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Petrogenesis of the Metasediments from the Pioneers Escarpment, Shackleton Range, Antarctica

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Summary: During the GEISHA expedition (Geologische Expedition in die Shackleton Range 1987/88), the Pioneers Escarpment was visited and sampled extensively for the first time. Most of the rock types encountered represent amphibolite facies metamorphics, but evidence for granulite facies conditions was found in cores of garnet. These conditions must have been at least partly reached during the peak of metamorphism.

For the Pioneers Escarpment a varicolored succession of sedimentary and bimodal volcanic origin is typical. It comprises:

- quartzites muscovite quartzite, sericite quartzite, fuchsite quartzite, garnet-quartz schists etc.;
- pelites: mica schists and plagioclase or plagioclase-microcline gneisses, aluminous schists;
- marls and carbonates: grey meta-limestones, carbonaceous quartzites, but also pure white, often fine-grained, saccharoidal marble, or a variety of tremolite marble, olivine (forsterite) marble, diopside-clinopyroxene-tremolite marble, etc.;
- basic volcanic rocks: amphibole fels, amphibolite schist, garnet amphibolite, and
- acidic to intermediate volcanic rocks: garnet-biotite schist, epidote-biotite-plagioclase gneiss, microcline gneiss.

These rocks are considered to be a supracrustal unit, called the Pioneers Group. In the easternmost parts of the Pioneers Escarpment, e.g. at Vindberget, non-metamorphic shales, sandstones and greywackes crop out, which are cover rocks of possibly Jurassic age. These metasediments, which represent a quartz-pelite-carbonate (QPC) association, indicate that deposition took place on a stable shelf, i.e. on the submerged rim of a craton. Marine shallow-water sedimentation including marls and aluminous clays form the protoliths. The volcanics may be part of a bimodal volcanics-arkose-conglomerate (BVAC) association.

Geochemical analyses support the assumption of volcanic protoliths. This is demonstrated especially by the elevated amounts of the immobile, incompatible high-field-strength elements (HFSE) Nb, Ta, Ti, Y, and Zr encountered in some of the gneisses. Microscopic investigation suggests the existence of ortho-amphibolites. This is confirmed by the geochemistry. A bimodal volcanic association is evident. The amphibolites plot in both the tholeiite and calc-alkaline fields. The acidic volcanics are mainly rhyolitic.

The sediments and volcanics were subjected to conditions of 10-11 kbar and 600 °C during the peak of metamorphism, i.e. granulite facies metamorphism, which can be deduced from the Fe mole ratios of 0.71-0.73 in the garnet cores. Due to the relatively low temperatures, no anatectic melting took place. The rims of the garnets show a Fe mole ratio of 0.84-0.86, and the coexisting mineral association garnet-biotite-staurolite-kyanite indicate amphibolite facies. The thermobarometry shows P-T conditions of 5-6 kbar and 570-580 °C for this stage.

The metamorphic history indicates deep burial at depths down to 35 km (subduction?) i.e. high pressure metamorphism, followed by pressure release due to uplift associated with retrograde metamorphism. This may have happened during a pre-Ross metamorphic event or orogeny. The Ross Orogeny at about 500 Ma probably just led to the weak greenschist facies overprint that is evident in the rocks of the Pioneers Group.

Finally, sedimentation resumed in the area of the present Shackleton Range, or at least in the eastern part of the Pioneers Escarpment, probably when detritus from erosion of the basement (Read Group and Pioneers Group) was deposited, forming sandstones and greywackes of possibly Jurassic age. There is no indication that these sediments belong to the former Turnpike Bluff Group.

Zusammenfassung: Während GEISHA (Geologische Expedition in die Shackleton Range 1987/88) wurde erstmals das Pioneers Escarpment der Shackleton Range intensiver beprobt. Es treten überwiegend Metamorphite der Amphibolitfazies auf. Granulitfazielle Bildungsbedingungen sind für Granatkerne nachweisbar. Sie sind vermutlich während des Höhepunktes der Metamorphose erreicht worden.

Für das Pioneers Escarpment ist eine bunte Abfolge von Sedimentgesteinen und bimodalen Vulkaniten typisch. Sie umfaßt

- Quarzite: Muskowitquarzite, Serizitquarzite, Fuchsitquarzite, Granat-Quarz-Schiefer, karbonatische Quarzite,
- Pelite: Glimmerschiefer und Plagioklas- bzw. Plagioklas-Mikroklin-Gneise, Al-reiche Schiefer,
- Mergel und Karbonate: graue Metakalksteine, karbonatische Quarzite, aber auch reine, weiße, oft feinkristalline, „zuckerkörnige" Marmore, Tremolitmarmor, Olivinmarmor, Diopsid-Klinopyroxen-Tremolit-Marmor etc.,
- basische Vulkanite: Amphibolfels, Amphibolschiefer, Granat-Amphibolit und
- saure bis intermediäre Vulkanite: Granat-Biotit-Schiefer, Epidot-Biotit-Plagioklas-Gneis, Mikroklin-Gneis.

Diese Gesteine repräsentieren die Pioneers Group. Nur in den östlichsten Aufschlüssen des Pioneers Escarpment, in Vindberget, sind nichtmetamorphe Tonsteine, Sandsteine und Grauwacken vermutlich jurassischen Alters aufgeschlossen. Die Metasedimente, die eine Quarz-Pelit-Karbonat-Assoziationen darstellen, sprechen für eine Sedimentation auf einem stabilen Schelf, d.h. auf dem zeitweilig untergetauchten Rand eines Kratons. Marine Flachwassersedimentation mit Kalken und Mergeln aber auch Al-reiche Tone bilden die Ausgangsgesteine. Die Vulkanite können Teil einer Vergesellschaftung von bimodalen Vulkaniten-Arkose-Konglomerat (BVAC association) sein.

Der vulkanischer Einfluß ist durch geochemische Untersuchungen nachweisbar. Hierfür sprechen die höheren Werte speziell der immobilen, inkompatiblen Spurenelemente Nb, Ta, Ti, Y, und Zr, die in einigen Gneisen angetroffen werden. Auch die Amphibolite, die bereits bei mikroskopischer Untersuchung ein vulkanisches Ausgangsgestein vermuten ließen, sind nach ihren geochemischen Charakteristiken Ortho-Amphibolite. Ein bimodaler Vulkanismus herrschte daher vor. Die Amphibolite liegen im Tholeiit- und im Kalkalkali-Basalt-Feld. Die sauren Vulkanite weisen überwiegend rhyolitschen Chemismus auf.

Die Sedimente und Vulkanite wurden während des Höhepunktes der Metamorphose einem Druck von 10-11 kbar und Temperaturen von 600 °C unterworfen, d.h. granulitfazieller Metamorphose, die an Granatkernen anhand der Fe-Molverhältnisse von 0,71-0,73 nachgewiesen werden kann. Infolge der zu niedrigen Temperatur wurde jedoch keine Anatexis bewirkt. Die Außenzone der Granate weist dagegen andere Fe- Molverhältnisse (0,84-0,86) auf, und die koexistierenden Minerale Granat-Biotit-Staurolith-Disthen sprechen für Amphibolitfazies. Die Thermobarometrie ergibt Drücke von 5-6 kbar und Tempera-

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turen von 570-580 °C. Der Metamorphoseablauf spricht für eine Versenkung bis 35 km (Subduktion?), dann Heraushebung und Druckentlastung, verbunden mit retrograden Metamorphosebedingungen. Dies kann während einer Prä-Ross-Orogenese erfolgt sein. Die Ross-Orogenese vor etwa 500 Ma hat vermutlich nur noch zu einer schwachen, grünschieferfaziellen Überprägung geführt, die ebenfalls an Gesteinen der Pioneers Group nachweisbar ist.

Das Gebiet der heutigen Shackleton Range, oder zumindest die östlichen Ausläufer des Pioneers Escarpment waren erneut Sedimentationsraum, als Sandsteine und Grauwacken - Verwitterungsschutt des Basements (Read Group und Pioneers Group) - vermutlich im Jura abgelagert wurden. Eine Zuordnung dieser Gesteine zur früheren „Turnpike Bluff Group“ ist nicht wahrscheinlich.

1. PREVIOUS WORK, NOMENCLATURE AND DEFINITION OF STRATIGRAPHIC UNITS

The northwestern part of the Shackleton Range was first visited during the Transantarctic Expedition of 1955-1958, whereas the northeastern part of the range, the Pioneers Escarpment, was not reached until 1968 by a land traverse of the British Antarctic Survey. About 10 years later several outcrops in the Pioneers Escarpment were visited on the 22 SAE (Soviet Antarctic Expedition 22) in 1977 and the 24 SAE in 1978/79. During the GEISHA expedition (Geologische Expedition in die Shackleton Range, 1987/88), all areas of the Shackleton Range were revisited, and practically all outcrops of the Pioneers Escarpment were visited by helicopter and sampled .

Stephenson (1966) distinguished the following stratigraphic units on the first geological map of the northwestern part of the Shackleton Range: Blaiklock Beds, Turnpike Metamorphics, and Shackleton Metamorphics. The rocks of the Shackleton Metamorphics were described as the most extensively developed, forming the northern and central mountains in the western part of the Shackleton Range, and they also were inferred to form much of the range further to the east.

More detailed surveys of the northern and northwestern part of the range (comprising the Haskard Highlands, Lagrange Nunataks, northern Fuchs Dome, and Herbert Mountains) were carried out by Hofmann (1982), Hofmann & Paech (1980, 1983), and Marsh (1983a and b, 1984), and a number of formations and sequences were recognized, and named after local occurrences in each of the areas investigated.

The Shackleton Metamorphics of Stephenson (1966) have been variously referred to as
- Shackleton Range Metamorphic Complex (Clarkson 1972, 1981, 1982, Grew & Halpern 1979, Marsh 1983a),
- Shackleton Crystalline Complex (Paech 1978, 1985, Hofmann & Paech 1980, 1983), and
- Shackleton Metamorphic Complex (Hofmann 1982)

All previous workers subdivided the metamorphics into two units: a lower and an upper structural stage, or a Precambrian Lower Crystalline stage (K_1,) and a Precambrian Upper Crystalline stage (K_2) (Paech 1985). For the upper structural stage, a variety of names have been used: the „metasediments“ of Clarkson (1981, 1982), the Skidmore Group (Paech 1978, 1985, Hofmann & Paech 1980, 1983), the Skidmore Complex (Kamenev & Semenov 1980), the Herbert Series (Hofmann 1982), and the Haskard and Schimper groups (Marsh 1984). Additionally, the groups were subdivided and local names were given to formations and sequences.

During a Shackleton Range workshop at the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, in April 1990, which brought together scientists from the USSR, the former GDR, UK and the FRG, i.e. from all countries which had worked in the Shackleton Range, it was decided to subdivide the metamorphics into the Read, Pioneers and Haskard groups (Tessensohn & Thomson 1990). The name Haskard Group has since been replaced by Stratton Group (Schubert et al., in press) to avoid further confusion, as the name Haskard was used by Marsh (1983, 1984) for supracrustal rocks.

The Stratton Group is encountered in the northern Shackleton Range and comprises all the gneisses, blastomylonites and migmatites (e.g. the former Fuchs Dome Gneiss, Mathys Gneiss, Wedge Ridge Gneiss, Mount Weston Gneiss, Wiggans blastomylonite etc.). For further details, see Schubert et al., (in press). Rocks of the Stratton Group are probably in tectonic contact with the Pioneers Group.

The Pioneers Group is represented by a variety of varicoloured metasediments and metavolcanics which can be traced from the Pioneers Escarpment to the Herbert Mountains and further west to the Lagrange Nunataks and Haskard Highlands.

The rock types encountered in the Pioneers Escarpment, their distribution, depositional environment, metamorphic history, and plate tectonic setting are described in the following chapters.

2. PIONEERS GROUP LITHOLOGIES

2.1 *Metasediments*

The metamorphic rocks of the Pioneers Group clearly represent a variegated series of metasedimentary rocks. The rock types can be labelled as quartzites, mica schists, Al-rich schists and gneisses, calc-silicate schists, metalimestones and marbles, and amphibolites. Several very distinctive types of metasediments are encountered in the northern Shackleton Range:
- the metalimestones may occur as very pure, white marbles,
- the metaquartzites are partly greenish due to a small amount of fuchsite,
- kyanite schists and staurolite-garnet-kyanite schists, derived from protoliths rich in alumina.

Especially the fuchsite quartzite and, to a lesser degree, the marbles can be used as marker horizons to track the metasedimentary sequence throughout the northern Shackleton Range. The prevailing quartz, pelite, and carbonate rocks make the metasediments of the Pioneers Group a typical QPC association (CONDIE 1989).

