Polarforschung 57 (1/2): 93—113, 1987

A Survey of Mesozoic Dolerite Dikes from Western Neuschwabenland, Antarctica, and their Geotectonic Significance

By G. Spaeth and P. Schüll*

Summary: In western Neuschwabenland basic dikes occur in the Jurassic lavas and Permian sediments of Vestfjella as well as in the Precambrian sedimentary-volcanogenic rock sequence of the Ahlmannryggen and in the Precambrian crystalline complexes of Heimefrontfjella and Mannefallknausane. The concentration of the dikes in Vestfjella is conspicuous. Two main directions of strike perpendicular to each other are recognizable, from which the NE-SW striking one is predominant. The direction of the dikes coincides with the Mesozoic and younger fracture tectonics. Age relationships by structural, petrographical and geochemical observations are confirmed by palaeomagnetic and radiometric age determinations from PETERS et al. (1986). Considerations on the geochemistry of further dolerite occurrences from Antarctica and other regions of the Gondwana continent are pointed out. Finally comparisons with the analogous South African dike system show the geotectonic significance of the dolerite dikes for the break-up of Gondwana.

Zusammenfassung: Im westlichen Neuschwabenland treten basische Gänge sowohl in den jurassischen Laven und permischen Sedimenten von Vestfjella, wie auch in den präkambrischen sedimentär-vulkanogenen Gesteinsfolgen des Ahlmannryggen und in den präkambrischen Kristallinkomplexen von Heimefrontfjella und Mannefallknausane auf. Auffällig ist ihre zahlenmäßige Konzentration in der erstgenannten Region. Die Gänge kommen in zwei, annähernd senkrecht aufeinanderstehenden Scharen vor, von denen die NE-SW-gerichtete die dominierende ist. Richtungsmäßig fallen die Gänge mit der mesozoischen und jüngeren Bruchtektonik zusammen. Die aus den Verbandsverhältnissen und unter Hinzuziehung von Petrographie und Geochemie gewonnenen relativen Altersbeziehungen werden durch die von PETERS et al. (1986) ermittelten paläomagnetischen und radiometrischen Altersbestimmungen bestätigt. Neben Betrachtungen zur Geochemie weiterer Doleritvorkommen Antarktikas und anderer Regionen des Gondwana-Kontinents werden schließlich Vergleiche mit dem analogen südafrikanischen Gangsystem gezogen, die die geotektonische Bedeutung der Doleritgänge für den Gondwanazerfall aufzeigen.

1. INTRODUCTION

Mafic dikes of Mesozoic age are very common in some parts of Dronning Maud Land particularly in western Neuschwabenland. They belong to the Jurassic tholeiitic rocks, which are widely distributed in the Transantarctic Mountains and on the margin of the East Antarctic shield. Stratigraphically, they are part of the Ferrar Dolerite Group as defined by KYLE et al. (1981). In this paper the term dolerite is used for fresh, hypabyssal basic rocks, which are medium- or fine-grained.

The Mesozoic mafic dikes of western Neuschwabenland indicate crustal extension. They help to elucidate the younger geotectonic history of this region together with fault structures and geophysical studies. Neuschwabenland being formerly joined with the southeastern part of Africa, the mafic dikes are also of special importance to the reconstruction of the Gondwana supercontinent and the course of its break-up.

Since ROOTS (1953) first mentioned the occurrence of such dikes in his reconnaissance work on the geology of western Dronning Maud Land, more detailed description with respect to individual regions has been done by several authors (JUCKES 1968, HJELLE & WINSNES 1972, FURNES & MITCHELL 1978, FURNES et al. 1982, WOLMARANS & KENT 1982, KAISER & WAND 1985). However, there is still missing a systematic description and a review for Neuschwabenland as a whole.

During three expeditions to western Neuschwabenland in the austral summers of 1982—83, 1983—84, and 1985—86 the senior author carried out structural investigations in northern Vestfjella (Kraulberge), in Ahlmannryggen, in Heimefrontfjella, and Mannefallknausane (Fig. 1). Those investigations gave the opportunity to look especially for the mafic dikes. 200 dikes were found and described with respect to their structural relations. Most of them were sampled for petrographical and geochemical analyses,

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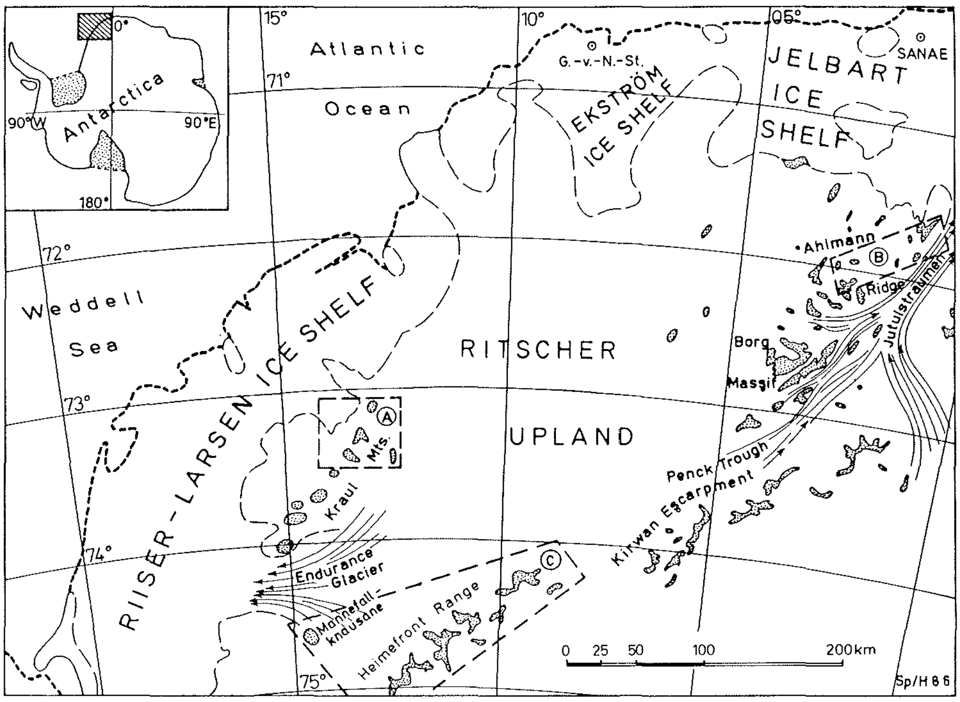

Fig. 1: Sketch map of western Neuschwabenland. Areas with outcrops are stippled. Areas of field work in 1982—83 (A), 1983—84 (B), and 1985—86 (C) are contoured.

