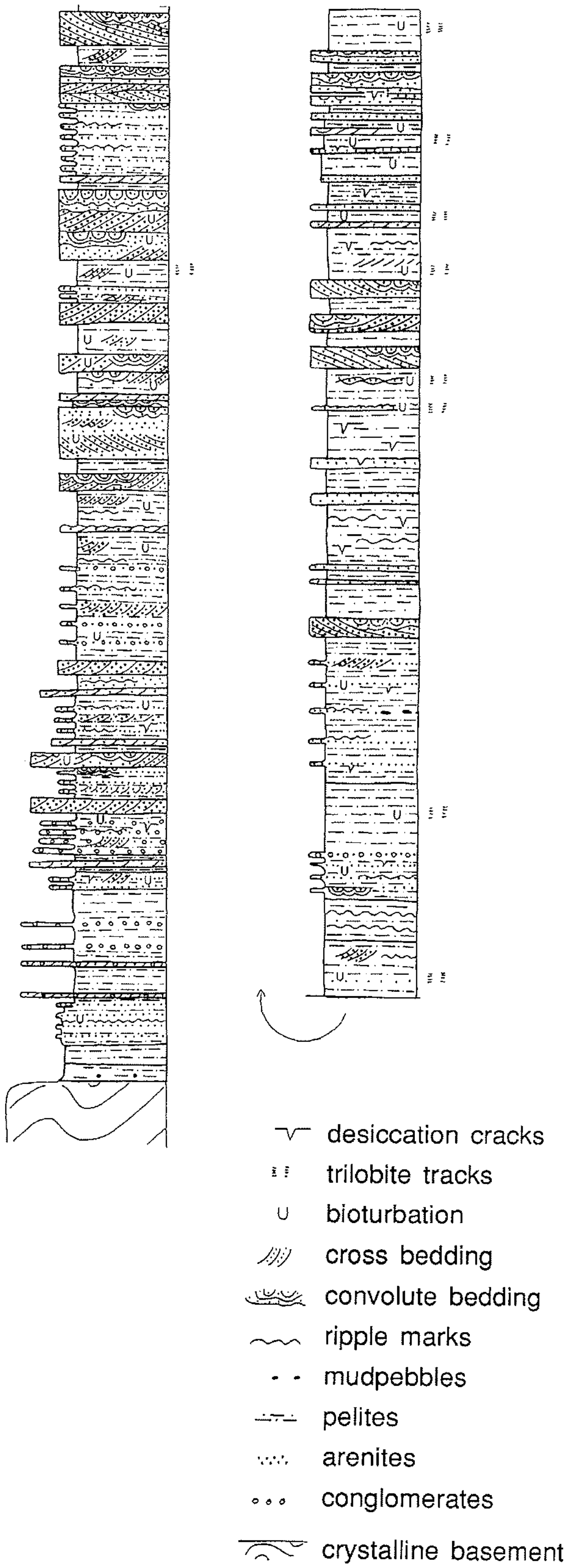

Fig. 25: Sedimentary section of Mount Provender Formation at Mount Gass.

Abb. 25: Säulenprofil der Mount-Provender-Formation am Mount Gass.

Fig. 26: Fanglomerates of Mount Provender Formation northeast of Wedge Ridge.

Abb. 26: Fanglomerate der Mount-Provender-Formation nordöstlich von Wedge Ridge.