2.1.1 Quartzites

A variety of quartzites occurs in the Pioneers Group metasediments. In most cases, accessory amounts of various micas are present. Biotite quartzites were mapped in the NE part of Freshfield Nunatak and at Meade Nunatak, a muscovite quartzite at Jackson Tooth, and a sericite quartzite at Bergan Castle. But the most characteristic quartzites are the pale green fuchsite quartzites, which can be used as marker horizons. They can be traced from Sauria Buttress to Mount Dewar, Lewis Chain and they also crop out west of the Herbert Mountains in the True Hills area (Fig. 1).

Different types of quartzitic schists and quartz-rich gneisses can be distinguished, e.g. a quartz-feldspar-microcline (perthite) gneiss (Lindqvist Nunatak) or garnet-quartz schists (Nobleknausane). One sample (HR 041) from Sauria Buttress contains kyanite and rutile, another sample tourmaline (HR 031, Jackson Tooth). SiO_2 is as high as about 98 % in the fuchsite quartzite of Sauria Buttress. The Bergan Castle and the Mount Dewar samples are similarly pure quartzites containing 96.41 and 94.25 % SiO_2, respectively.

The quartzites show fine- to coarse-grained granoblastic consertal texture, sometimes blastomylonitic texture with the micas recrystallized, and strongly unidirectional orientation. Even the quartz grains sometimes show elongation due to intense stress. Despite the deformation and /metamorphism, cross-bedding is preserved.

2.1.2 Mica schists and gneisses

Naturally the mica schists and gneisses are the most diversified group of rocks, but also the least typical one. Generally the mica schists contain biotite, but muscovite and/or sericite, mainly secondary, occur as well. Garnet is very common and often displays fractures filled with muscovite, sericite or sillimanite needles. Plagioclase and perthitic K-feldspar may occur together (HR 012, Nobleknausane) .

The schists may contain a variety of accessory minerals like sillimanite, apatite, zircon, epidote, opaque minerals (ilmenite and others), tourmaline, orthite. Chlorite, saussurite, prehnite and muscovite are found as secondary minerals.

Often, the mica schists show blastomylonitic texture, with a distinct mineral layering (e.g. on Lindqvist Nunatak) or distinct, very fine-grained mylonite layers, e.g. at M'Clintock Bastion. At the same locality, crenulation cleavage was observed which had even affected the garnets.

2.1.3 Al-rich schists and gneisses

Some metasediments are characterized by a high Al_2O_3 content, which is expressed by the presence of mainly kyanite and staurolite. The staurolite of the Lord Nunatak sample shows numerous quartz inclusions, which form a helicitic structure. Garnet also shows numerous inclusions. Additionally feldspar (alkali-feldspar and plagioclase An_{30}) and biotite occur.

The staurolite-kyanite-garnet schist from the Lord Nunatak (HR 026) proved to have more than 26 % Al_2O_3. But it can be shown in correlation diagrams after VALETON (1972) that the Al_2O_3 content was not enriched in the original rock during weathering. This means that the protolith was not a bauxite, or bauxitic or lateritic clay.

As staurolite and kyanite coexist in these schists, they were used for mineral analyses to estimate the P-T conditions during the peak metamorphism (see chapter 7).

2.1.4 Calcsilicate schists, metalimestones, and marbles

The calcareous metasediments range from calcareous quartzites to metalimestones with a varying degree of quartz content (Fig.2) to different types of marble, including a pure white variety of the Carrara type.

The following types of marbles were sampled in the northern Shackleton Range:

- tremolite marble,
- olivine-tremolite marble,
- chondrodite-olivine marble,
- tremolite-muscovite marble, graphite bearing,
- diopside-tremolite marble,
- pure, white, Carrara-type marble.

A silicate marble, containing olivine, diopside (some passing peripherally into tremolite), and tremolite was found at Whymper Spur. The clinopyroxene and the tremolite tend to form clusters.

Nearly all marble occurrences show light-green to yellow grains and patches of olivine and white tremolite. The composition of the olivines is generally close to that of forsterite. They may be partially serpentinised.

The content of forsterite, $Mg_2(SiO_4)$, indicates the presence of magnesium and silica, i.e the protolith was most probably a quartz-bearing dolomitic limestone or a dolomite. Most of the calcareous rocks in the northern Shackleton Range have a content of 11-23 % MgO. According to the definition of PETTIJOHN (1957), an MgO content of 19.5-21.6 % indicates a dolomite.

There are just three samples from the Spaeth Nunatak, which have a MgO content of 0.36 %, 2.95 % and 3.39 %, respectively. These samples are remarkable with respect to two more as-

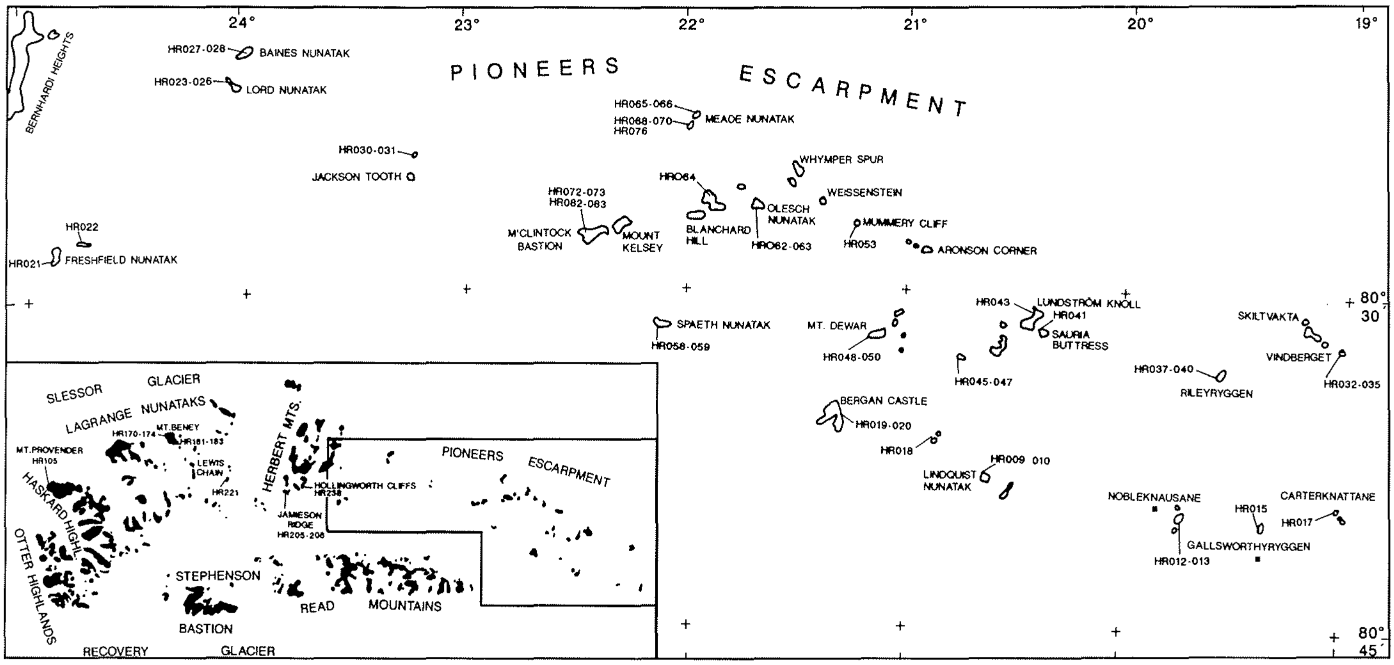


Fig.1: The northern and northeastern Shackleton Range, including Pioneers Escarpment, Herbert Mountains, and Lagrange Nunataks, showing outcrop areas and sample localities.

Abb. 1: Die nördliche und nordöstliche Shackleton Range mit Pioneers Escarpment, Herbert Mountains und Lagrange Nunataks: Aufschlüsse und Probenpunkte.

pects: They are the only samples containing opaque ore minerals and they have a comparatively high strontium content (809, 1395 and 1970 ppm), whereas all other samples show a strontium content between 39 and 65 ppm. Besides the ore at Spaeth Nunatak, the opaque minerals also include graphite, e.g. at Aronson Corner, demonstrating a slight amount of organic material in these metalimestones .

The number of analyses is definitely too small for a statistically significant result, but it seems that the northernmost outcrops (Aronson Corner-Whymper Spur) show a higher SiO_2 content than the outcrops further south (Chevreuil Cliffs, Spaeth Nunatak, M'Clintock Bastion, Jackson Tooth, Hollingworth Cliffs), although the pure, white marble of the Weissenstein is in the north as well. As the mainland was probably in the south or southeast of these localities during the time of deposition of the Pioneers Group limestones and dolomite, a larger influx of clastic sediments and thus a higher content of SiO_2 would be expected in the southern outcrops.

Clinohumite/chondrodite was also found on the Spaeth Nunatak. Minerals of the humite group often indicate contact metamorphism by granitic intrusions, and the granites are thought to supply the fluorine in the metadolomites. Humite-clinohumite group minerals were tentatively identified in some of the marbles and their metasomatic origin was inferred by OLESCH & SCHUBERT 1988). But fluorine does occur relatively commonly in dolomite and can be correlated with a slightly evaporitic environment (FÜCHTBAUER 1988). This seems to be an equally appropriate explanation .

The question whether the protolith was a sediment or a carbonatite can be answered clearly. The concordant layering, the occurrence of the calcsilicate rock and marble in horizons that can be followed throughout the northern Shackleton Range, and additionally the geochemical characteristics are all in favour of a sedimentary, non-magmatic origin.

2.2 *Metavolcanics*

Microscopically and geochemically, amphibolites and some felsic gneisses revealed typical volcanic features. Relics of igneous and pyroclastic textures have been mentioned already by KAMENEV & KAMENEVA (1993 unpubl. report) in rocks of Mount Skidmore (Lagrange Nunataks) and Herbert Mountains. This is also true of samples from the northern and southern sides of Mount Beney, which were grouped by MARSH (1984) with the infracrustal rocks (Stratton Group), but also of the mafic and felsic rocks of the Pioneers Group in the Pioneers Escarpment (ROLAND et al., in press, and chapter 5).

2.2.1 Amphibolites

The amphibolites normally consist of plagioclase, hornblende (some with quartz inclusions), and biotite, which often shows inclusions of sphene, zircon, rutile (sagenite), leucoxene. At Lindquist Nunatak the feldspar (An_{55}) shows very weak normal zoning. On Carterknattane, all minerals are strongly altered. The core of the hornblende is chloritised, the feldspars (some microcline) saussuritised. This amphibolite-mica schist contains biotite, as well as muscovite, and accessory apatite.

In other places, e.g. the Lord Nunataks, an amphibole fels (HR 023) was encountered, which was definitely derived from a non-sedimentary protolith, i.e. a former lamprophyre or a basic ash. The amphibole fels revealed higher values of chromium (993 ppm; sample HR 025 even 1972 ppm Cr), nickel (581 ppm) and iron (12.37 %). Another sample (HR 024) from the Lord Nunatak showed a garnet amphibolite, with idioblasts of garnet and amoeboid opaque minerals. Its iron content is 14.51 %. At Meade Nunatak, the hornblende has a relict texture, which may be inherited from former clinopyroxene. Epidote is also present. The protolith may be a basic intrusive or sub-volcanic rock.

We assume that the amphibolites are generally derived from basic volcanic rocks. This is in agreement with the geochemical data (see chapter 5).

2.2.2 Gneisses of rhyolitic composition

There is a variety of gneisses with a rhyolitic composition. The geochemical data show that some contain elevated trace element concentrations, which is in agreement with the assumption of volcanic protoliths. An epidote-biotite-plagioclase gneiss with dark-green to brown biotite and inverse zoning of plagioclase (core An_{25}, rim An_{40}) from Meade Nunatak and two garnet-biotite schists from the outcrop south of Meade Nunatak are examples of HFSE-enriched rocks (see chapter 5).

3. SEDIMENTS IN THE VINDBERGET AREA

A variety of sediments occur east of Vindberget in the easternmost outcrops of the Pioneers Escarpment. They are unmetamorphosed or show only incipient metamorphism. They strike NW-SE and dip slightly towards the NE. The rocks can be referred to as shales, some are dark-grey to black shales. The shales often contain laminae of fine sandstone or siltstone, the matrix is clay. Greywackes are present as well. One sample (HR 032b) revealed sedimentary structures probably caused by slumping. Clay, silt and sand layers are recognizable. Coarse grains include rounded fragments of sandstone, and angular fragments of quartz, arkose, mica schist, limestone(?). This rock is a greywacke. Sample HR 033 is a fine-grained sandstone with a carbonate matrix. Grains of epidote are present. Another sample (HR 035) shows angular quartz grains with undulatory extinction. Feldspar is rather scarce, but if plagioclase occurs, it is mainly chloritised.