Abb. 1: Übersichtskarte des westlichen Neuschwabenlands. Aufgeschlossene Gebiete sind gepunktet dargestellt. Die Arbeitsgebiete von 1982/83 (A), 1983/84 (B) und 1985/86 (C) sind umrissen.

which are presented in this paper together with the structural data. Regarding the age relationships based on radiometric determinations we refer to the above-mentioned authors and to REX (1972). Meanwhile radiometric data from samples of our expeditions are available as well (PETERS et al. 1986).

2. GEOLOGICAL SETTING

Western Neuschwabenland is situated on the western margin of the East Antarctic shield. To the east it is delimited by the important Jutulstraumen rift. To the west a complex rift system has to be assumed in the Weddell Sea. Fig. 2 shows a simplified geologic map of western Neuschwabenland. The presented pole diagrams in Fig. 2 will be discussed further on. The mountain ranges and nunatak groups strike mainly SW-NE. Concerning morphology and structural setting they are connected to horst and graben structures. The following geologic units of different crustal levels and ages can be distinguished.

The uppermost unit builds up the whole Vestfjella and can be found as remnants in Heimefrontfjella and Kirwanveggen. In its major part it is composed of probably Jurassic basic volcanic rocks with few thin sedimentary intercalations. It is underlain by a Permian sedimentary sequence with local thin coal seams.

The nunataks of Ahlmannryggen and Borgmassivet are composed of the next unit, the Proterozoic platform sediments with basic to intermediate volcanic rocks. Proterozoic intrusions of intermediate, basic and ultrabasic composition cut this platform sequenc.

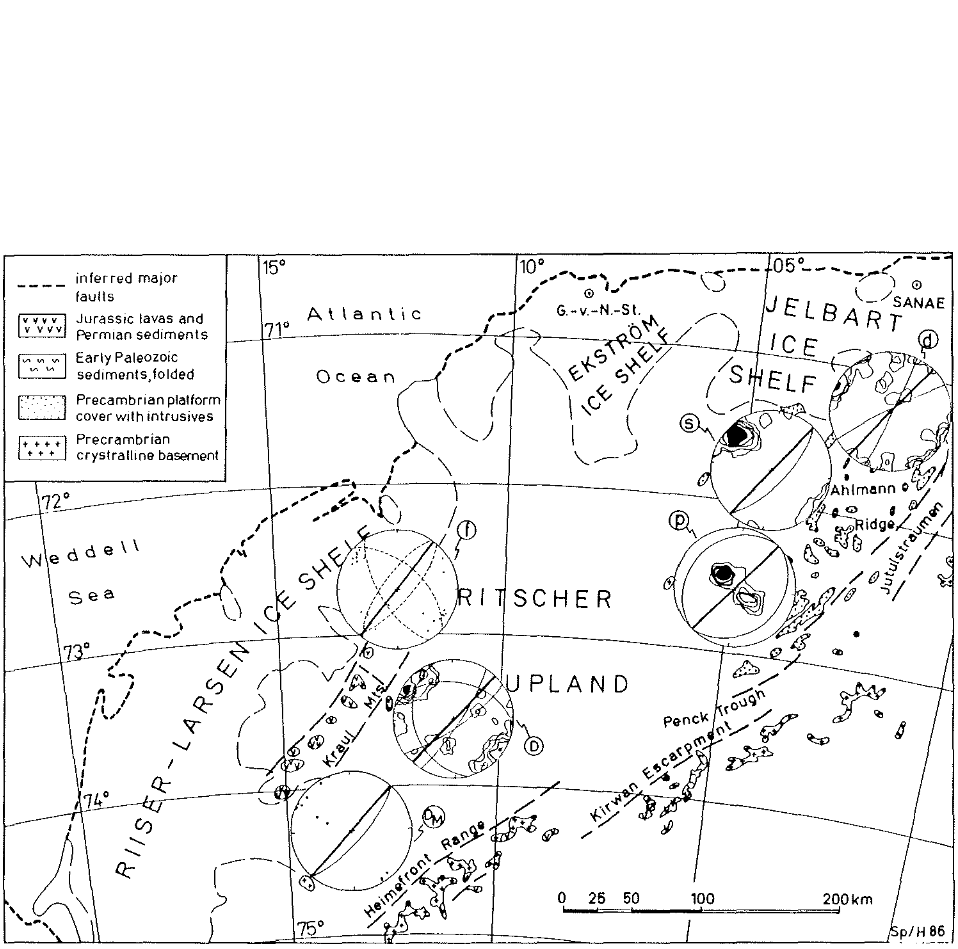

Fig. 2: Geological sketch map of western Neuschwabenland. Pole diagrams as insets indicate the main trends of Mesozoic mafic dikes and the orientation of structural data:
(D) dikes and (f) normal faults of Kraulberge (Vestfjella); (d) Mesozoic dikes, (s) s-planes and (p) small overthrusts of Precambrian to Lower Palaeozoic age from Ahlmannryggen; (D_M) dikes from Heimefrontfjella and Mannefallknausane.

Abb. 2: Geologische Übersichtskarte des westlichen Neuschwabenlands. Die eingezeichneten Gefügediagramme zeigen die Hauptrichtungen der mesozoischen basischen Gänge und die Orientierung weiterer tektonischer Daten an:
D = Gänge und f = Abschiebungen in den Kraulbergen; d = mesozoische Gänge, s = s-Flächen und p = Kleinüberschiebungen präkambrisch-altpaläozoischen Alters im Ahlmannryggen; D_M = Gänge in Heimefrontfjella und Mannefallknausane.