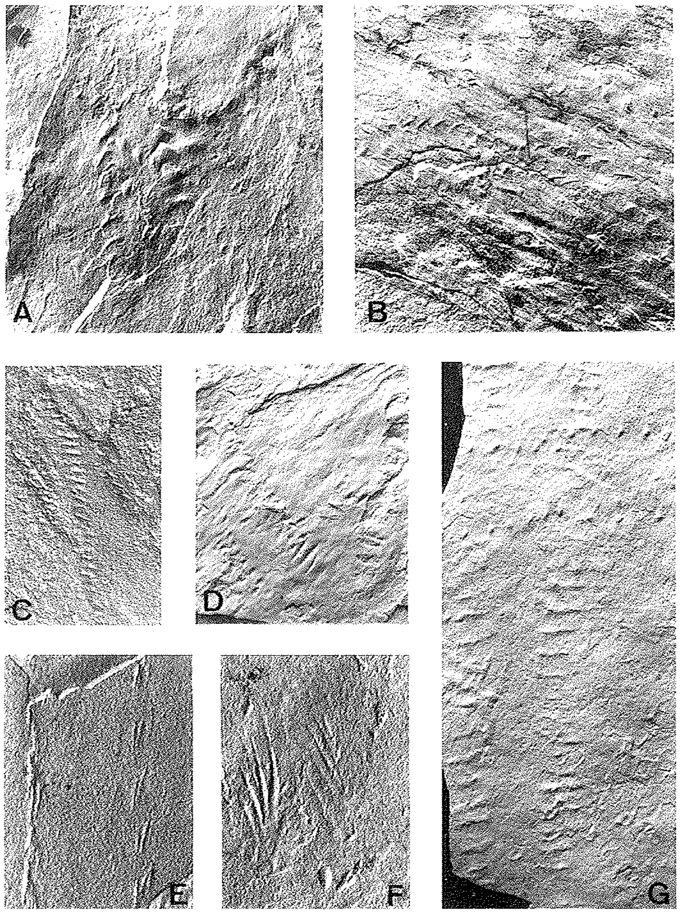

Fig. 27: Traces of trilobites in the Mount Provender Formation at Mount Gass (x0.65).

Abb. 27: Arthropodenspuren (Trilobiten ?) aus der Mount-Provender-Formation am Mount Gass (0,65-fach).

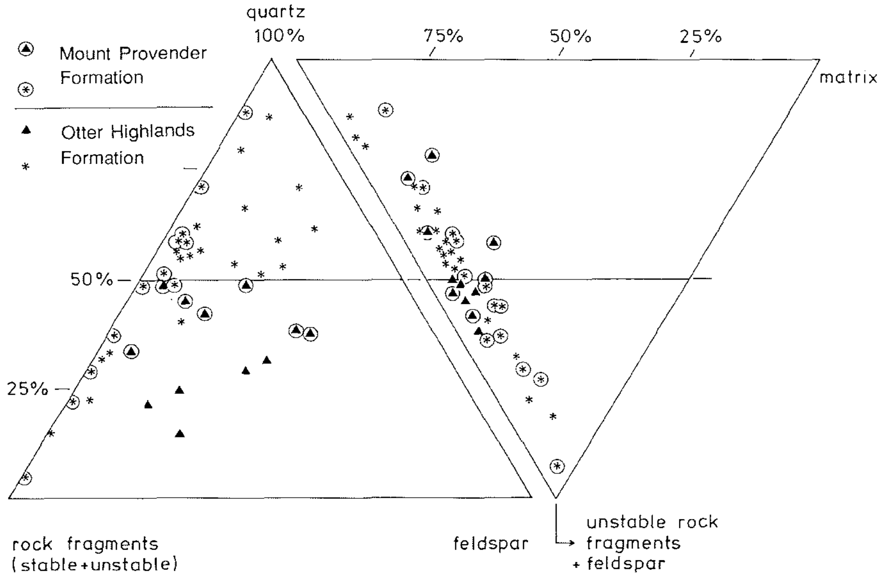

Fig. 28: Modal composition of arenites of the Blaiklock Glacier Group; triangles = this study; asterisk = from CLAKSON & WYETH (1983).

Abb. 28: Modalbestand der Sandsteine der Blaiklock-Glacier-Gruppe. Dreiecke = eigene Untersuchungen, Sterne = aus CLARKSON & WYETH (1983).

plete data set, the results discussed below should be considered as preliminary.

Nine samples from different sites yielding 36 specimens were investigated. For most of the samples, the natural remanent magnetization had an inclination between 0° and ± 30°. Alternating-field demagnetization up to 60 mT generally did not produce significant changes in the remanence intensity and direction. In most cases, progressive thermal demagnetization up to 700 °C yielded characteristic magnetizations with a low inclination. Examples of the thermal demagnetization results are shown in Figure 29 (as plots of vector components and intensity as functions of heating temperature).

Thermal demagnetization shows that hematite with a Curie temperature of about 670 °C is the predominant carrier of the remanent magnetization in these rocks. This is confirmed by the high stability of the natural remanent magnetization in the alternating-field demagnetization tests and by isothermal remanence acquisition experiments.