The samples from E Vindberget are not interpreted as tuffites (Buggisch et al 1994). The sandstones and greywackes are probably derived from the weathering of the underlying basement, i.e. Pioneers Group or Read Group rocks. According to Buggisch et al. (1994), a K/Ar radiometric age determination on the 2-6 mm fraction yielded a date of 185 Ma, thus indicating a Jurassic age. There is no indication that these rocks belong to the former „Turnpike Bluff Group". Neither the very low-grade to low-grade metasediments of the Mount Wegener Formation (sandstones, conglomerates, and slates) of probably Early Cambrian age, nor the very low-grade Stephenson Bastion Formation (conglomerates, sandstones, siltstones, and slates), for which a minimum age of 1000 Ma is reported (Buggisch et al. 1994), can be considered as equivalents. The Wyeth Heights Formation (quartz arenites, partly slightly arkosic) was tentatively correlated with the Stephenson Bastion Formation, although correlation with the Mount Wegener Formation cannot be totally excluded (Buggisch et al. 1994).

4. REGIONAL DISTRIBUTION AND CORRELATION

4.1 *Distribution of the metasedimentary and metavolcanic rocks in the Pioneers Escarpment*

The occurrences of Pioneers Group rocks in the Pioneers Escarpment are limited to small isolated nunataks. The main rock types at each of these nunataks are described briefly as there have been very few investigations in this part of the Shackleton Range. The outcrops are listed from west to east and north to south.

Freshfield Nunatak is included in the description of Pioneers Escarpment occurrences although it might belong to the Herbert Mountains. Biotite schists and biotite quartzite were sampled.

Lord Nunatak: Amphibolite probably derived from an igneous rock. Elevated concentrations of chromium (993 ppm), nickel (581 ppm) and iron (12.37 %) indicate that a basite (?basaltic komatiite) has to be considered as parent rock. Garnet amphibolite and hornblende schists also occur on Lord Nunatak.

Baines Nunatak: Garnet-two-mica schist and hornblende-garnet-plagioclase gneiss

Jackson Tooth: About 150 m of marbles are exposed: Medium-grained marble, light grey to white, containing tremolite, is about 50 m thick. It is underlain by grey marble, about 100 m thick, which contains star-like aggregates of chrysotile-asbestos (up to 10 vol.%, VNIIOkeangeologia 1994). Duplication due to isoclinal folding or stacking is possible; schistosity 215/15; lineation-parallel fold axis 80/00. The marble is possibly in contact with muscovite schists and muscovite quartzite, the latter containing accessory tourmaline, as these rocks crop out about 2 km north of Jackson Tooth .

M'Clintock Bastion: Tremolite marble, garnet-two-mica schist and staurolite-garnet-muscovite schist are the dominant rock types. The schists show mylonitic horizons, indicating rather cold deformation.

Mount Kelsey: not visited

Spaeth Nunatak: A hitherto unnamed nunatak on the 1600 m contour line (new place name, not yet officially approved), about 10 km SSW of Blanchard Hill: Impure marble, sometimes containing quartzitic layers. Other parts of the coarse-grained marble show rounded olivines, partly serpentinized. Chondrodite is present, some opaque minerals, and some quartz. This chondrodite-olivine marble shows a high concentration of strontium (1375 ppm), another sample of tremolite marble contains as much as 1970 ppm Sr. This is 10-30 times more than the Sr in other occurrences of the Shackleton Range marble. The strontium is probably concentrated in calcite (strontio-calcite).

Meade Nunatak: Epidote-biotite-plagioclase gneiss and epidote-biotite amphibolite occur in the northern part of Meade Nunatak. The latter had a basic intrusive or basic volcanic protolith. The texture of the amphibole suggests that it has replaced clinopyroxene.

Southern Meade Nunatak: Biotite quartzite, biotite schist, garnet-biotite schist, plagioclase gneiss with a small mica content, or plagioclase-quartz-mica schists prevail, but garnet-kyanite-staurolite-mica schists and staurolite-garnet-plagioclase gneiss or even a kyanite-quartzfels occur as well and suggest that the protolith had a relatively high aluminum content. Additionally, a slightly schistose amphibole fels was sampled.

Blanchard Hill: A garnet-mica schist and biotite-garnet-amphibole schist, intensely folded with NW vergence (B 070/00), upthrust to the northwest onto an intensely folded quartzite sequence (B about 90/00) with 20 m thick layers decreasing in thickness upwards, containing beds of light grey calciphyre about 40 cm thick.

Olesch Nunatak (new place name) about 4.5 km WSW of Whymper Spur shows a quartz-carbonate rock or carbonate-bearing quartzite, but also a garnet-two-mica schist and a garnet-hornblende-biotite schist.

Whymper Spur: About 80-100 m of marble with intercalated amphibolite, the latter mostly in boudins. Schistosity 60/25; lineation parallels fold axis 140/05. The marble can be described as a tremolite marble or as a silicate marble containing clinopyroxene and/or tremolite aggregates. According to VNII-OKEANGEOLOGIA (1994) one sample from a layer within the marble is a talc-phlogopite-tremolite-plagioclase-diopside-olivine-carbonate rock with accessory sphene and secondary serpentine-talc aggregates.

Weissenstein (White Spur): An outcrop halfway between Mummery Cliff and Whymper Spur is called Weissenstein (new place name) due to its white appearance. It is totally composed of a very pure, even-grained, white marble .

Mummery Cliff: Garnet-two-mica gneiss

Mount Dewar: Fine-grained fuchsite quartzite. The proportion of mica is very small. The quartzite occurs together with amphibolite (similar to Sauria Buttress) and microcline gneiss.

Bergan Castle: A sericite quartzite or muscovite quartzite, partly blastomylonitic, which is intensely folded: B_1, isoclinal, refolded by B_2. B_2 is nearly isoclinal, e.g. 300/00; 90/10 variation due to B_3 (030/45). B_2 is dominant in the outcrop (KLEINSCHMIDT, pers. com). The quartz grains show signs of late deformation, such as undulatory extinction and stretching, partly with strain recrystallization. The light grey quartzite shows intercalations of biotite-amphibole schist 20-30 cm thick.

Aronson Corner: Metacarbonate in association with metaquartzite; dark grey calciphyres (phlogopite-tremolite-diopside marble) occur together with quartz-tremolite rocks (VNIIOKEANGEOLOGIA 1994) . Layering dips 105/15, the schistosity 150/30, a fold axis 60/00.

Chevreul Cliffs: The marble of Chevreul Cliffs shows light-green to yellow stains and wollastonite. A two-mica schist shows evidence of postcrystalline deformation, the muscovite describes a flaser texture or a mm-sized zig-zag folding. Some layers within the mica schist contain epidote as well as hornblende.

Lindqvist Nunatak: A plagioclase-microcline (perthite) gneiss and a quartzitic gneiss with cataclastic and/or blastomylonitic texture, showing late-kinematic recrystallization. Additionally, an amphibolite was sampled that contained some light-brown biotite with inclusions of zircon and rutile, as well as chlorite and prehnite on fractures parallel to the c-axis of biotite; ore and apatite occur as accessory minerals.

Lundström Knoll: North of Sauria Buttress, a two-mica gneiss was encountered which partly shows augengneiss texture.

Sauria Buttress: Thick beds of quartzite containing fuchsite, giving the quartzite a typical pale green appearence. The meta-sandstone alternates with amphibolites. The unit is isoclinally folded (schistosity: 150/86; B-axis: 093/05).

The easternmost outcrops of the Pioneers Escarpment are not included in the 1: 250 000 Reconnaissance Series „Shackleton Range" (USGS 1983), i.e. (from north to south) Skiltvagta, Rileyryggen, Vindberget, Nobleknausane, Gallsworthyryggen, and Carterknattane.

Skiltvagta: mainly biotite schists to biotite gneisses

Rileyryggen: quartzitic plagioclase gneiss, partly with hornblende, and microcline gneiss. The protolith of the microcline gneiss may have been derived from an arkose.

Vindberget: The outcrops revealed nonmetamorphic to just very slightly metamorphosed shales, siltstone, sandstones, and greywackes. The greywackes contain fragments of arkose, mica schist and brecciated quartz. They represent a younger sedimentary cover, probably Jurassic in age (BUGGISCH et al. 1994), but volcanic origin or influence could not be confirmed with our samples. These rocks are not included in the Pioneers Group.

Nobleknausane: Garnet-kyanite gneiss and garnet-quartz schists were encountered on Nobleknausane, i.e. the same rock types as in the outcrops further west.

Gallsworthyryggen: A finely laminated blastomylonitic biotite gneiss crops out which has undergone strong tectonic deformation. The same rock type occurs on Lindqvist Nunatak about 23 km WNW of Gallsworthyryggen.

4.2 *Relation to the supracrustals of the Herbert Mountains, Lagrange Nunataks, and Haskard Highlands*

STEPHENSON (1966) suggested that the supracrustals encountered in the northwestern Shackleton Range might continue further east. This has been confirmed by the work presented here. The metasediments which occupy the Pioneers Escarpment are in many ways comparable to the rocks described from the northwest, with the exception that Read Group or Stratton Group rocks were not definitely identified, though we have to keep in mind that gneisses do occur, but they were considered to belong to the Pioneers Group. Additionally the outcrop conditions in the east are rather poor.

The term Pioneers Group replaces the former term Skidmore Group (e.g. PAECH 1985, HOFMANN & PAECH 1980,1983), for which the terms Skidmore Complex (KAMENEV & SEMENOV 1980) and Herbert Series (HOFMANN 1982) have also been used, and comprises the former Haskard and Schimper Groups (*sensu* MARSH 1983a, b, 1984) (see ROLAND et al, in press) .

5. GEOCHEMISTRY

Major and trace elements in 76 samples of gneisses, quartzites, amphibolites and marbles (Tab. 1), as well as Vindberget greywackes, which are probably of Jurassic age (Tab. 2), were analysed in the XRF laboratory of BGR.

In addition to the trace elements listed in Tabs. 1 and 2, the following elements were determined, but in most of the samples they were below the detection limits (given in parentheses):

As	(<7)	4 samples showed 8-9 ppm As;
Hf	(<18)	3 samples showed 19-27 ppm Hf;
Mo	(<4)	9 samples showed traces between 4-8 ppm molybdenum;
Sn	(<50)	No sample revealed measurable amounts of tin;
Ta	(<10)	6 samples showed 11-14 ppm thallium;
W	(<10)	4 samples with traces of 10-12 ppm tungsten.

The analytical data were plotted in various discrimination diagrams (Figs.2 through 9), using the „NEWPET" program of the Department of Earth Sciences, Memorial University of Newfoundland, Canada.

The different groups of rocks, i.e. the quartzites, gneisses and schists, amphibolites, marbles, as well as the greywackes of probable Jurassic age, are mostly clearly distinguished in the Al_2O_3, Fe_2O_3, TiO_2, and CaO +MgO versus SiO_2 diagrams (Fig.2). The Cr, Ni, Co, and V *versus* SiO_2 plots reveal the elevated concentrations of these elements (Fig. 2) and thus provide additional evidence that the amphibolites are of volcanic origin. This is in accordance with the findings of the microscopic analysis, as well as the initial geochemical analyses (Tabs. 1 and 2).