The lowermost unit reaches the largest extent. This unit forms the crystalline basement of complex composition and is of Precambrian age. It builds up Mannefallknausane, Heimfrontfjella, Kirwanveggen and its northeastern continuation. Middle to high grade metamorphics (amphibolite to granulite facies) are the main rock units. An early Palaeozoic to Late Precambrian age is attributed to an unmetamorphosed sedimentary rock sequence (Urfjell Group) of the southwestern part of Kirwanveggen.

In Fig. 3 schematic profiles from the different working areas (Fig. 1) show the relationship between the above described geologic units and the Mesozoic intrusions. At Vestfjella (region A) dikes cut the Jurassic lavas and the Late Palaeozoic sediments at Fossilryggen. They occur in very great numbers. Numerous basic sills, which are related to the dikes, are also common in the lava sequence. At Ahlmannryggen (region B) the dikes cut the crystalline basement and the Proterozoic sedimentary-volcanogenic platform sequence. Mesozoic sills are unknown until now. At Heimefrontfjella and Mannefallknausane (region C) the young basic intrusions appear as dikes and sills in the crystalline basement. In the Permian cover only one large sill with branchings could be observed.

The dolerite dikes can be easily recognized in the outcrops (cliffs and ridges of the nunataks and mountain massifs) by their red-brownish to grey-brownish weathering colour and their columnar jointing. This is also valid for the sills. Except for the thin weathering crust the rocks of these young intrusions look very fresh and have a grey to grey-blackish colour. In contrast, the older intrusions, also occurring in the crystalline basement and Proterozoic platform sequence, look distinctly altered. Morphologically the di-

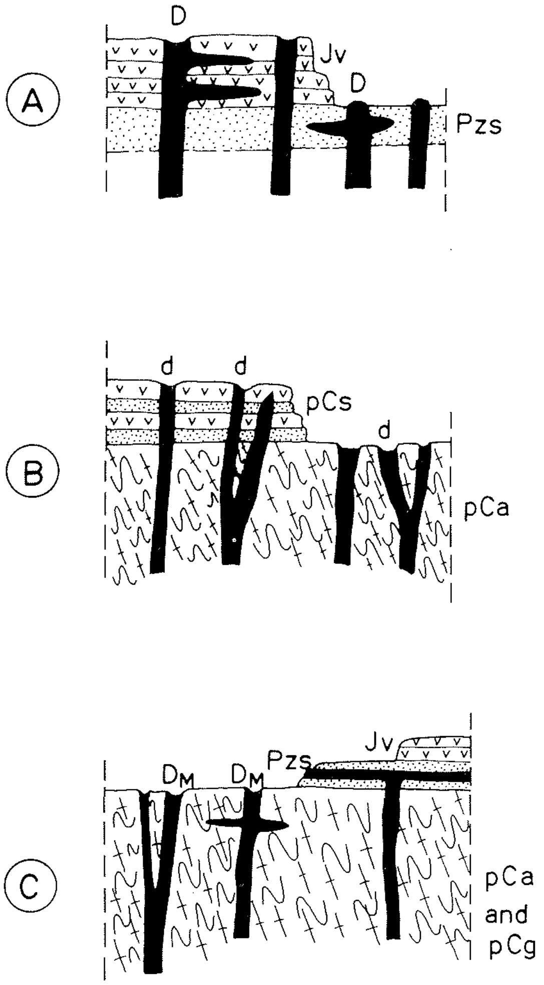

Fig. 3: Geological setting of the Mesozoic dolerite intrusions in the areas of field work. (A) Vestfjella-N (Kraulberge), (B) Ahlmannryggen and southeastern adjacent areas, (C) Heimefrontfjella and Mannefallknausane; pCa and pCg — Precambrian crystalline basement, pCs — Proterozoic sediments, lavas, and intrusions, Pzs — Late Palaeozoic sedimentary sequence, Jv — Jurassic lavas, D, d and D_M — Mesozoic dolerite dikes and sills.

Abb. 3: Schematische Darstellung der geologischen Position der mesozoischen Doleritintrusionen in den verschiedenen Arbeitsgebieten. A — Vestfjella-Nord (Kraulberge), B — Ahlmannryggen und südöstlich benachbarte Gebiete, C — Heimefrontfjella und Mannefallknausane; pCa und pCg — Präkambrisches kristallines Basement, pCs — Proterozoische Sedimente, Laven und Intrusionen, Pzs — Jungpaläozoische Sedimentfolge, Jv — Jurassische Laven, D, d und D_M — Mesozoische Doleritgänge und -sills.

kes are well recognizable, too. They occur as sharp notches in the ridges and cliffs of the nunataks. When intruding sediments, however, they form erosional ridges.

Because of the above described characteristics of the dikes it can be assumed that only few or none of them were missed on the visited nunataks and mountain massifs. This gives approximate indications for their frequency in the three regions. Thus were found

in region A: 150 dikes on 7 nunataks and massifs,
in region B: 38 dikes on 16 nunataks and massifs,
in region C: 12 dikes on 70 nunataks and massifs.

Even when considering the different dimensions of the nunataks and mountain massifs, there is evidence that the dolerite dikes are most frequent (forming dike swarms) in the Vestfjella area and that their frequency in western Neuschwabenland diminishes to the E and SE. It has, however, to be noted that BANKWITZ & BANKWITZ (1985) report a particularly great density of basic dikes from the crystalline basement of the Wohlthatmassiv (eastern Neuschwabenland). They account a number of 700—800 dikes