One would expect a predominantly low inclination of the characteristic remanent magnetization if the magnetization was acquired in Ordovician times. According to palaeocontinental reconstructions (e.g. SMITH et al. 1981, ZIEGLER 1981) and the palaeomagnetic pole data base (PIPER 1987), Antarctica would have been situated at low latitudes during the Ordovician, leading to low inclinations of remanent magnetizations in rocks of this age. If the magnetization had been acquired in Antarctica during Permian times, it would have a steep inclination, since at this time Antarctica was in polar regions. These preliminary palaeomagnetic results, therefore, support an Ordovician rather than a Permian age for the Blaiklock Glacier Group.

5.2.3 The Otter Highlands Formation

The Otter Highlands Formation is exposed only in the northern Otter Highlands. Whether it represents the more distal sequence of the Mount Provender Formation or the overlying part is unclear due to the lack of continuous sections. The type section at MacQuarry Edge was described by CLARKSON & WYETH (1983). Thin-section studies confirm their results. The sandstones are composed of quartz (24 %), feldspar (25 %) and rock fragments (51 %). The feldspar content is higher than in the rocks of the Mount Provender Formation. The amount of matrix is low. The cement is calcite. Detrital mica is common, unstable heavy minerals such as garnet are enriched up to 30 % in placers. The sandstones can be classified as lithic arenites. They represent fluvial deposits laid down in a deltaic environment.

The direction of sediment transport varies considerably in the Mount Provender Formation. A NE to SW current direction was determined by crossbed measurements in the Otter Highlands Formation (Fig. 30).

6. JURASSIC SEDIMENTS

The easternmost Nunatak of the Shackleton Range, which is shown at about 80° 30' S, 19° W on CLARKSON's (1982a) map, consists of few meters of flat-lying black and green „shales and sandstones“. Under the microscope the fine-grained sediments exhibit clusters of quartz and feldspar clasts supported by a very fine matrix of quartz and white mica (illite?). These sediments are interpreted as tuffites. A K/Ar analysis of the 2-6 µm fraction yielded a date of 185 Ma (BUGGISCH et al. 1994, Tab. 2). Therefore these tuffaceous sediments probably belong to the Jurassic volcanic cycle of Antarctica (Ferrar Dolerite and associated sediments, ELLIOT & LARSEN 1993).

7. THE SEDIMENTARY ENVIRONMENTS

The following depositional model must be taken into consideration: The Shackleton Range Metamorphic Complex mainly consists of Middle to Late Precambrian continental crust with