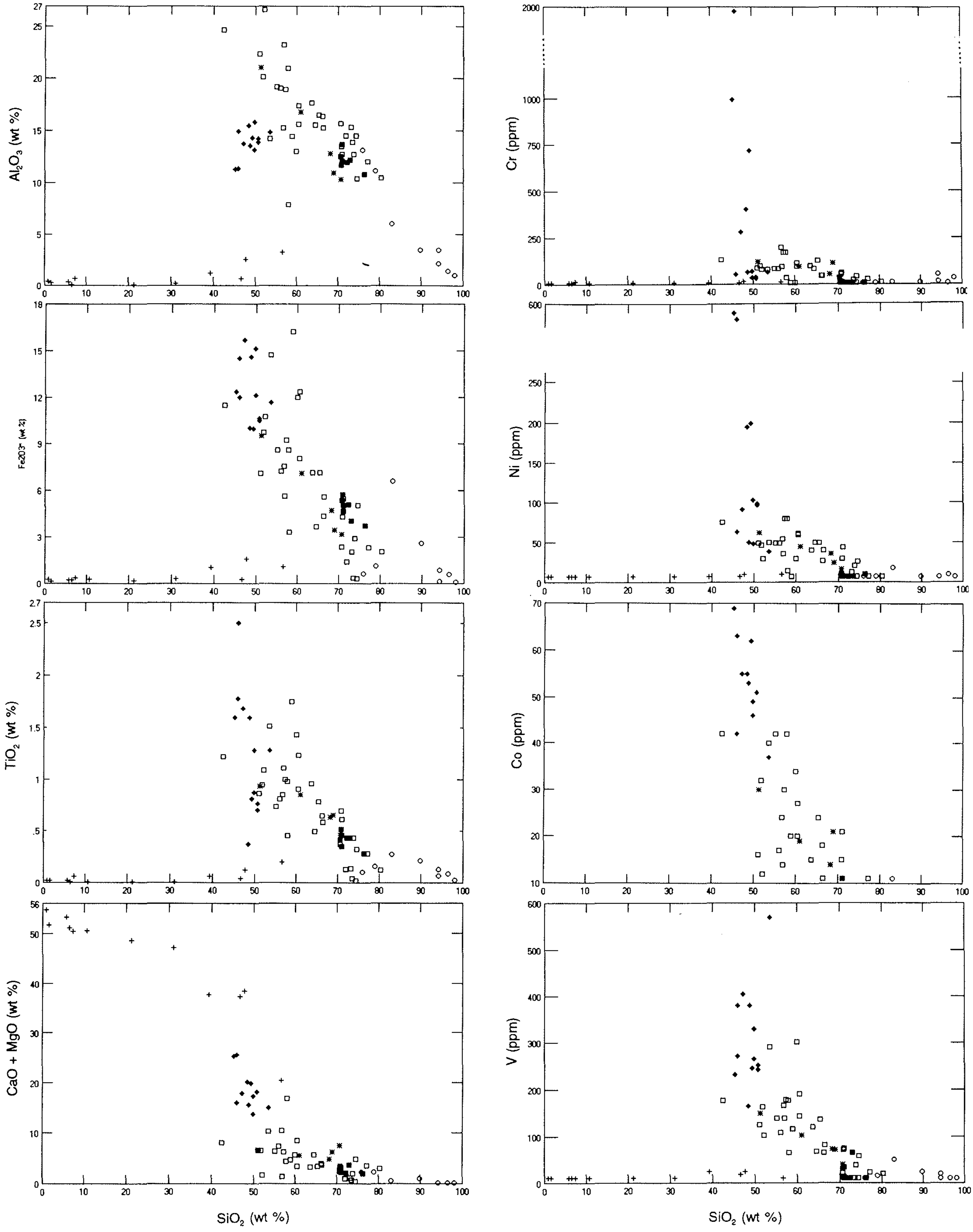
In the Ba-SiO_2 plots, but especially in the plots of high field strength elements (HFSE) Nb-Y and Zr-Y, a group of gneisses clearly plots separately from most of the other gneiss samples (Fig.3). The elevated Zr, Y, and Nb values of this group are also in favour of a volcanic origin (see below) .

Considering the fact that volcanic rocks are involved, the Na_2O/K_2O values were plotted versus $Na_2O + K_2O$ values to distinguish between fresh and spilitic volcanic rocks (Fig. 4). All of the samples plot in the field of fresh volcanic material (MIYASHIRO 1975). Therefore, further discrimination plots can be used to better subdivide the metavolcanic rocks on the basis of composition. In the CaO-Fe_2O_3-MgO diagram, practically all the amphibolite samples plot in the ortho-amphibolite field (Fig. 5) after WALKER et al. (1960).

The $Na_2O + K_2O$ *versus* SiO_2 diagram of IRVINE & BARAGAR (1971) and the P_2O_5-Zr plots of WINCHESTER & FLOYD (1977) show that the amphibolites fall within the sub-alkaline or the tholeiitic field (Fig. 6). Only one sample shows an elevated amount of P_2O_5, shifting the sample into the alkaline field. In the WINCHESTER & FLOYD (1977) Zr/TiO_2-Nb/Y diagram (Fig. 7), the amphibolites trend from the andesite/basalt field towards the alkali basalt and the felsic gneisses plot in the rhyolite field; in the LE MAITRE (1989) diagram, the amphibolites show a basalt composition (B) and only one sample shows a basaltic andesite composition (field 01), whereas the felsic volcanics all group in the rhyolite field (R), some close to the dacite field (03) (Fig. 8).

Although most of the amphibolites are mafic, two samples of hornblende felses from Lord Nunatak are ultramafic. In the Fe+Ti - Al - Mg triangular diagram of JENSEN (1976), they plot in the high-Fe and high-Mg fields, and the two hornblende felses samples from Lord Nunatak in the basaltic komatiite field (Fig. 9). The latter are enriched in nickel (567 and 581 ppm) and chromium (993 and 1972 ppm) (Fig. 2) and they have the low K_2O (<0.2 %) and elevated MgO contents (about 15 %) typical of komatiites. The SiO_2 content is 45-46 %. Komatiites are known to be very old, with age maxima between 2.7 and 3.5 billion years (ARNDT et al. 1989) and not many occurrences (about 25) are known worldwide. Komatiites in the Shackleton Range would be worth investigating, but we are well aware that the two Lord Nunatak samples cannot be definitely identified as komatiites only on the basis of their chemical composition.

The ortho-amphibolites indicate the existence of mafic dykes/sills which intruded the sediments and/or mafic tuffites which were deposited in the same environment as the limestone or the precursor of the fuchsite quartzite, which are both found in contact with the amphibolites.


Al2O3 (wt %)
Cr (ppm)
Fe2O3* (wt %)
Ni (ppm)
TiO2 (wt %)
Co (ppm)
CaO + MgO (wt %)
V (ppm)
SiO2 (wt %)
SiO2 (wt %)

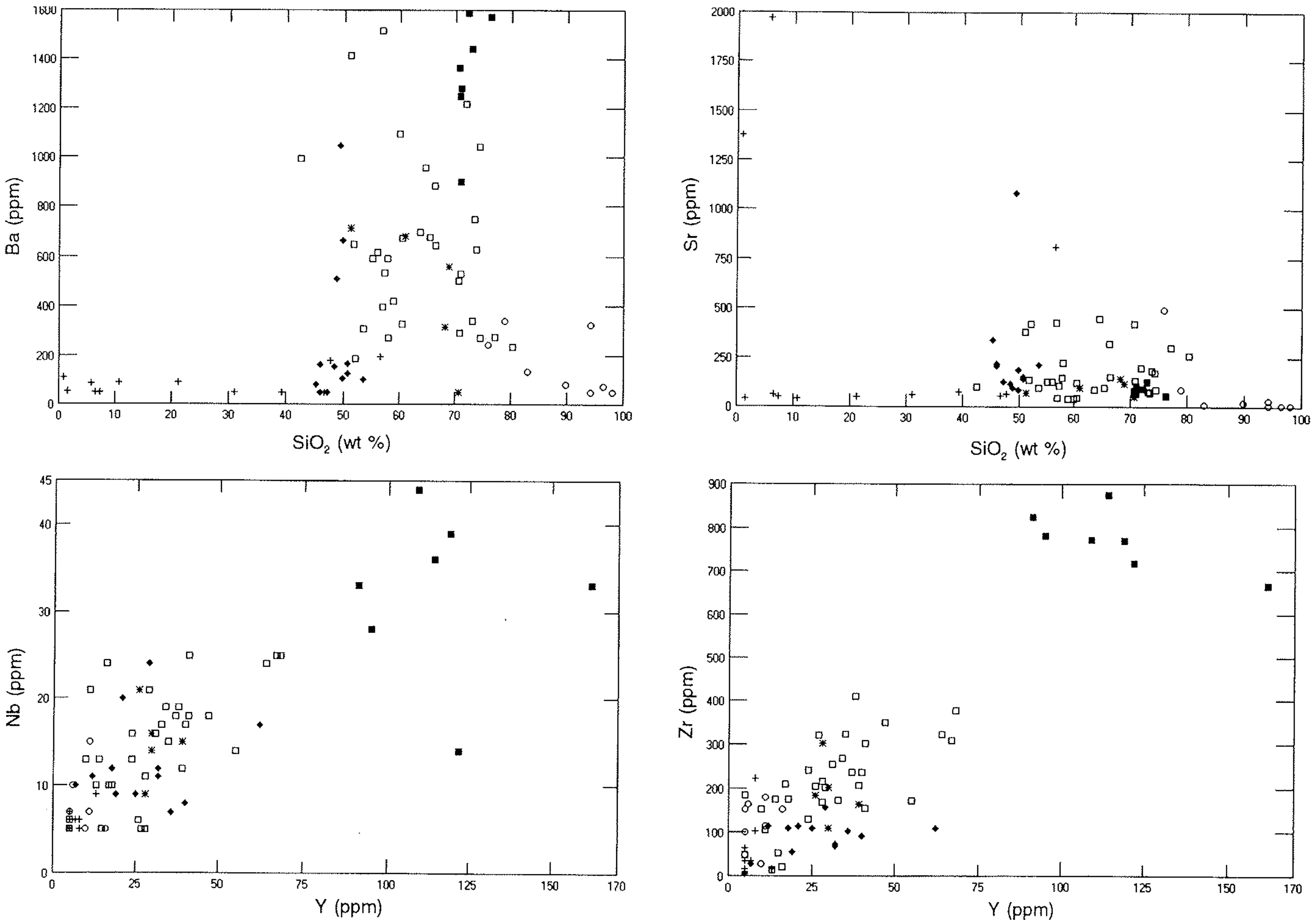


Fig. 3: The elements Ba and Sr versus SiO_2 and Nb and Zr versus Y. The elevated amounts of the high field strength elements Nb, Zr, and Y in some felsic gneisses (filled squares) indicate volcanic origin.

Abb. 3: Darstellung der Elemente Ba und Sr gegen SiO_2, sowie Nb und Zr gegen Y. Die höheren Anteile der HFS-Elemente Nb, Zr und Y in einigen sauren Gneisen (schwarze Quadrate) weisen auf ein vulkanisches Ausgangsgestein hin.

The felsic volcanic rocks (represented by a variety of biotite gneisses, garnet-biotite gneisses, two-mica gneisses, and microcline gneisses) plot in two distinct groups. This is best shown in diagrams in which the relatively immobile, incompatible HFSE elements are plotted (Nb-Y and Zr-Y diagrams), but also in the Ba-SiO_2 diagram (Fig. 3). The samples were taken at Meade Nunatak (HR 065, 069, 070) and Mount Dewar (sample HR 050), and for comparison, some samples from Mount Beney (HR 170, 171, 174, 183.), where the Stratton and Pioneers groups occur, are included. The Mount Beney samples show strong similarities to the samples from Mount Dewar and Meade Nunatak in the northeastern Pioneers Escarpment.

Barium, although a mobile element which might be enriched and transported in anoxic intraformational water, should be mentioned as it is detected in elevated amounts in the same group of rocks (see the Ba-SiO_2 diagramm, Fig.3). These elevated barium, zirconium, niobium and yttrium contents, as well as an SiO_2 content above 70 %, indicate that volcanic suites of intermediate to acidic composition have to be regarded as the protoliths.

The volcanics show a broad range from mafic/partly ultramafic to intermediate/acidic composition with a bimodal distribution. Following Condie (1989), both tholeiitic and calc-alkaline magmas characterize volcanic arcs. Andesites and basaltic andesites often dominate. Although felsic magmas are generally emplaced as batholiths, felsic volcanism producing large volumes of rhyolite is common in most continental-margin arcs.

Fig. 2: Plots of various oxides versus SiO_2 for different types of rocks in the Pioneers Group. Filled diamonds = amphibolites of volcanic origin; filled squares = felsic gneisses of volcanic origin; open squares = various gneisses; open circles = quartzites; crosses = marbles, metalimestones; asterisks = sediments, possibly of Jurassic age.

Abb. 2: Darstellung verschiedener Oxide gegen SiO_2 für verschiedene Gesteinstypen der Pioneers Group. Schwarze Rauten = Amphibolite vulkanischen Ursprungs, schwarze Quadrate = saure Gneise vulkanischen Ursprungs, offene Quadrate = verschiedene Gneise, offene Kreise = Quarzite, Kreuze = Marmore und Metakalksteine, Sterne = Sedimente, vermutlich jurassischen Alters.