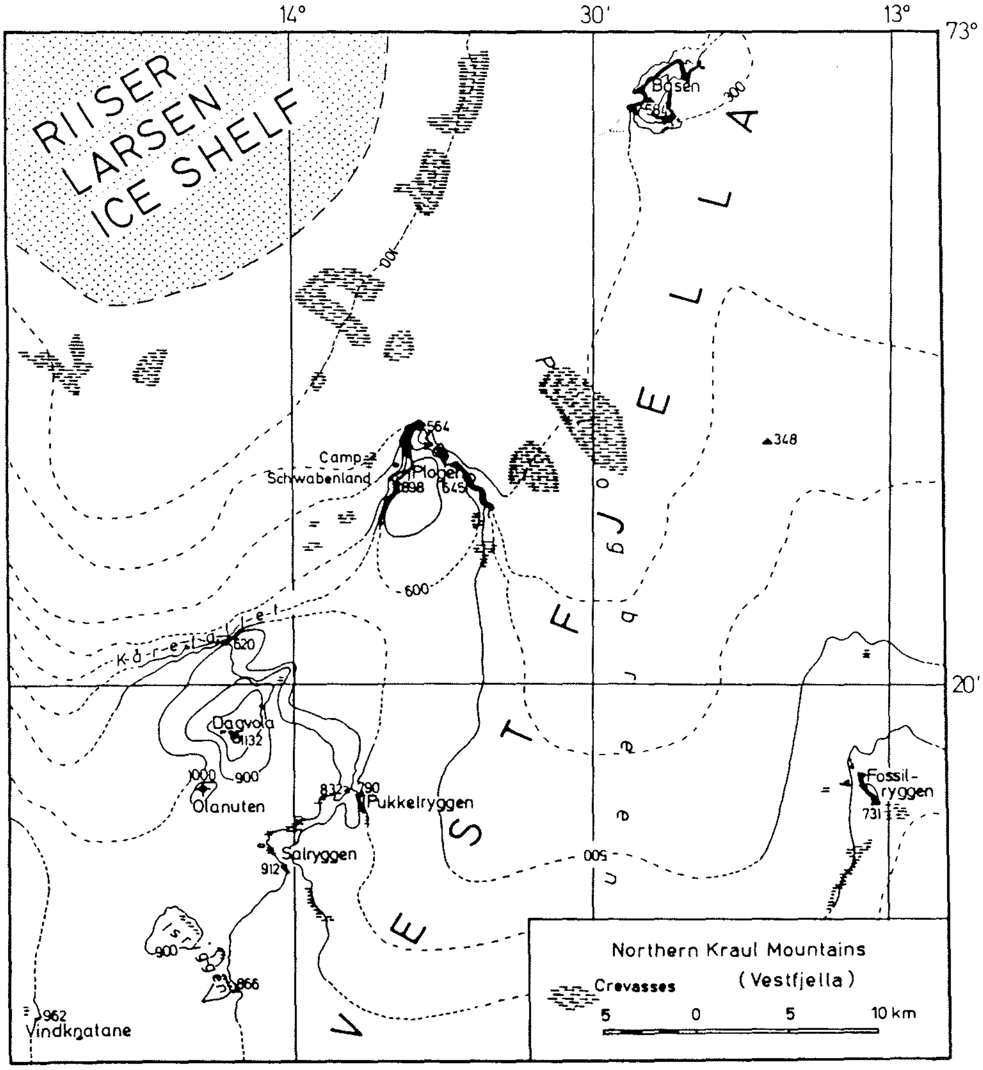

Fig. 4: Topographical sketch map of Vestfjella-N (Kraulberge), drawn after the Norwegian topographical map of Dronning Maud Land 1:250.000.

Abb. 4: Topographische Kartenskizze von Vestfjella-Nord (Kraulberge), gezeichnet nach der norwegischen topographischen Karte von Dronning Maud Land 1:250.000.

for approximately 160 km² of ice-free hard rock area. However, it is a photogeological survey, which cannot distinguish Mesozoic and older, metamorphic dikes. BANKWITZ & BANKWITZ (1985) do not preclude an erroneous interpretation of the dark photo-lineations by confounding dikes with faults.

3. THE DIKES OF NORTHERN VESTFJELLA

In the northern Kraulberge (in newer maps also named Vestfjella) the basic dikes are particularly numerous. In some areas they appear as dense swarms with a spacing of the dikes from several ten to a few

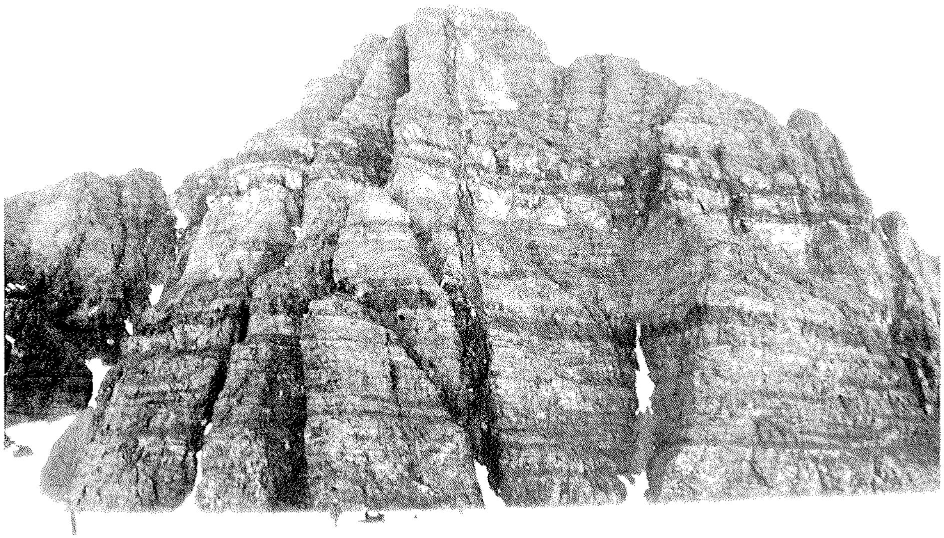

Fig. 5: Dolerite dikes, dark and producing notches (centre and left), and sills intruding a sequence of Jurassic basaltic lava flows. Vestfjella, western Neuschwabenland; northeastern cliff of Plogen, height of the wall approximately 300 m.

Abb. 5: Steile Doleritgänge (dunkel und Kerben erzeugend; Bildmitte und links) und Dolerit-Lagergänge (dunkel) in der jurassischen Basaltlaven-Folge von Vestfjella, W-Neuschwabenland. NE-Flanke von Plogen, Höhe der Wand ca. 300 m.