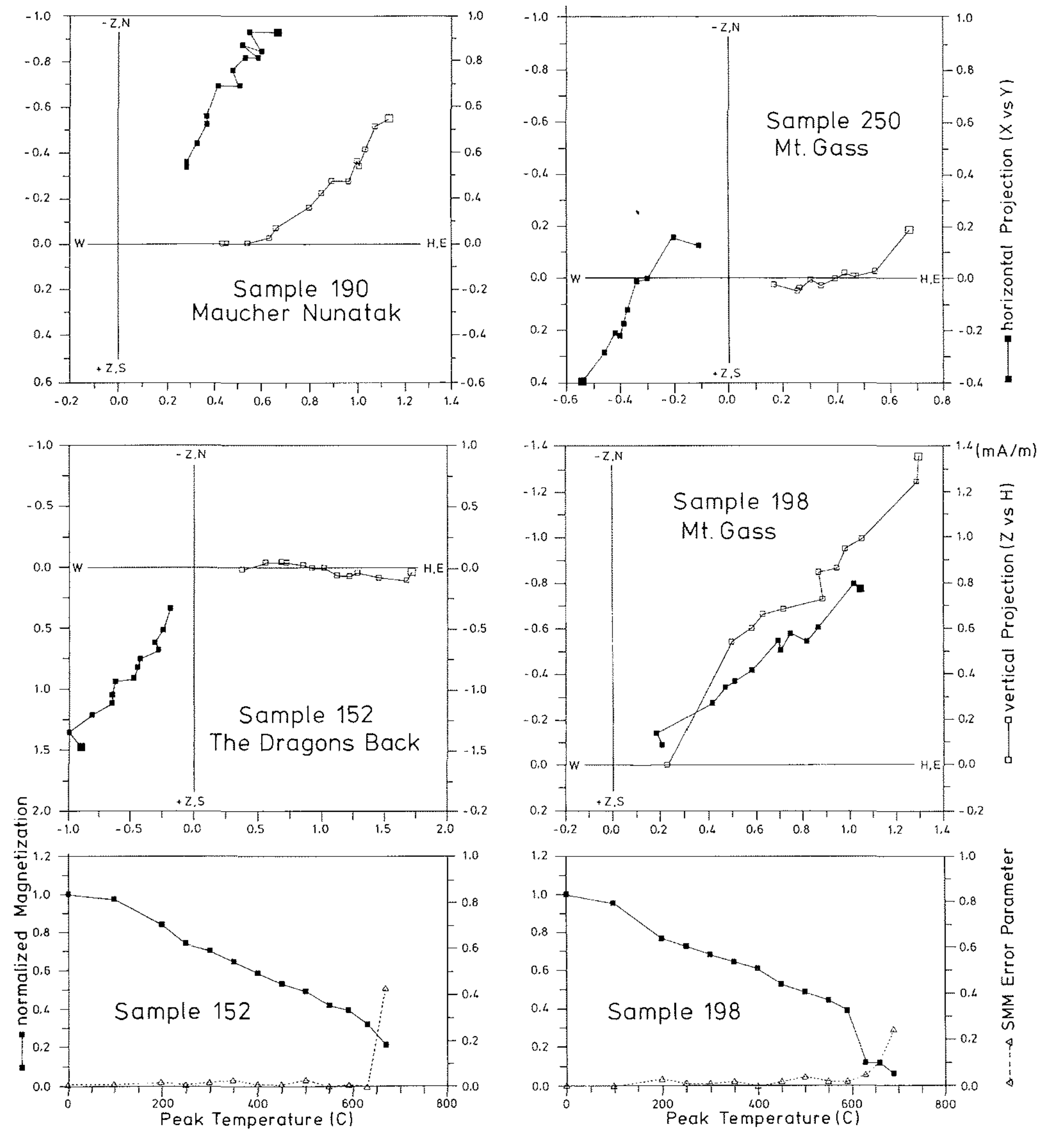

Fig. 29: Orthogonal projections of magnetization vector end points during progressive thermal demagnetization. Solid symbols = projections on the horizontal plane, open symbols = projection on a vertical plane through the horizontal component, showing the inclination of the remanent magnetization. Large symbols indicate the natural remanent magnetization. The direction of the horizontal component has no significance, since azimuthal orientation was not measured during sampling. The temperature steps applied are indicated in the lower part of the figure, where the decrease of the magnetization intensity reveals the blocking temperature distribution.

Abb. 29: Orthogonale Projektion der Magnetisierungsvektoren während progressiver thermischer Entmagnetisierung. Ausgefüllte Symbole = Deklination; offene Symbole = Inklination. Große Symbole = Natürliche Remanente Magnetisierung (NRM). Die Richtung der horizontalen Komponente besitzt keine Signifikanz, da der Azimuth während der Probennahme nicht orientiert worden war. Die Temperaturschritte während der Entmagnetisierung sind unten angegeben, wobei die Intensitätsabnahme der Magnetisierung die Verteilung der „Blokking"-Temperaturen widerspiegelt.

a K/Ar biotite closure age of about 1600 Ma in the Read Group. In the northern Shackleton Range, the Stratton and Pioneers Groups were strongly metamorphosed during the Ross Orogeny.

The Stephenson Bastion Formation and the Wyeth Heights Formation(?) probably form the oldest sedimentary cover. The predominance of microcline in the feldspathic greywackes is typical of a metamorphic or plutonic source area. The sediments were probably deposited in a shallow-marine environment with increasing maturity from the base to the top of Stephenson Bastion, as well as from east to west (e.g. from Stephenson Bastion to the Southern Otter Highlands, Fig. 31). Metamorphism of these sediments during the Late Precambrian is documented by scattered K/Ar dates of about 1000 Ma (940-1050 Ma) from the 2-6 μm fractions of siltstones from Stephenson Bastion. The provenance of the sediments of the Stephenson Bastion Formation and the Wyeth Heights Formation is unclear. Probably, both were deposited north of the Read Group and thrust above this (not exposed) part of the crystalline basement.