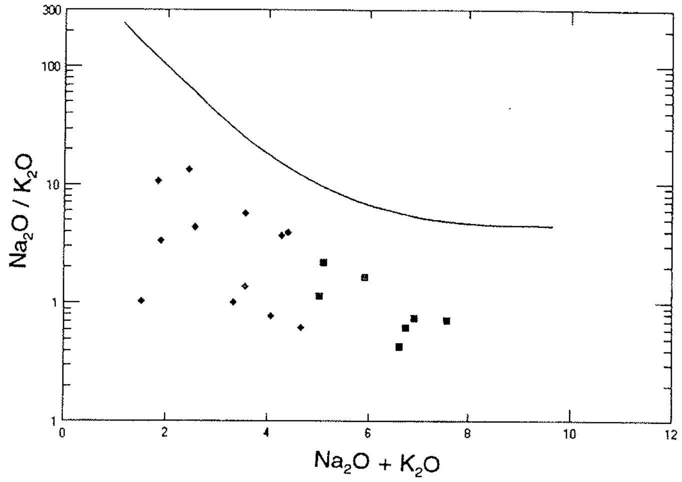


Fig. 4: Log Na_2O/K_2O versus $Na_2O + K_2O$, after MIYASHIRO (1975). The curve represents the upper limit for fresh, non-spilitic volcanic rocks. The volcanic rocks are well below this line.

Abb. 4: Log Na_2O/K_2O gegen $Na_2O + K_2O$, nach MIYASHIRO (1975). Die Kurve stellt die Grenze zwischen frischen und spilitisierten Vulkaniten dar. Die Proben liegen im Feld für frische Vulkanite.

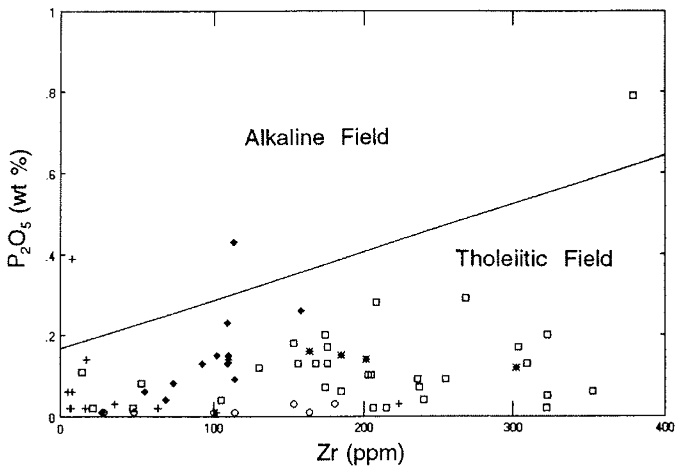


Fig. 6: P_2O_5-Zr plot after WINCHESTER & FLOYD (1976), for distinguishing subalkaline from tholeiitic volcanic rocks

Abb. 6: P_2O_5-Zr-Diagramm nach WINCHESTER & FLOYD (1976) zur Unterscheidung subalkalischer und tholeiitischer Vulkanite.

6. DEPOSITIONAL ENVIRONMENT OF PIONEERS GROUP PROTOLITHS

In general, the Pioneers Group rocks can be assigned to two associations, the „quartzite-pelite-carbonate (QPC) association", and the „bimodal volcanics-arkose-conglomerate (BVAC) association". The sediments can be viewed as a typical QPC association.

At least some of the protoliths of the Pioneers Group supracrustal rocks were sediments deposited in a shallow marine environment. This is especially true of the carbonate series, which range from grey calcareous schists and grey metalimestones to white marble. We assume that the lime sedimentation was autochthonous, although some transport, e.g. in tidal flats, may have occurred. Several units can be observed, and although tectonic repetition cannot be excluded, they seem to be part of a metalimestone sequence which can be interpreted as a cyclic carbonate shelf deposition.

Extensive tectonic/orogenic activity is unlikely as uplift would have caused considerable influx of terrigenous material. Since the pure, white marbles contain hardly any terrigenous siliciclastic material, a very small influx rate either in an offshore bank situation or in protected areas in quite water behind a bar-

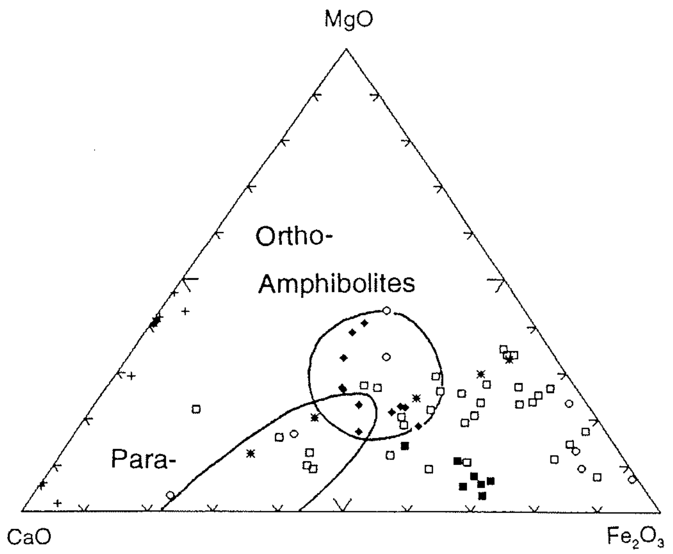


Fig. 5: All amphibolite samples plot in the ortho-amphibolite field of WALKER et al (1960).

Abb. 5: Im Diagramm nach WALKER et al (1960) ist zu erkennen, daß alle Amphibolite in das Ortho-Amphibolitfeld fallen.

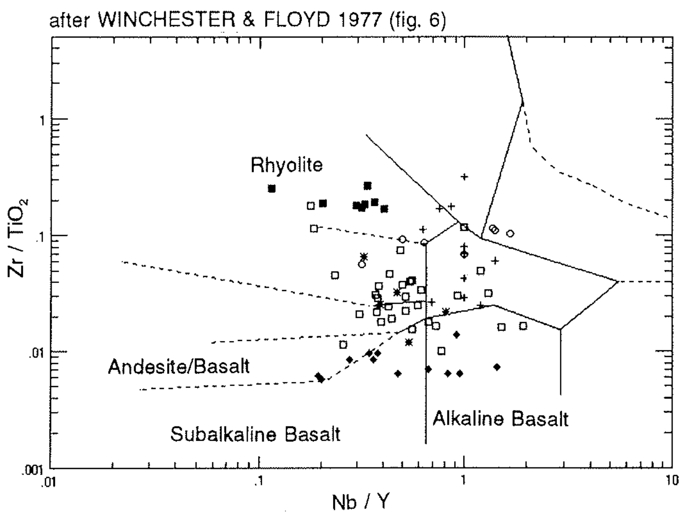


Fig. 7: In a plot of Zr/TiO_2 versus Nb/Y, the felsic gneisses of volcanic origin (filled squares) fall within the rhyolite field, the basic volcanics (filled diamonds) range from andesite/basalt to alkali-basalt (after WINCHESTER & FLOYD 1977) .

Abb. 7: In der Darstellung Zr/TiO_2 gegen Nb/Y (nach WINCHESTER & FLOYD 1977) fallen die sauren Gneise vulkanischen Ursprungs (schwarze Quadrate) in das Rhyolith-Feld, die basischen Vulkanite (schwarze Rauten) erstrecken sich vom Andesit/Basalt- zum Alkali-Basalt-Feld .

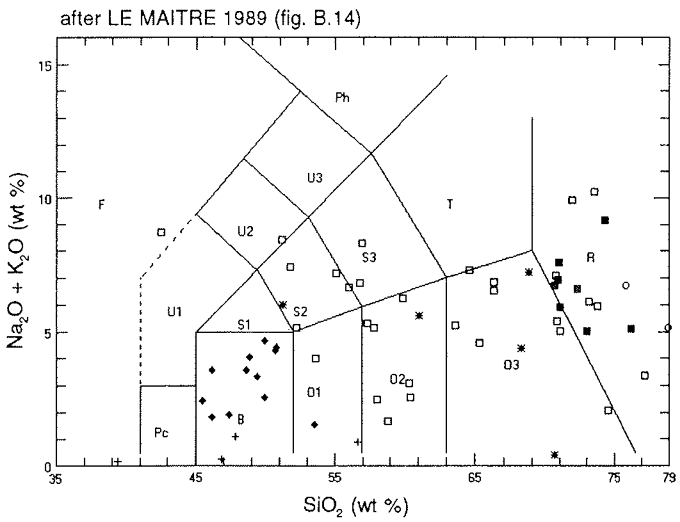


Fig. 8: In a plot of $Na_2O + K_2O$ versus SiO_2, the basic volcanics (filled diamonds) fall in the basalt field, except for one sample that plots in the basaltic andesite field (01); the felsic volcanics (filled squares) plot in the rhyolite field close to the dacite field (03) (after LE MAITRE 1989)

Abb. 8: Im Diagramm $Na_2O + K_2O$ gegen SiO_2 fallen die basischen Vulkanite (schwarze Rauten) in das Basalt-Feld, mit Ausnahme einer Probe, die in das Feld 01 (basaltische Andesite) fällt. Die sauren Vulkanite (schwarze Quadrate) liegen im Rhyolith-Feld nahe der Grenze zum Dazit-Feld (03) (nach LE MAITRE 1989)

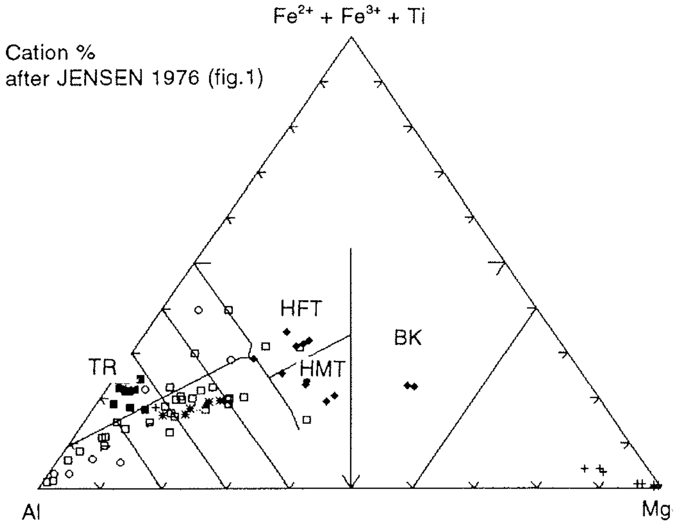


Fig. 9: The felsic volcanics (filled squares) in a JENSEN (1976) cation plot in the tholeiitic rhyolite (TR) field. The basic volcanics fall in the high-Fe tholeiite (HFT) and high Mg tholeiite (HMT) fields. Two samples plot in the basaltic komatiite (BK) field.

Abb. 9: Die sauren Vulkanite (schwarze Quadrate) liegen im Kationen-Diagramm nach JENSEN (1976) im Rhyolith-Feld (TR). Die basischen Vulkanite fallen in die Felder HFT (Hoch-Fe-Tholeiite) und HMT (Hoch-Mg-Tholeiite), zwei Proben liegen im BK-Feld (basaltische Komatiite).

Sample	Location	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	(SO_3)	LOI
GNEISSES AND SCHISTS													
HR 012	Noble Knausane	63,62	0,96	17,61	7,16	0,09	2,76	0,44	0,67	4,54	0,06	<0,05	1,77
HR 013	Noble Knausane	58,79	1,75	14,41	16,23	0,24	2,41	2,29	<0,10	1,57	0,29	0,06	1,62
HR 015	Gallsworthy Ryggen	70,72	0,37	15,63	2,36	0,05	0,88	1,48	5,16	1,92	0,06	<0,05	1,11
HR 017	Carter Knattane	56,84	0,85	15,22	7,57	0,13	4,82	5,68	2,94	3,88	0,28	0,21	1,16
HR 018	NW of Lindquist N.	73,16	0,14	15,28	2,07	0,03	0,35	0,82	2,93	3,18	0,11	<0,05	1,73
HR 021	Freshfield Nunatak	64,58	0,49	15,50	3,70	0,09	2,54	3,10	4,96	2,33	0,18	<0,05	2,19
HR 026	Lord Nunatak	52,22	1,09	26,63	10,75	0,16	0,95	0,76	3,36	1,79	0,11	<0,05	1,85
HR 027	Baines Nunatak	56,05	0,81	19,06	7,26	0,12	4,27	3,09	2,25	4,39	0,13	0,16	2,14
HR 028	Baines Nunatak	53,62	1,51	14,20	14,70	0,35	6,85	3,48	1,90	2,11	0,20	0,06	0,77
HR 030	Jackson Tooth	56,93	1,11	23,27	5,63	0,02	1,24	0,22	1,02	7,27	0,05	<0,05	2,95
HR 036	Skiltvagta	73,77	0,43	12,71	2,92	0,05	0,95	1,05	3,71	2,25	0,17	0,06	1,68
HR 038	Rileyryggen	73,49	0,04	13,89	0,36	0,02	0,18	0,58	2,79	7,47	0,02	<0,05	0,91
HR 043	Lundström Knoll	66,29	0,64	16,31	4,39	0,07	1,83	2,12	3,44	3,08	0,04	<0,05	1,45
HR 045	Chevreuil Cliffs	71,02	0,61	12,73	5,46	0,05	2,29	0,77	2,09	2,95	0,04	<0,05	1,70
HR 047	Chevreuil Cliffs	66,35	0,58	15,23	5,59	0,07	1,93	1,78	4,20	2,65	0,13	<0,05	1,18
HR 050	Mount Dewar	74,29	0,02	14,49	0,30	0,02	<0,10	0,38	3,02	6,14	0,08	0,08	0,92
HR 053	Mummery Cliffs	70,84	0,69	13,48	4,34	0,06	1,98	1,47	2,52	2,86	0,20	<0,05	1,29
HR 059	Spaeth Nunatak	51,19	0,86	22,37	7,09	0,09	3,54	3,00	1,43	6,99	0,09	<0,05	2,88
HR 062	Olesch Nunatak	55,13	0,73	19,20	8,61	0,14	5,30	1,11	1,09	6,07	0,12	0,06	2,16
HR 063	Olesch Nunatak	58,02	0,45	7,87	3,33	0,07	4,42	12,39	1,05	1,44	0,10	<0,05	10,62
HR 064	Blanchard Hill	42,51	1,22	24,68	11,49	0,30	6,62	1,48	1,11	7,59	0,10	0,05	2,46
HR 068b	Mead Nunatak South	59,93	1,43	12,99	11,97	0,12	4,41	1,21	1,48	4,75	0,13	<0,05	1,16
HR 072	M'Clintock Bastion	51,80	0,94	20,16	9,74	0,15	5,55	1,04	1,89	5,51	0,13	0,15	2,64
HR 073a	M'Clintock Bastion	57,83	0,98	20,99	8,60	0,10	3,01	1,42	1,53	3,62	0,09	<0,05	1,48