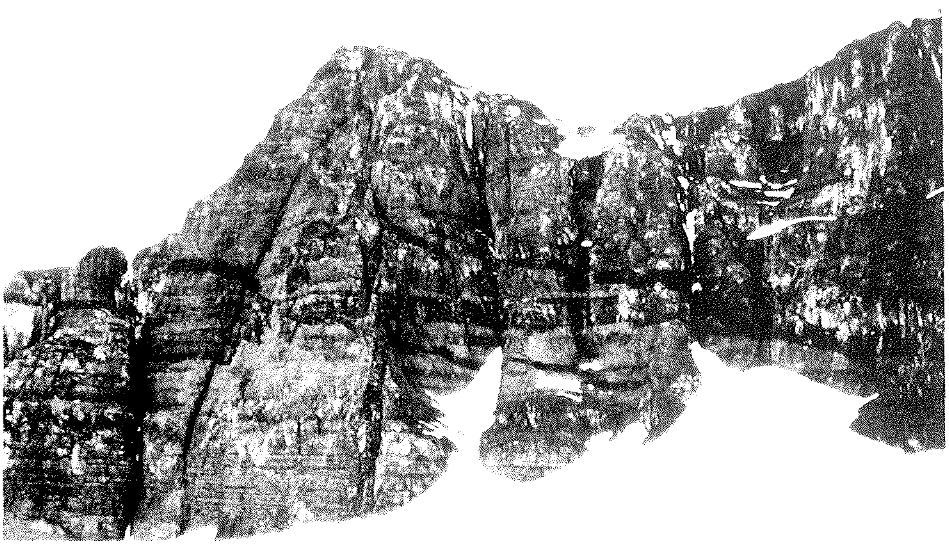

Fig. 6: Dolerite dikes in a sequence of Jurassic basaltic lava flows. Vestfjella, western Neuschwabenland; northeastern cliff of Plogen, height of the wall approximately 250 m.

Abb. 6: Steile Doleritgänge und Dolerit-Lagergänge in der jurassischen Basaltlaven-Folge von Vestfjella, W-Neuschwabenland. NE-Flanke von Plogen, Höhe der Wand ca. 250 m.

Fig. 7: A ridge-like outcrop of a dolerite dike crossing Late Palaeozoic sediments. Main nunatak of Fossilryggen, east of Vestfjella, western Neuschwabenland.

Abb. 7: Ausbiß eines Doleritgangs, als Rippe herauspräpariert, in jungpaläozoischen Sedimentgesteinen des Hauptnunataks von Fossilryggen, östlich von Vestfjella, W-Neuschwabenland.

hundred meters. At nearly all visited nunataks and mountain massifs shown on the map of the working area (Fig. 4) these dikes were found. Fig. 5 and 6 show parts from the NE-cliff of the Plogen massif. The dikes and sills, also recognizable with a thickness of several meters, cross the altered basaltic lava flows of Mesozoic age which dip gently to the west. The dikes are obvious by their colour and by their weathering to notches on the cliff. Fig. 7 shows a dike with a thickness of 8 m intruded into the Permian sediments of the main nunatak of Fossilryggen. Here, in contrast, the outcropping dike forms a narrow ridge, because of the more advanced erosion on the sediments. The dikes of Fossilryggen have particularly well developed chilled margins and contact-metamorphic features on the sedimentary rocks, e. g. the degree of coalification of carbonaceous matter is very high.

A total of 150 dikes were observed. Their thickness ranges from 0.1 m to 35 m, most frequent are those from 1 m to 10 m. The length in striking direction is estimated to be in the range of a few hundred meters to a few kilometers, their limits rarely being observed. Fig. 8a shows that the dikes are relatively tightly oriented and that two groups are present. The dominant set (120 dikes) strikes approximately NE-SW and dips steeply to the SE or NW. A second, subordinate set (30 dikes) strikes approximately NW-SE and dips mor gently to the NE or SW. Where the two systems occur together the steeper NE-trending dikes were always observed to cut the SE-trending dikes. Many examples were found, where the more gently dipping dikes merge into sills. Several small normal faults were identified at Plogen and Basen (Fig. 8b). Two groups can be divided: one set strikes NW-SE (f_3 and f_4), the other one NE-SW (f_1 and f_2). The latter is the most frequent. Vertical displacements along the faults are between 1 m and 30 m. In many cases the steeply dipping dikes coincide with faults with movements having occurred along contact zones as indicated by slickensides. Many of the dikes have been sheared into large lens-shaped bodies cut by slickensided surfaces. So it can be deduced that the fracturing outlasted or post-dated the emplacement of the dikes.

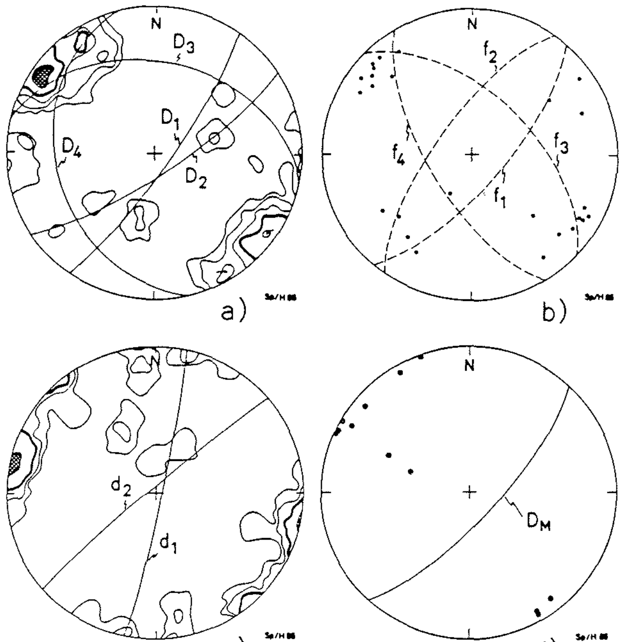

Fig. 8: Pole-diagrams with data of dikes and faults from the investigated areas of western Neuschwabenland. Schmidt net, lower hemisphere. (a) 150 dolerite dikes (D_1—D_4), Vestfjella; contours 1, 3, 5, 7, 10%. (b) 25 normal faults (f_1—f_4), Vestfjella. (c) 38 dolerite dikes (d_1—d_2), Ahlmannryggen; contours 2.5, 5, 10, 25%. (d) 12 dolerite dikes (D_M), Heimefrontfjella and Mannefallknausane.