The Watts Needle Formation rests unconformably on the deeply weathered Read Group. It was deposited on a shallow-marine, epicontinental shelf (Watts Needle Shelf in Fig. 32) and forms a deepening-upward sequence from a basal soil through coastal sandstones to intertidal carbonates and subtidal shales.

The southward tectonic transport of the Mount Wegener Nappe suggests that the Mount Wegener Formation was deposited in the Mount Wegener Basin north of the Watts Needle Shelf. A basinal marine environment is substantiated by the presence of distal turbidites and the trace fossil *Oldhamia.* Limestone clasts in the conglomerates were derived from shallow-marine carbonates. The dominance of plagioclase (up to 50 vol.%) in the feldspathic greywackes and rare volcaniclasts in the conglomerates indicate a volcanic source area. This is consistent with a (intracontinental) back-arc environment for the deposition of Mount Wegener Formation (Fig. 32).

The Haskard Highlands Formation (Middle Cambrian) consists of dark siltstones and finegrained calcareous sandstones containing brachiopods and trilobites. The lack of coarse-grained clastics and the fauna suggest deposition in a low-energy environment on a probably extensive open-marine shelf. The original depositional area is unknown because of the allochthonous (tec-

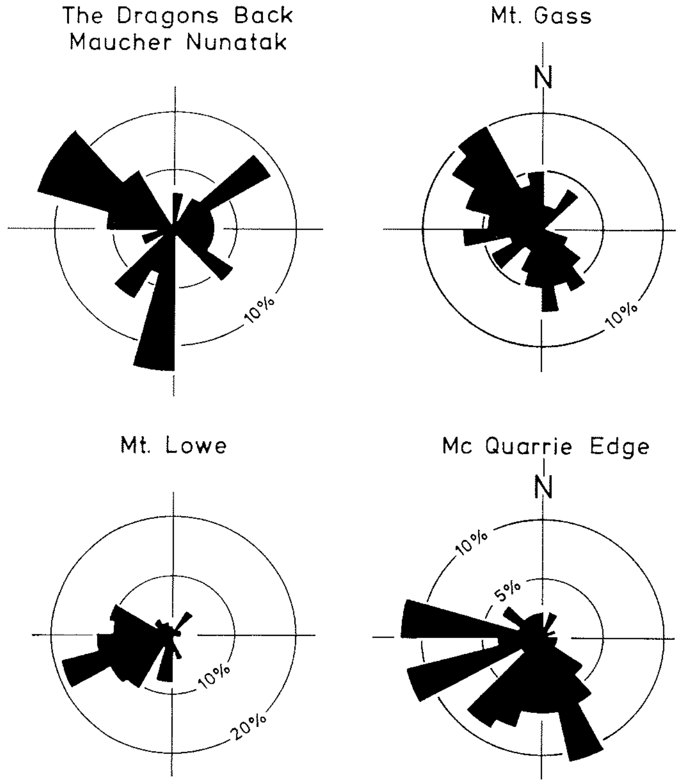

Fig. 30: Dip of crossbeds in the Mount Provender and Otter Highlands Formations.

Abb. 30: Einfallen von Schrägschichtungskörpern in den Mount-Provender- und Otter-Highlands-Formationen.