Tab. 1: Distribution of major and trace elements in Pioneers Group rocks (quartzites, mica schists and gneisses, alumina-rich schists, marbles, and amphibolites).

Tab. 1: Verteilung der Haupt- und Spurenelemente in den Gesteinen der Pioneers Group (Quarzite, Glimmerschiefer und Gneise, Al-reiche Schiefer, Marmore und Amphibolite).

Tab. 1 continned

Sample	Location	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	(SO_3)	LOI
HR 076b	Meade Nunatak	57,33	1,00	18,94	9,24	0,11	3,61	2,61	2,80	2,51	0,02	<0,05	1,51
HR 082	M'Clintock Bastion	80,30	0,12	10,45	2,05	0,05	0,47	2,51	2,20	0,68	0,02	<0,05	0,91
HR 083	M'Clintock Bastion	77,20	0,28	12,02	2,33	0,05	0,59	2,98	2,58	0,78	0,02	<0,05	0,92
HR 205	Jamieson Ridge	60,44	1,23	17,39	12,37	0,07	2,34	1,10	0,11	2,46	0,79	<0,05	1,37
HR 206	Jamieson Ridge	74,55	0,32	10,38	5,08	0,27	1,21	3,62	0,55	1,51	0,07	0,09	2,13
HR 207	Jamieson Ridge	60,37	0,90	15,61	8,08	0,47	3,40	5,09	0,27	2,80	0,17	0,07	2,46
HR 208	Jamieson Ridge	71,90	0,13	14,52	1,39	0,02	0,22	0,76	2,35	7,57	0,02	<0,05	0,80
HR 221	Lewis Chain	65,33	0,78	16,44	7,15	0,12	2,48	0,89	1,26	3,32	0,07	<0,05	1,86
QUARTZITES													
HR 010	Lindquist Nunatak	75,85	0,10	13,14	0,62	0,03	<0,10	2,14	3,14	3,58	<0,01	<0,05	1,09
HR 019	Bergan Castle	96,41	0,09	1,44	0,60	0,01	<0,10	0,05	<0,10	0,51	<0,01	<0,05	0,63
HR 020	Bergan Castle	94,25	0,13	2,21	0,87	0,01	<0,10	0,08	<0,10	0,70	0,03	0,15	1,27
HR 022	NE Freshfield Nunatak	89,84	0,21	3,46	2,61	0,07	0,83	0,10	0,47	0,56	0,03	<0,05	1,63
HR 031	Jackson Tooth	82,91	0,27	6,04	6,62	0,02	0,52	0,07	<0,10	1,82	0,03	<0,05	1,47
HR 037	Rileyryggen	78,94	0,16	11,15	1,15	0,02	0,56	1,65	3,20	1,96	0,01	<0,05	0,98
HR 041	Sauria Buttress	97,99	0,03	1,02	0,08	0,01	<0,10	0,05	<0,10	0,15	<0,01	<0,05	0,58
HR 048	Mount.Dewar	94,26	0,07	3,50	0,12	0,01	<0,10	0,08	<0,10	0,96	<0,01	<0,05	0,79
ACID GNEISSES (Volc.Orig.)													
HR 065	Meade Nunatak	73,00	0,43	12,16	4,06	0,08	1,11	2,58	2,66	2,35	0,10	0,08	0,97
HR 069	Meade Nunatak	71,01	0,35	13,65	4,71	0,15	0,82	2,01	3,69	2,24	0,10	<0,05	0,87
HR 070	Meade Nunatak	76,21	0,28	10,79	3,72	0,09	0,31	1,61	3,50	1,60	0,04	0,42	1,01
HR 170	Mount Beney	70,94	0,46	12,08	5,05	0,09	0,44	1,86	3,17	4,40	0,10	<0,05	0,99
HR 171	Mount Beney	70,91	0,51	11,68	5,72	0,09	0,56	1,92	2,94	3,98	0,12	<0,05	1,13
HR 174	Mount Beney	72,28	0,43	11,99	5,11	0,08	0,26	1,92	2,00	4,62	0,10	0,06	0,70
HR 183	Mount Beney	70,62	0,42	12,48	5,39	0,11	0,63	2,07	2,59	4,15	0,12	0,07	0,92
AMPHIBOLITES													
HR 009	Lindquist Nunatak	49,35	0,81	14,31	9,99	0,16	9,92	9,94	1,67	1,67	0,43	0,09	1,17
HR 023	Lord Nunatak	45,41	1,59	11,28	12,37	0,16	15,35	9,95	2,27	0,17	0,15	<0,05	0,90
HR 024	Lord Nunatak	46,10	2,50	14,89	14,51	0,21	6,95	9,11	3,02	0,54	0,26	0,06	1,60
HR 025	Lord Nunatak	46,10	1,78	11,35	12,00	0,18	14,56	10,99	1,68	0,16	0,09	<0,05	0,67
HR 039	Rileyryggen	47,35	1,68	13,75	15,68	0,22	7,22	10,67	1,46	0,44	0,15	0,17	0,98
HR 040	Rileyryggen	49,93	0,87	15,78	12,10	0,17	6,72	10,62	2,09	0,48	0,06	0,26	0,72
HR 049	Mount Dewar	48,59	0,37	15,44	10,03	0,18	9,99	10,08	2,07	1,50	<0,01	0,13	1,36
HR 066	Meade Nunatak	48,86	1,59	13,54	14,59	0,22	6,78	8,79	1,77	2,29	0,13	<0,05	1,12
HR 172	Mount Beney	50,81	0,76	13,86	10,60	0,16	7,54	10,65	3,52	0,89	0,08	<0,05	0,88
HR 173	Mount Beney	50,71	0,70	14,24	10,49	0,17	7,62	10,55	3,36	0,92	0,04	<0,05	0,97
HR 181	Mount Beney	49,96	1,28	13,09	15,13	0,18	5,35	8,41	1,78	2,89	0,13	0,08	1,42
HR 182	Mount Beney	53,58	1,28	14,85	11,67	0,23	4,61	10,40	0,77	0,75	0,23	<0,05	1,36
MARBLES, META-LIMESTONES etc.													
HR 058	Spaeth Nunatak	56,65	0,20	3,26	1,08	0,03	0,36	20,07	0,22	0,68	0,03	<0,05	17,16
HR 029	Jackson Tooth	6,53	0,01	0,04	0,23	0,03	20,81	30,43	<0,10	0,02	0,06	0,07	41,77
HR 044	Chevreuil Cliffs	21,25	0,01	0,07	0,18	0,02	22,97	25,69	<0,10	0,01	0,02	0,16	29,49
HR 051	Aronson Corner	46,80	0,04	0,67	0,27	0,01	15,75	21,55	<0,10	0,16	0,14	0,11	14,30
HR 054	Weißenstein	1,63	0,02	0,25	0,13	0,01	21,59	30,22	<0,10	0,11	0,06	0,23	45,96
HR 056	Whymper Spur	39,39	0,06	1,24	1,05	0,03	11,32	26,36	<0,10	0,08	0,02	0,08	20,31
HR 057	Whymper spur	47,87	0,12	2,59	1,60	0,03	17,30	21,19	<0,10	1,01	0,03	0,11	7,96
HR 060	Spaeth Nunatak	0,95	0,02	0,44	0,27	0,01	2,95	51,80	<0,10	0,20	0,03	0,79	42,48
HR 061	Spaeth Nunatak	5,86	0,02	0,36	0,25	0,01	3,39	49,69	<0,10	0,06	0,02	0,31	39,48
HR 073b	M'Clintock Bastion	7,40	0,06	0,68	0,38	0,01	20,85	29,60	<0,10	0,14	<0,01	0,12	40,69
HR 105a	Mount Provender	31,02	0,01	0,20	0,32	0,03	19,94	27,32	0,17	0,07	0,39	0,05	20,35
HR 238	Hollingworth Cliffs	10,76	0,01	0,02	0,28	0,05	20,73	29,93	<0,10	0,01	0,02	<0,05	38,16