Abb. 8: Lagenkugel-Diagramme von Doleritgängen und Verwerfungen in den untersuchten Gebirgen des westlichen Neuschwabenlands. Schmidtsches Netz, untere Halbkugel. a) D_1—D_4: 150 Pole von Doleritgängen, Vestfjella; Dichtelinien 1, 3, 5, 7, 10%. b) f_1—f_4: 25 Pole von Abschiebungen, Vestfjella. c) d_1 und d_2: 38 Pole von Doleritgängen, Ahlmannryggen; Dichtelinien 2.5, 5, 10, 25%. d) D_M: 12 Pole von Doleritgängen, Heimefrontfjella und Mannefallknausane.

In the northeastern cliff of Plogen, which is approximately 6 km long and where the NE-striking dikes are common, the cumulative thickness of the 66 dikes is 275 m. This suggests a crust extension in a NW-SE-direction of approximately 5%. For the nunatak group Pukkelryggen, a similar extension of 4.7% is indicated.

The age of the dolerite intrusions in the sediments at Fossilryggen interpreted on structural evidence has to be post-Permian. By geochemical and petrographic similarities between the dikes and sills on the one side and the lava flows on the other, HJELLE & WINSNES (1972) assumed that both lithological units were approximately of the same age, implying a Jurassic age for the basaltic flows. Some new K-Ar radiometric age determinations on plagioclase (PETERS et al. 1986) yielded ages between 160 Ma and 180 Ma for several dolerite dikes and sills of northern Vestfjella, which are comparable to those published by FURNES & MITCHELL (1978) for dikes of southern Vestfjella. Palaeomagnetic investigations on samples from the flows and intrusives also point to a Jurassic age (PETERS et al. 1986). These data suggest that the magmatic event of Vestfjella can be placed roughly in the early Jurassic period.

4. THE DIKES OF THE NORTHEASTERN AND CENTRAL AHLMANNRYGGEN

The Proterozoic rock sequence of the Ahlmannryggen (Fig. 9) was not only intruded by the Proterozoic Borgmassivet Intrusives but also by younger Mesozoic basic dikes. No Mesozoic sills can be observed. The dikes are, however, less frequent than in Vestfjella. Only 38 of them were observed. Most were found in northeastern Ahlmannryggen (Straumsnutane), where Proterozoic intrusions are missing. In this region the dikes cross the Straumsnutane Volcanics (Fig. 10). Some dikes were recorded in the central Ahlmannryggen during fieldwork near the South African summer station Grunehogna. They intrude the sedimentary sequence and the Proterozoic intrusions. Fig. 11 and 12 show two examples with the dikes cutting diorites of the Borgmassivet Intrusives. Mesozoic dolerite intrusions can here be distinguished from Precambrian ones, because they have distinctly different chemical composition and show only insignificant alteration.

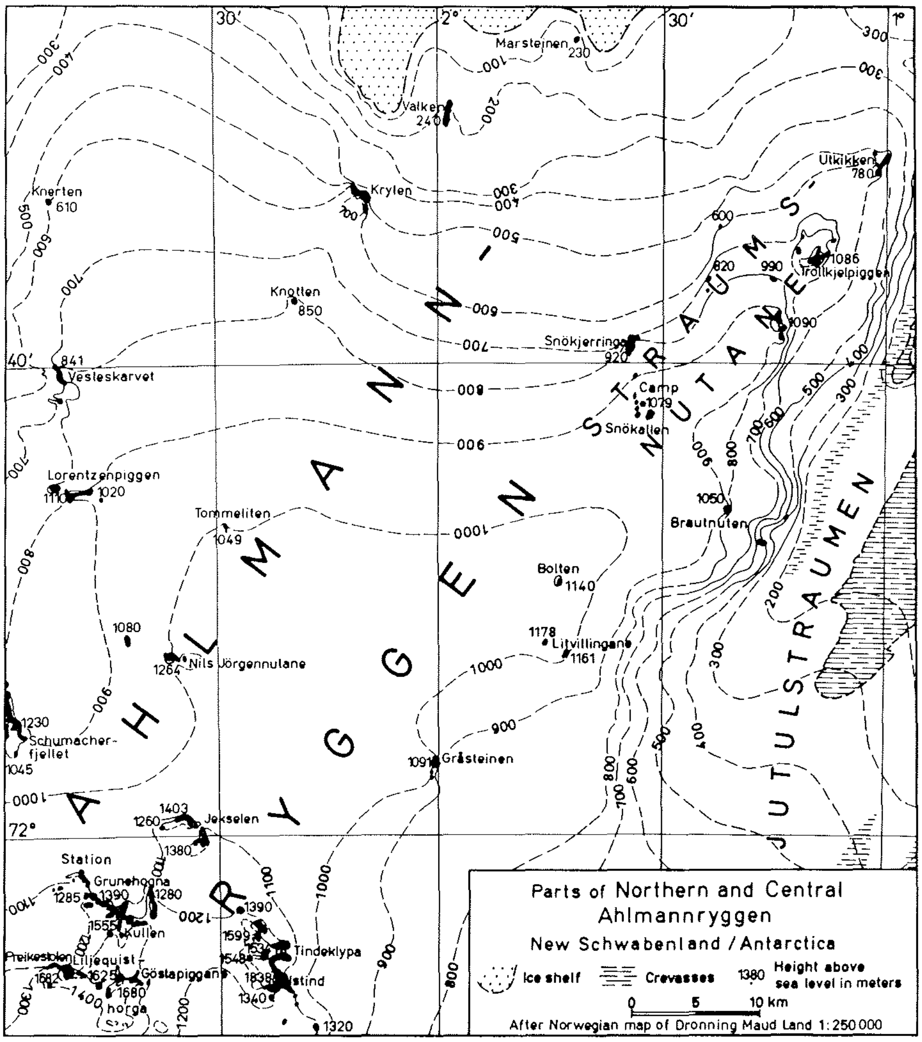

Fig. 9: Topographical sketch map of the central and northeastern Ahlmannryggen, drawn after the Norwegian topographical map of Dronning Maud Land 1:250.000.

Abb. 9: Topographische Kartenskizze vom zentralen und nordöstlichen Ahlmannryggen, gezeichnet nach der norwegischen topographischen Karte von Dronning Maud Land 1:250.000.