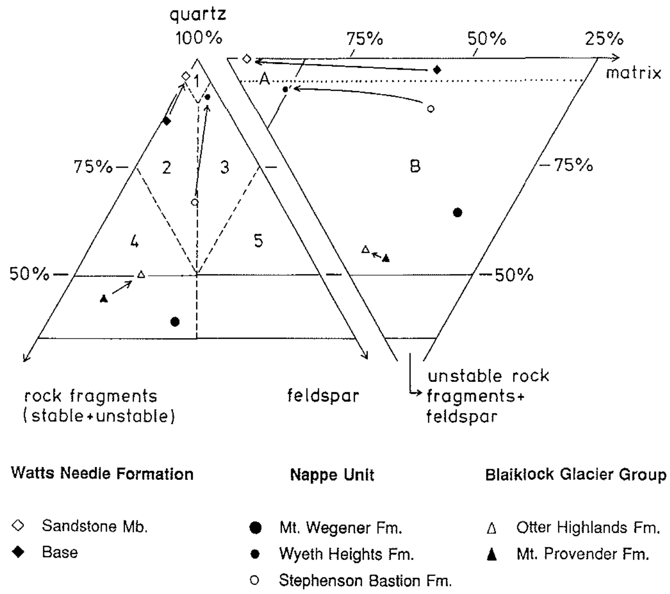

Fig. 31: Mean modal composition of the sandstones in the Shackleton Range.

Abb. 31: Mittlerer Modalbestand der Sandsteine in der Shackleton Range.

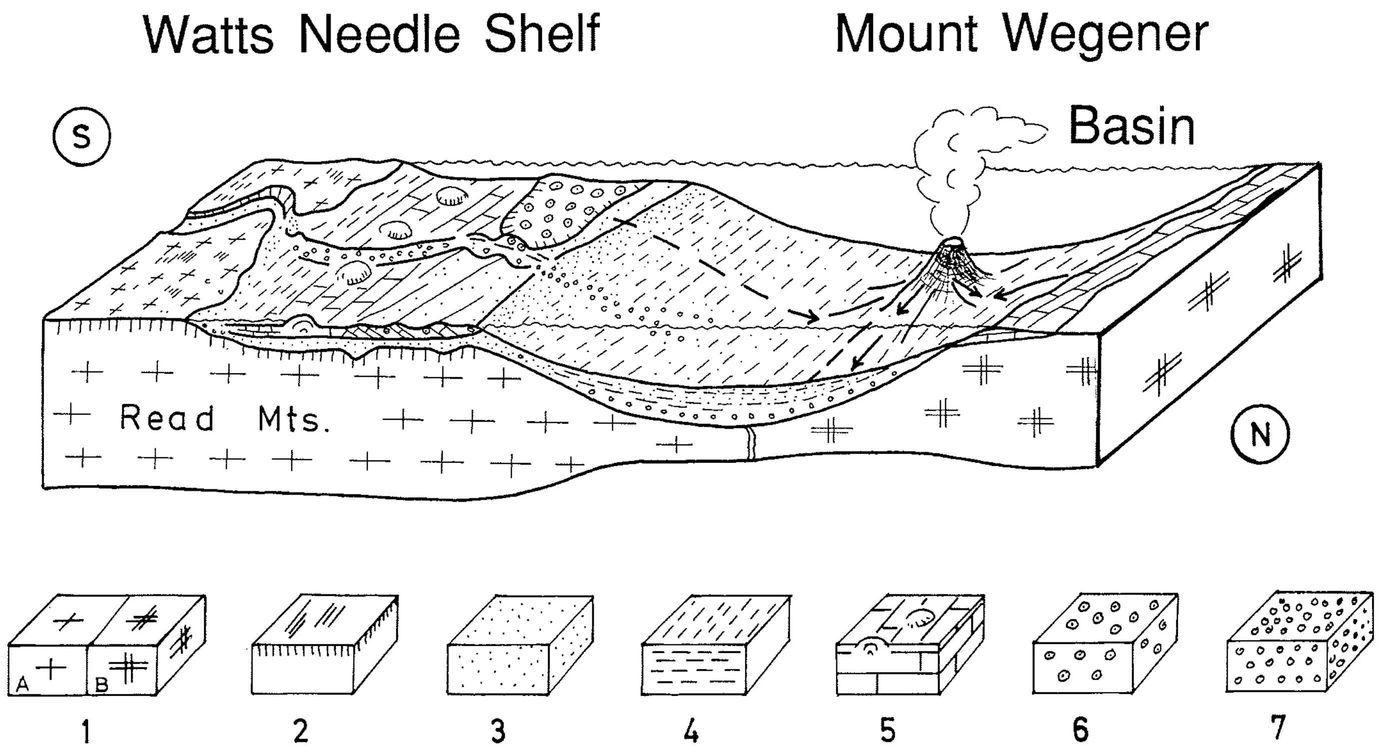

Fig. 32: Diachronous depositional model of Late Precambrian to Early (Middle) Cambrian metasediments of the Shackleton Range. 1 = basement rocks (A = Read Group, B = Pioneers Group and Stratton Group), 2 = palaeosoil, 3 = arenites, 4 = pelites, 5 = carbonates (including stromatolites), 6 = oolites, 7 = conglomerates.