Tab. 1 continned

Sample	Location	Ba	Bi	Ce	Co	Cr	Cu	Ga	Nb	Ni	Pb	Rh	Sr	Th	U	V	Y	Zn	Zr
GNEISSES AND SCHISTS																			
HR 012	Noble Knausane	696	<10	126	15	98	11	26	18	40	16	239	88	32	11	121	47	124	352
HR 013	Noble Knausane	423	<10	58	20	<7	<10	22	19	<7	<10	71	39	<10	<5	117	34	270	269
HR 015	Gallsworthy Ryggen	504	<10	59	<7	<7	<10	20	6	<7	18	74	420	<10	<5	21	<5	44	185
HR 017	Carter Knattane	1513	<10	72	24	196	90	18	10	54	11	178	424	12	11	167	17	91	209
HR 018	NW Lindquist Nunatak	340	<10	<35	<7	<7	<10	13	10	12	24	111	77	<10	<5	<10	13	<7	14
HR 021	Freshfield Nunatak	955	10	99	<7	85	<10	23	13	50	16	79	445	<10	<5	68	10	63	153
HR 026	Lord Nunatak	187	<10	149	12	80	<10	29	19	229	151	69	422	26	<5	104	38	139	410
HR 027	Baines Nunatak	617	13	108	17	82	22	27	18	49	24	184	129	21	7	110	41	127	156
HR 028	Baines Nunatak	308	<10	66	40	81	47	15	14	50	<10	45	96	<10	7	291	55	97	174
HR 030	Jackson Tooth	396	<10	100	14	95	<10	32	24	35	<10	264	47	20	12	139	64	<7	323
HR 036	Skiltvagta	626	<10	49	<7	24	<10	16	10	20	<10	136	180	23	<5	38	18	49	176
HR 038	Rileyryggen	750	<10	<35	<7	<7	<10	16	<5	<7	41	198	73	<10	<5	<10	5	<7	47
HR 043	Lundström Knoll	882	<10	129	18	45	10	27	21	27	24	114	317	32	<5	66	11	68	105
HR 045	Chevreuil Cliffs	531	13	97	21	60	25	15	13	43	<10	142	108	14	8	74	24	30	241
HR 047	Chevreuil Cliffs	644	12	87	11	45	34	23	13	40	25	131	152	23	<5	82	14	64	176
HR 050	Mount Dewar	1042	<10	<35	<7	<7	<10	11	<5	<7	26	170	173	<10	6	1	15	<7	53
HR 052	Mummery Cliffs	291	<10	113	15	54	113	20	15	29	17	128	131	15	<5	72	35	66	323
HR 059	Spaeth Nunatak	1412	<10	177	16	89	<10	31	16	49	38	266	379	39	<5	126	31	100	256
HR 062	Olesch Nunatak	590	<10	91	42	83	<10	30	16	49	31	263	128	18	<5	140	24	135	130
HR 063	Olesch Nunatak	270	<10	43	9	34	<10	12	6	14	18	59	225	<10	<5	65	26	28	205
HR 064	Blanchard Hill	991	<10	153	42	132	<10	45	21	75	14	360	103	25	<5	177	29	189	203
HR 069b	Meade Nunatak South	1094	21	213	34	8	<10	22	25	29	<10	245	42	38	<5	302	67	227	309
HR 072	M'Clintock Bastion	649	15	109	32	97	<10	33	11	46	24	262	135	18	<5	164	28	144	168
HR 073a	M'Clintock Bastion	591	11	82	42	172	22	30	17	80	34	227	149	19	15	178	40	143	237
HR 076b	Meade Nunatak	534	<10	105	30	170	41	33	12	80	29	121	104	14	<5	179	39	202	207
HR 082	M'Clintock Bastion	236	<10	55	<7	10	<10	16	<5	<7	<10	26	259	<10	<5	19	28	9	216
HR 083	M'Clintock Bastion	274	<10	47	11	28	<10	16	5	7	11	29	301	<10	<5	23	27	15	322
HR 205	Jamieson Ridge	329	<10	162	27	114	37	25	25	59	<10	203	44	27	<5	192	68	105	379
HR 206	Jamieson Ridge	270	<10	81	10	42	10	16	18	26	<10	95	87	<10	<5	57	37	38	238
HR 207	Jamieson Ridge	671	<10	119	20	94	50	24	25	61	32	174	121	14	8	145	41	78	304
HR 208	Jamieson Ridge	1217	<10	<35	<7	<7	<10	18	24	<7	57	186	195	<10	<5	11	16	29	21
HR 221	Lewis Chain	677	<10	114	24	129	18	23	17	50	24	197	98	20	8	137	33	96	174
QUARTZITES																			
HR 010	Lindquist Nunatak	245	<10	<35	<7	<7	<10	24	15	<7	61	222	489	151	20	<10	11	9	114
HR 019	Bergan Castle	71	11	44	<7	8	218	<5	7	10	<10	19	6	<10	<5	<10	5	<7	100
HR 020	Bergan Castle	326	<10	52	<7	15	<10	<5	<5	<7	<19	27	29	13	<5	<10	<5	<7	153
HR 022	NE Freshfield Nunatak	79	<10	<35	<7	12	<10	6	7	<7	<10	29	21	<10	<5	24	11	11	181
HR 031	Jackson Tooth	135	<10	<35	11	11	<10	11	<5	18	<10	81	10	12	5	50	16	<7	153
HR 037	Rileyraggen	342	<10	<35	<7	<7	<10	12	10	<7	23	72	84	14	<5	15	6	14	164
HR 041	Sauria Buttress	<50	<10	44	<7	33	<10	<5	<5	<7	<10	10	7	<10	<5	<10	10	<7	28
HR 048	Mount Dewar	<50	<10	<35	<7	52	<10	<5	<5	<7	<10	27	<5	<10	17	19	<5	<7	48
ACID GNEISSES (volc. orig.)																			
HR 065	Meade Nunatak	1443	<10	188	<7	<7	<10	16	33	7	22	97	128	42	<5	65	91	89	824
HR 069	Meade Nunatak	898	<10	139	11	13	17	25	33	<7	22	73	105	32	6	34	162	45	665
HR 070	Meade Nunatak	1570	<10	220	<7	<7	23	16	14	10	11	51	58	31	<5	11	122	54	717
HR 170	Mount Beney	1282	11	227	<7	<7	<10	23	44	<7	36	140	67	30	<5	13	109	119	773
HR 171	Mount Beney	1248	<10	255	<7	<7	<10	21	36	8	32	126	71	30	6	<10	114	117	875
HR 174	Mount Beney	1589	<10	230	<7	<7	<10	23	28	<7	55	149	91	43	<5	11	95	104	782
HR 183	Mount Beney	1364	<10	172	<7	<7	<19	23	39	11	32	145	79	21	<5	31	119	142	769

Tab. 1 continned

Sample	Location	Ba	Bi	Ce	Co	Cr	Cu	Ga	Nb	Ni	Pb	Rh	Sr	Th	U	V	Y	Zn	Zr
AMPHIBOLITES																			
HR 009	Lindquist Nunatak	1044	17	88	62	717	45	15	11	199	<10	101	1083	<10	14	246	12	72	113
HR 023	Lord Nunatak	81	<10	49	69	993	78	14	12	581	<10	7	339	25	<5	233	18	85	110
HR 024	Lord Nunatak	163	<10	37	42	55	83	22	24	63	<10	15	219	<10	<5	379	29	117	158
HR 025	Lord Nunatak	<50	<10	<35	63	1972	<10	12	20	567	<10	7	207	<10	<5	272	21	67	114
HR 039	Rileyryggen	<50	<10	<35	55	280	33	15	7	91	<10	7	127	11	<5	404	36	104	102
HR 040	Rileyryggen	107	15	<35	49	35	107	16	9	103	<10	12	186	11	<5	266	19	87	55
HR 049	Mount Dewar	155	12	52	55	402	<10	17	10	195	<10	81	116	<10	<5	165	7	83	27
HR 066	Meade Nunatak	512	<10	37	53	65	72	17	8	50	19	62	95	14	<5	379	40	104	92
HR 172	Mount Beney	125	<10	<35	51	32	<10	17	12	98	20	16	144	14	6	252	32	101	73
HR 173	Mount Beney	165	13	46	61	38	<10	16	11	97	14	16	164	11	6	243	32	102	68
HR 181	Mount Beney	666	<10	55	46	68	31	20	17	48	<10	82	86	<10	7	330	62	160	109
HR 182	Mount Beney	103	<10	58	37	63	15	32	9	38	<10	31	213	<10	<5	569	25	128	109
MARBLES, META-LIMESTONES etc.																			
HR 058	Spaeth Nunatak	194	<10	54	<7	10	<10	<5	<5	10	15	22	809	13	<5	<10	8	<7	224
HR 029	Jackson Tooth	<50	<10	<35	<7	<7	<10	<5	<5	<7	<10	<5	60	<10	9	<10	<5	<7	8
HR 044	Chevreuil Cliffs	88	<10	<35	<7	<7	<10	<5	7	<7	<10	5	52	<10	<5	<10	<5	16	6
HR 051	Aronson Corner	<50	<10	<35	<7	<7	<10	<5	5	<7	11	7	58	<10	6	18	<5	26	17
HR 054	Weißenstein	53	<10	<35	<7	<7	<10	<5	6	<7	<10	7	39	<10	<5	<10	<5	<7	<5
HR 056	Whymper Spur	<50	<10	<35	<7	<7	<10	<5	9	<7	<10	7	76	12	<5	24	13	16	16
HR 057	Whymper Spur	177	<10	<35	<7	15	<10	6	<5	10	<10	26	65	<10	8	25	5	30	35
HR 060	Spaeth Nunatak	109	12	<35	10	<7	<10	<5	6	<7	11	15	1375	<10	6	<10	7	<7	35
HR 061	Spaeth Nunatak	87	<10	<35	<7	<7	<10	<5	5	<7	<10	10	1970	<10	12	<10	<5	<7	63
HR 073b	M'Clintock Bastion	<50	<10	59	<7	14	<10	<5	6	<7	<10	13	50	<10	<5	<10	8	12	102
HR 105a	Mount Provender	<50	<10	<35	<7	<7	<10	<5	<5	7	<10	8	60	11	6	<10	<5	12	8
HR 238	Hollingworth Cliffs	90	<10	<35	<7	<7	<10	<5	<5	<7	<10	6	41	<10	<5	<10	<5	19	7

Sample	Location	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	(SO_3)	LOI
HR 032a	E of Vindberget	51,24	0,93	21,08	9,54	0,10	5,28	1,22	0,84	5,15	0,14	0,10	4,09
HR 032b	E of Vindberget	61,07	0,85	16,76	7,13	0,12	3,76	1,73	1,50	4,08	0,15	<0,05	2,57
HR 033	E of Vindberget	70,61	0,46	10,29	3,19	0,08	1,35	6,22	0,26	0,15	0,12	0,28	6,80
HR 034	E of Vindberget	68,81	0,65	10,91	3,45	0,15	1,95	4,30	2,24	4,98	0,16	0,24	1,90
HR 035	E of Vindberget	68,26	0,63	12,80	4,72	0,10	2,35	2,54	2,35	2,02	0,14	0,20	3,67

Sample	Location	Ba	Bi	Ce	Co	Cr	Cu	Ga	Nb	Ni	Pb	Rh	Sr	Th	U	V	Y	Zn	Zr
HR 032a	E of Vindberget	712	<10	116	30	120	47	39	16	62	<10	252	72	34	6	150	30	128	110
HR 032b	E of Vindberget	679	<10	92	19	96	<10	28	21	44	32	196	94	18	13	103	26	110	185
HR 033	E of Vindberget	<50	<10	49	<7	25	<10	13	9	16	11	9	51	<10	<5	40	28	61	302
HR 034	E of Vindberget	558	<10	87	21	113	<10	12	15	24	32	212	116	14	<5	72	39	84	164
HR 035	E of Vindberget	317	<10	93	14	54	<10	17	14	35	12	94	140	22	6	73	30	79	202

Tab. 2: Distribution of major and trace elements in the Jurassic(?) sedimentary unit of Vindberget.

Tab. 2: Verteilung der Haupt- und Spurenelemente in den jurassischen(?) Sedimentgesteinen von Vindberget.

	Mica-poor plagioclase gneiss	Plagioclase-quartz-mica schist		Garnet-kyanite-staurolite-mica schist						Slightly foliated hornblende fels
	W 677	W 678	W679	W 680	W 681	W 682	W 683	W 684	W 685	W 688
Quartz	44	57	8	18	14	19	1	4	1	13
Plagioclase	43	17	16	9	5	9	2	12	2	7
Biotite	6	11	52	43	41	37	53	45	68	1
Muscovite	12	+	+	+	+	+	+	+	+	-
Hornblende	-	-	-	-	-	-	-	-	-	78
Garnet	5	3	8	5	4	13	3	9	2	-
Staurolite	-	-	7	12	20	12	25	16	19	-
Kyanite	-	-	10	12	15	10	16	14	6	-
Tourmaline	-	-	+	+	-	+	-	+	+	-
Apatite	-	-	+	-	-	-	-	-	-	+
Rutile	-	+	+	+	+	+	+	+	+	+
Zircon	+	+	+	+	+	+	+	+	+	+
Opaques	2	-	+	1	+	1	+	2	2	1
Mol% Anorthite	24-26	25-29	30-37	30-36	31-35	29-34	32-41	31-37	-	-

Tab. 3: Modal composition and anorthite contents of plagioclase (optically measured) in representative rock types from the southern Meade Nunatak (21° 58.8' W / 80° 22.8' S)

Tab. 3: Modalbestände und Anorthitgehalte von Plagioklasen (optisch gemessen) in repräsentativen Gesteinstypen vom südlichen Meade Nunatak (21° 58,8' W / 80° 22,8' S)

rier has to be assumed. The fluorine content indicated by humite group minerals can be an indication of a slightly evaporitic environment.

Detrital siliceous grains are also significant in environmental interpretation. Zones of rounded, frosted, sometimes rather large quartz grains are known in many carbonate occurrences. They are interpreted as probably coastal dune and beach sands reworked in a shallow marine environment (Wilson 1975). Well rounded quartz grains can be observed in samples from the Spaeth Nunatak, and hence the proximity of coastal dunes and beach sands has to be postulated.

Present-day carbonate deposition demonstrates a clear correlation with the equatorial belt and warm ocean currents (Wilson 1975). Clear, warm, shallow water is essential and has to be accepted as likely for the Pioneers Group depositional environment. The only feature of this model that does not apply is the presence of rather fast-growing coral reefs in subsiding basins; this can be excluded for the Precambrian.

Besides shallow-water marine sedimentation, terrestrial deposition can be assumed, e.g. residual deposits enriched in Al_2O_3. The kyanite and staurolite schists have to be derived from aluminium-rich sediments and/or tuffites.

The quartzites of the Pioneers Group sometimes show cross bedding. They are often derived from pure quartz sands, but the actual depositional environment of the sandstone protoliths (braided streams, sand dunes) is uncertain. As there is an indication of the existence of dune and beach sands during the deposition of the calcareous sediments (see above), dune and beach sands as protoliths are likely.

Besides the metasediments, bimodal volcanics were encountered in the northern Shackleton Range. They could be assigned to an BVAC association, consisting mostly of bimodal volcanics - arkoses-conglomerates. The volcanics of the BVAC association are typically tholeiitic basalts and felsic, mainly rhyolitic rocks, both of which occur in the Pioneers Group sequences. Immature terrigenous clastic sediments (i.e. arkoses, feldspathic quartzites, and conglomerates), which indicate rapid uplift, are not very obvious in the Pioneers Group, but a rock very much resembling a conglomerate occurs in the Mount Gass area (Mount Gass Formation, *sensu* Marsh 1983a). In other BVAC associations - they are said to be the most diverse of Proterozoic assemblages - pelites, massive mature quartzites, BIF, and carbonates predominate (Condie 1989). Such an assemblage resembles the Pioneers Group rocks more closely - with the exception of the BIF. Although Kamenev (1990) mentions ferruginous quartzites, there are definitely no sediments exposed in the Shackleton Range that belong to a thick banded iron formation sensu stricto.