Structural measurements were carried out on most nunataks of the northeastern Ahlmannryggen (Straumsnutane region), in particular on the Snökallen, Snökjerringa, Bolten, Utkikken, and Trollkjelpiggen nunataks (Fig. 9). The dikes are mostly 1 m to 5 m thick with 25 m as maximum in one case, a few very thin existing, too. Except for the ubiquitous columnar jointing, no other structural features could be observed inside the dikes. The layering of the Proterozoic lava beds is often horizontal to weakly inclined to the SE and NW. Also occurring steep dipping is associated to shear zones of assumend normal faults and to the western border of the Jutulstraumen. Shearing is a conspicuous feature in the Proterozoic volcanic rocks of Straumsnutane (Fig. 10). Another notable structural feature of the Straumosnutane region is a system of small overthrusts. The dolerite dikes cut the overthrust planes, but are not affected by overthrusts. Most of these Mesozoic dikes strike in a NNE- or NE-direction (d_1 and d_2 in Fig. 8c) and are either vertical or steeply dipping. A few strike WNW-ESE or W-E and partly dip more gently.

Fig. 10: A thin Mesozoic dolerite dike cutting the Proterozoic Straumsnutane Volcanics. The layering dips gently to the right (NW), the s-planes dip steeply to the left (SE), the dike partly runs parallel to the s-planes. Near the summit of the nunatak Snökallen, northeastern Ahlmannryggen.

Abb. 10: Schmaler mesozoischer Doleritgang in den proterozoischen Vulkaniten von Straumsnutane. Die Schichtung fällt flach nach rechts (NW), s-Flächen fallen steil nach links (SE), der Gang verläuft teilweise parallel zu den s-Flächen. Am Gipfel des Nunataks Snökallen, nordöstlicher Ahlmannryggen.

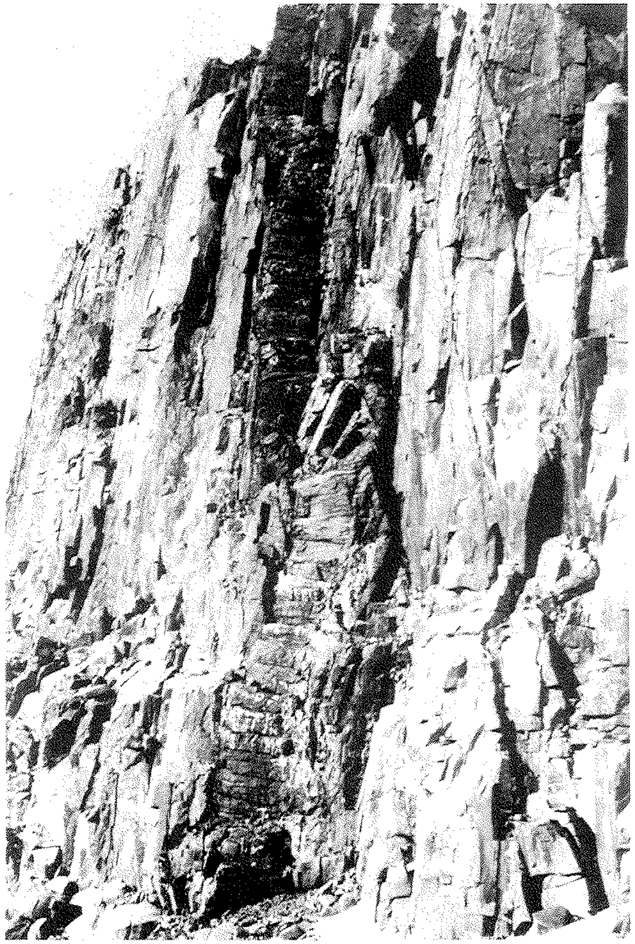

Fig. 11: A Mesozoic dolerite dike cutting a diorite of the Proterozoic Borgmassivet Intrusives. Northeastern part of the Grunehogna massif, central Ahlmannryggen. Height of the wall approximately 30 m.

Abb. 11: Mesozoischer Doleritgang in Diorit der proterozoischen Borgmassivet-Intrusionen. Nordostteil des Grunehogna-Massivs, zentraler Ahlmannryggen. Höhe des Aufschlusses ca. 30 m.

Fig. 12: A Mesozoic dolerite dike cutting a diorite of the Proterozoic Borgmassivet Intrusives. Northern cliff of the nunatak Jekselen, central Ahlmannryggen. Height of the cliff approximately 50 m.

Abb. 12: Mesozoischer Doleritgang in Diorit der proterozoischen Borgmassivet-Intrusionen. Nordflanke des Nunataks Jekselen, zentraler Ahlmannryggen. Höhe der Flanke ca. 50 m.

An olivine dolerite from the central Ahlmannryggen has yielded an age of 192 Ma (AUCAMP 1972). Radiometric age determination on samples taken by M. Peters during our fieldwork have yielded a deformation age of about 526 Ma (K-Ar method on sericite) for sheared Straumsnutane Volcanics, which proves the Proterozoic age of the main rock complexes; for dolerite dikes ages around 200 Ma (K-Ar method) are reported (PETERS et al. 1986). Palaeomagnetic measurements on several dolerite dikes of the Ahlmannryggen again confirm a Mesozoic, probably early Jurassic age.

5. DIKES AND SILLS OF HEIMEFRONTFJELLA AND MANNEFALLKNAUSANE

In Heimefrontfjella and Mannefallknausane (working area C, Fig. 1) only a few young basic dikes were found. They can be distinguished well from numerous older, metamorphosed dikes of the crystalline basement. Altogether only 12 dikes were observed. Six of them are from more than 70 visited nunataks and mountain massifs of Heimefrontfjella. Two sills were found, too. One large sill intrudes the Permian sediments (Fig. 13) and a less important one the crystalline basement. The other six dikes occur together with several, often large sills at the few nunataks of Mannefallknausane (JUCKES 1968). Mannefallknausane, situated between Vestfjella and Heimefrontfjella, links both regions concerning the frequency of the dikes.