Abb. 32: Diachrones Ablagerungsmodell der jungpräkambrischen und unterkambrischen (bis mittelkambrischen ?) Sedimente der Shackleton Range. 1 = Basement (A = Read Group, B = Pioneer und Stratton Gruppen), 2 = Paläoboden, 3 = Arenite, 4 = Pelite, 5 = Karbonate (einschließlich Stromatolithe), 6 = Oolithe, 7 = Konglomerate.

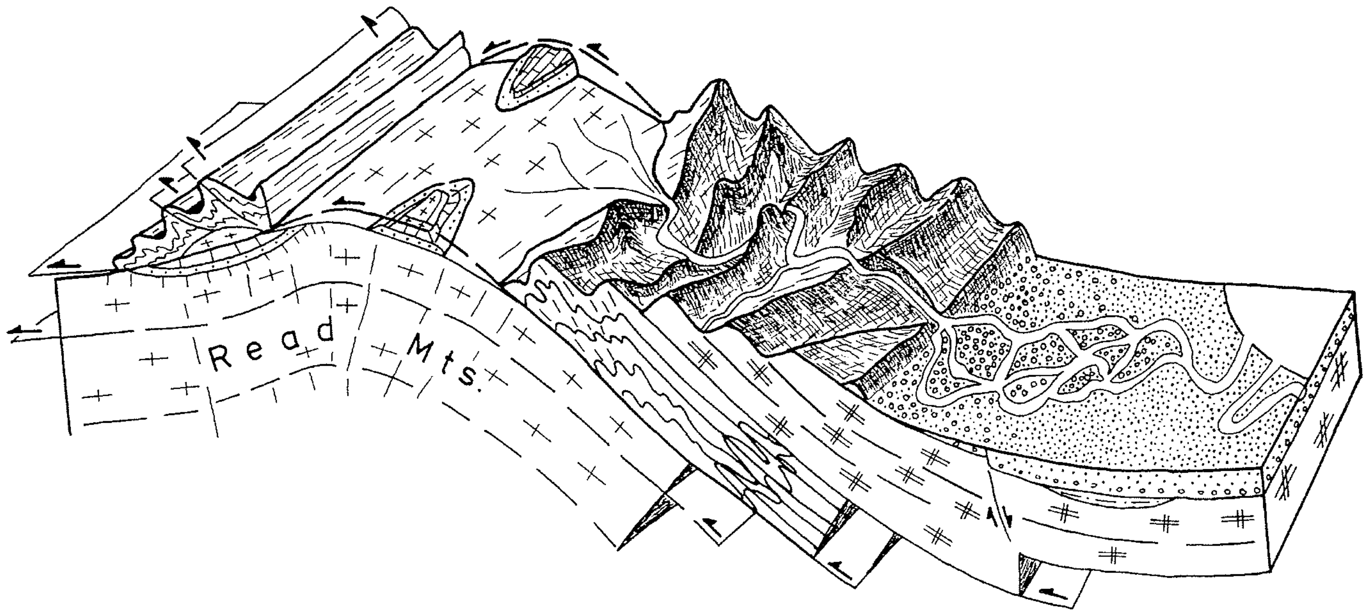

Fig. 33: Depositional model of the Blaiklock Glacier Group.

Abb. 33: Ablagerungsmodell der Blaiklock-Glacier-Gruppe.

tonic) position of the Haskard Highlands Formation on top of the northern Shackleton Range basement complex (Pioneers and Stratton Groups).

The Blaiklock Glacier Group represents a typical molasse facies related to the Ross Orogeny with proximal gravity slides grading into fan conglomerates, braided river deposits and marine siltstones and sandstones in the Mount Provender Formation. The more distal and/or younger Otter Highlands Formation consists of fluvial sandstones laid down in a deltaic environment (Fig. 33). A plate-tectonic interpretation is given by KLEINSCHMIDT & BUGGISCH (1994).