7. METAMORPHIC HISTORY

Generally, the metasediments and metavolcanics of the Pioneers Group show an amphibolite facies mineral assemblage, but several phases of metamorphism may have occurred. The last one, maybe related to the Ross Orogeny, caused a greenschist metamorphic overprint of the higher-grade metasediments. Mineral analyses were carried out on garnet-kyanite-staurolite-mica schists and P-T conditions were estimated for samples from the southern Meade Nunatak.

The paragenesis quartz-plagioclase-biotite-kyanite-garnet-staurolite allows the P-T conditions under which metamorphism of the garnet-kyanite-staurolite-mica schists (W 684) took place to be estimated. A first approximation is possible by considering the stability fields of the Al_2SiO_5 polymorphs, as kyanite is the only stable phase present. The P-T diagram of the KFMASH system (K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O) of SPEAR & CHENEY (1989) allows an interpretation of the observed parageneses (Fig. 10). The reaction curves shown in this diagram are based on thermodynamic data from BERMAN et al (1985) and BERMAN (1988). As the Fe/Mg ratio in a mineral solid solution correlates with pressure and temperature, it is possible to draw Fe/(Fe+Mg) isopleths, which make it possible to place constraints on the P-T conditions in the stability fields of the different parageneses.

The absence of primary muscovite and chlorite in coexistence with garnet shows that the equilibrium curve of the reaction garnet + chlorite + muscovite = staurolite + biotite + quartz + H_2O was reached or passed during the peak of metamorphism. The position of this curve is a function of the proportion of Mn (X_{Mn} = Mn/(Mn + Fe + Mg)) in the garnets, but there was so little Mn in the analysed crystals ($X_{Mn} < 0.05$) that a correction of the curve would not shift the curve significantly (SPEAR & CHENEY 1989). The position of the Fe/(Fe+Mg) isopleths of garnets indicate a temperature of 570-580 °C at about 6 kbar pressure for the rim of the garnets of sample W684 ($X_{Fe} \approx 0.85$). The lower X_{Fe} value of approximately 0.73 in the cores of the garnets indicates an elevated temperature of 600-670 °C at 6-10.5 kbar.

This relatively broad field of P-T conditions can be further constrained by the solidus of granites in water-saturated systems ($P_{H2O} = P_{total}$ following THOMPSON & ALGOR 1977). This solidus was not crossed to higher temperatures as demonstrated by the lack of migmatization. It can be concluded that the conditions during the growth of the garnet started at temperatures of 600 °C and pressures of about 10.5 kbar.

The zoning of the garnets (pyrope-rich core, almandine-rich rim) indicates growth under retrograde conditions, i.e. during a phase of uplift. The relict cores are a strong argument for granulite facies conditions. But the temperature of „only" 600 °C shows that anatectic conditions were not reached, in spite of the high pressure conditions. This is in accordance with the field observations. The continuous gradient displayed by the garnet zoning excludes the possibility of the garnet cores being xenocrysts derived from other protoliths.

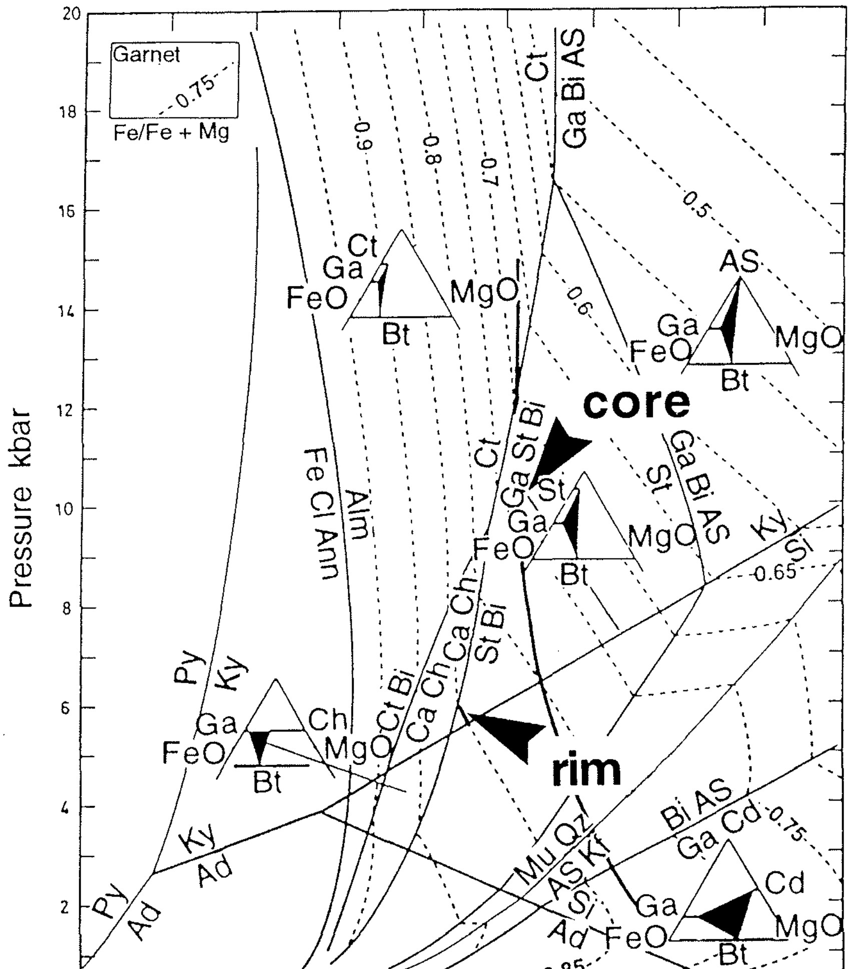


Fig. 10: P-T diagram showing the Fe/(Fe+Mg) isopleths of garnet in biotite- and garnet-bearing parageneses (from: SPEAR & CHENEY 1989, Fig. 3). The solidus of granite (1) after THOMPSON & ALGOR (1977) is shown. The arrow shows the amount of almandine in the core ($X_{Fe} \approx 0.73$) and in the rim ($X_{Fe} \approx 0.85$) of the garnet. Ad = Andalusite, Alm = Almandine, Ann = Annite, AS = Al-Silicate, Bi = Biotite, Cd = Cordierite, Ch = Chlorite, Ct = Chloritoid, Ga = Garnet, Kf = K-feldspar, Ky = Kyanite, Mu = Muscovite, Py = Pyrophyllite, Qz = Quartz, Si = Silimanite, St = Staurolite.

Abb. 10: P-T-Diagramm gibt die Fe/(Fe+Mg) Isoplethe von Granat in Biotit- und Granat-führenden Paragenesen wieder (nach SPEAR & CHENEY 1989, Fig. 3). Die Solidus-Kurve von Granit ist nach THOMPSON & ALGOR (1977), der Pfeil zeigt den Betrag an Almandin für Kern ($X_{Fe} \approx 0.73$) und Rand ($X_{Fe} \approx 0.85$). Ad = Andalusit, Alm = Almandin, Ann = Annit, AS = Al-Silikate, Bi = Biotit, Cd = Cordierit, Ch = Clorit, Ct = Chloritoid, Ga = Granat, Kf = K-Feldspat, Ky = Disthen, Mu = Muscovit, Py = Pyrophyllit, Qz = Quarz, Si = Silimanit, St = Staurolit.

This strongly suggests that not only the Read Mountains underwent granulite facies metamorphism (SCHULZE & OLESCH 1990), but also the Pioneers Group rocks.

8. GEOTECTONIC SETTING AND PLATE TECTONIC IMPLICATIONS

With regard to the geotectonic setting of the Pioneers Group, the environment in which the protoliths were deposited is of interest. One possibility is that the protoliths were platform sediments covering a stable part of the craton, i.e. shield rocks submerged along a continental cratonic margin; another possibility is that deposition took place in a back-arc basin.

In general, the Pioneers Group rocks form a typical quartzite-pelite-carbonate (QPC) association. Similar associations comprise 60 % of the known Proterozoic supracrustal rocks (CONDIE 1989). In addition, the bimodal volcanics are indicative of a BVAC association.

The QPC association is associated with three stable tectonic settings: rifted continental margins, cratonic margin of back-arc basins, or intracratonic basins (CONDIE 1989). An intracratonic basin model is unlikely due to the existence of bimodal volcanics and their calc-alkaline character.

Calc-alkaline volcanics may occur in both island arcs and continental margin arcs. The occurrence of both the QPC association and the BVAC association in the Pioneers Group suggests a cratonic margin in a back-arc basin situation.

If we consider the Read Group to represent the cratonic basement on which the Pioneers Group metasediments were deposited, we would expect the volcanic arc to be located further north. In fact, the metavolcanics seem to be concentrated in a „belt" north of the marble occurrences, i.e. from Mount Beney (northern Lagrange Nunataks) at Baines Nunatak/Lord Nunatak and Meade Nunatak, where the amphibolites are concentrated. The dacitic-rhyolitic gneisses are encountered at Meade Nunatak, especially in the eastern part of the Pioneers Escarpment. Rhyolitic gneisses were sampled at Lundström Knoll, Gallsworthy Ryggen, Chevreuil Cliffs, Mummery Cliff and Jamieson Ridge, but they do not have the same volcanic geochemical fingerprints as the Mount Beney and Meade Nunatak samples. The assumption of a northward increasing proportion of metavolcanics could be confirmed or disproved by more detailed N-S traverses through the Pioneers Group rocks. These traverses could also provide evidence for a relationship between the highly deformed gneissose Mount Beney volcanic units (Stratton Group) and the Pioneers Group volcanic rocks.

As both Stratton Group and Pioneers Group are exposed and seemingly closely related at Mount Beney, the possibility of highly deformed Pioneers Group rocks resembling the infracrustal Stratton Group cannot be totally excluded. For a more detailed discussion of the partly unsolved relationship between the Stratton Group and the Pioneers Group (ROLAND et al., in press).

Geochemical studies have demonstrated that metasediments and metavolcanics occur in the Pioneers Group. It is probable that the metasediments and the metavolcanics can be assigned to different formations within the Pioneers Group, but during field work the problem will arise of assigning the rocks to the correct formation. We therefore decided not to subdivide the Pioneers Group at present.

The geologic histories of the Read Group and the Pioneers Group differ greatly. We can assume from age determinations (PANKHURST et al. 1983) and from the deformational history (BRAUN 1995) that the Read Group in the south is the older complex, which underwent erosion when the Pioneers Group sediments and volcanics were being deposited.

The rather stable position of the Shackleton Range seems to have been preserved throughout geologic history. Granitoid orthogneisses exist in the older Read Group, but there is little evidence pointing to the presence of granitoids in the Pioneers Group.BRAUN (1995) believes that the Stratton Gneiss is a syntectonic to late tectonic intrusion. Feldspar blastesis was observed by PAECH (1985) within the supracrustals and taken to indicate migmatisation which may have been caused by underlying granitoids. No further granitoid intrusives, especially younger ones or high level intrusives, are known, but mafic dykes of different ages cut the metasediments (SPAETH et al. 1995).

During the peak of metamorphism, the pressure was unusually high and the temperature only moderate. We can conclude that the sediments were buried to a depth of about 35 km (collision, subduction?), which led to the high-grade metamorphism. The later amphibolite-facies metamorphism is retrograde and probably associated with an uplift phase. Granulite facies was not reached. The last event was a greenschist facies overprint, which might be related to the Ross Orogeny.

It is not known whether the Pioneers Group metasediments occur *in situ*, or were they transported southward, similar to the Lagrange Nappe, which includes the Mount Gass Formation and Nostoc Lake Formation (MARSH 1983b), or to the Turnpike Bluff nappe in the Read Mountains (BUGGISCH et al. 1994).

The metasediments of the Pioneers Escarpment show similar signs of tectonism, i.e. subhorizontal mylonitic horizons. But no slivers of supracrustal rocks were observed in the underlying basement or vice versa as has been described from the Haskard Highlands by MARSH (1883a). Nevertheless, we assume a similar type of deformation for the Pioneers Escarpment. Compressional forces during the ?Ross Orogeny might be the cause for the thrust and/or nappe tectonics. At present, we cannot prove that the metasediments are allochthonous, which would clearly confirm the nappe tectonics.

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