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Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr^*$	isochron data
Stephenson Bastion - Clayton Ramparts					
222	158	27.6	17.03	0.99738	
223	125	30.0	12.28	0.94843	
224	37.9	16.4	6.765	0.84129	
225	36.9	13.0	8.318	0.85872	
236	112	37.0	8.991	0.88238	
238	94.1	38.3	7.236	0.86553	
grain-size fractions					
234					
0.6-2 µm	205	70.3	8.415	0.86875	
235					
0.6-2 µm	292	55.1	15.51	0.98198	
2-6 µm	287	52.9	15.88	0.99891	
Stephenson Bastion - Ram Bow Bluff					
226	83.0	13.8	18.01	1.04589	
227	82.4	13.2	18.73	1.06436	1251 ± 24 Ma
229	107	30.4	10.41	0.90925	0.7224 ± 32
233	124	29.5	12.47	0.94230	MSWD = 2.1
243	120	38.5	9.177	0.88467	
245	71.0	39.5	5.256	0.81743	
grain-size fractions					
226					
0.6-2 µm	181	11.6	48.25	1.53200	
2-6 µm	113	13.4	24.90	1.15249	
242					
0.6-2 µm	223	85.6	7.505	0.85108	
2-6 µm	218	83.5	7.546	0.85445	
244					
0.6-2 µm	193	22.6	25.45	1.17201	
2-6 µm	96.9	20.2	14.00	0.98231	
Wyeth Heights Formation					
88-168	218	28.1	23.43	1.12729	(1150 Ma)
88-169	228	29.3	23.38	1.09935	(0.728)
88-172	174	35.1	14.70	0.97002	
88-173	186	41.0	13.37	0.90173	(1013 Ma)
88-178	127	14.0	27.26	1.10295	(0.708)

Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr^*$	isochron data
Watts Needle Formation - sandstone member					
88-1	175	133	3.836	0.78547	
88-32	173	76.0	6.656	0.78898	680 ± 57 Ma
88-33	194	12.2	48.12	1.18408	0.726 ± 8
88-50	113	30.8	10.70	0.82791	MSWD = 16
88-51	253	52.0	14.29	0.86685	
88-57	93	27.2	10.02	0.82919	
Watts Needle Formation (Mount Wegener) - shale member					
88-76	173	34.7	14.61	0.82786	
88-86	218	60.7	10.51	0.79745	584 ± 41 Ma
88-87	220	46.6	13.80	0.82322	0.708 ± 6
88-88	216	99.1	6.337	0.76056	MSWD = 5.4
88-146	208	58.2	10.44	0.79812	
88-147	217	58.6	10.80	0.79617	
Mount Wegener Formation (low-grade)					
88-132	216	46.1	13.73	0.82022	
88-133	212	160	3.852	0.74736	535 ± 9 Ma
88-136	205	69.5	8.610	0.78008	0.7139 ± 5
88-143	217	65.8	9.635	0.78604	MSWD = 1.8
88-145	156	431	1.047	0.72188	
88-152	200	71.0	8.204	0.77687	
88-155°	195	20.3	28.16	0.78909	
88-156	229	56.7	11.79	0.80247	
Mount Wegener Formation (very low-grade)					
88-108°	211	46.4	13.28	0.81018	
88-109	177	113	4.565	0.74844	561 ± 18 Ma
88-111	160	72.0	6.477	0.76335	0.7113 ± 17
88-117	193	59.6	9.473	0.78705	MSWD = 2.2
88-118	156	116	3.922	0.74223	
88-120	207	48.6	12.44	0.81210	
88-125	188	50.5	10.87	0.79660	

Tab. 1: Rb-Sr data on metasediments in the Shackleton Range. Rb, Sr concentrations in ppm, NBS 987 = 0.71023 ± 0.00007, analytical error at the 95% confidence level is ± 2% for $^{87}Rb/^{86}Sr$ and ± 0.06% for $^{87}Sr/^{86}Sr$. Quoted errors are at the level of 95% confidence. Decay constants as in STEIGER & JÄGER (1977). * normalized to $^{86}Sr/^{88}Sr = 0.1194$; ° samples omitted for regression calculation

Tab. 1: Rb-Sr Daten aus Metasedimenten der Shackleton Range.

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