The thickness of the dikes ranges around 1 m with 4 m as maximum and 0.20 m as minimum. In one case, however, representing probably the end of a dike, it reaches only 0.1 m. This dike could be followed only for a few tens of meters in its striking direction. The other dikes could always be followed over the whole nunataks. Strike of all 12 dikes is SW-NE with some scattering (Fig. 8d). They predominantly dip steeply to the SE, some also steeply to the NW. In this area the dikes again strike parallel to the assumed main di-

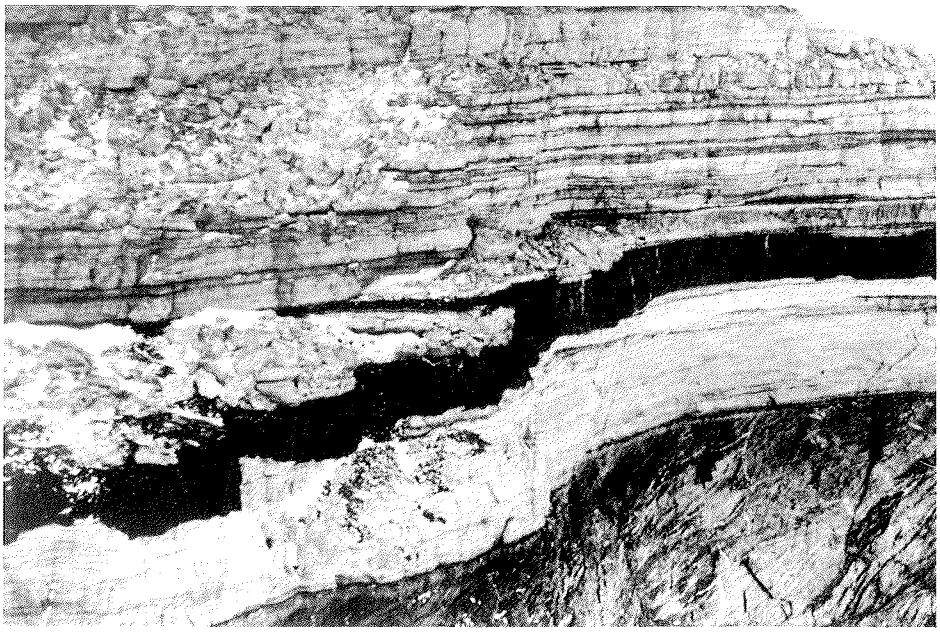

Fig. 13: Mesozoic dolerite sill with a thickness of approximately 10 m in Permian sediments. A branching of the sill can be seen in the centre. At the lower right the unconformity between the crystalline basement and the Permian cover sequence is visible. Northern wall of Schivestolen, Kottasberge, Heimefrontfjella.

Abb. 13: Mesozoischer Dolerit-Lagergang, ca. 10 m mächtig, in den permischen Sedimenten der Kottasberge. In der Bildmitte ist eine Aufspaltung des Lagergangs zu erkennen, in der rechten unteren Bildhälfte die Diskordanz zwischen dem kristallinen Basement und der jungen Deckgebirgsfolge. Nordflanke von Schivestolen, Kottasberge, Heimefrontfjella.

rection of the fracture tectonics. The sills always dip gently to the SE as well as the Late Palaeozoic-Mesozoic cover. This agrees well with western Neuschwabenland being a fractured margin of the East Antarctic shield, built up of tilted faults blocks.

REX (1972) determined Middle Jurassic age data (162 Ma and 173 Ma) for the basaltic lavas of the Kottasberge (northern Heimefrontfjella) and an Early Jurassic age (179 Ma) for a dolerite intrusion in the Permian of the Kottasberge. For the dolerite intrusions from Mannefallknausane he noted, however, only two pre-Mesozoic ages. Radiometric age determinations were not yet carried out by us on the dike samples from Heimefrontfjella and Mannefallknausane. By reasons of analogy (freshness of the rocks, structural relationships, occurrence together with the petrographically and geochemically identical sills), however, an early Jurassic age is assumed for all.

6. PETROGRAPHY

Most of the dikes sampled were examined in thin sections. Here detailed petrographic descriptions assign samples to groups, based upon their phenocrysts, their texture and degree of alteration. First the components are described:

Plagioclase occurs (together with pyroxene) as the main mineral. Andesine is the most common variety, labradore and oligoclase are found rarely. Compositional differences between phenocrysts and plagioclase in groundmass were not found. This can be explained by the relatively slow cooling rates, which allowed various equlibrations of crystal and melt as is typical for hypabyssal rocks. Phenocrysts are tabular, they often show polysynthetic twins and/or normal zoning. Crystal shape in fine-grained groundmass can be columnar; in this case it presents variolithic textures. Alterations, such as sericitization and fluid inclusions were found rarely.

Clinopyroxene crystals occur as euhedral phenocrysts or as glomerocrysts. Augite is the predominant pyroxene, in some samples pigeonite and titanaugite are found as well. Zoning and simple twins can also be seen. The pale green colour stems from the dominance of magnesia. Brownish colours at the rims show the trend of iron enrichment from core to rim. Hydrothermal or postmagmatic alterations allow pleochroitic rims of hornblende and chlorite to grow. Pigeonite sometimes remains as prismatic core in augite phenocrysts. Another typical clinopyroxene for alkali-rich basic and ultrabasic rocks is titanaugite. It occurs when Ti-content and cooling rate increase.

Orthopyroxene, represented by hypersthene, is not found in all samples. The crystal shape is often subhedral tabular to prismatic or anhedral. Weak pleochroism can be seen. Being instable during crystallization of the melt, exsolution lamellae of diopside or alteration rims can be recognized in every crystal. Hydrothermal influence leads to growth of hornblende rims, chlorite, serpentine and seladonite. These minerals form fibrous rims or displace the host completely.

Olivine phenocrysts only occur in some of the analysed samples. Euhedral phenocrysts are completely altered to chrysotile (serpentinization) during hydrothermal processes. Samples of the Ahlmannryggen show the only exception. Here the content of olivine increases to 25% (the mean in other samples is <10%) and alteration is less strong.

Accessory minerals: Opaque minerals such as magnetite, ilmenite and even chromite occur in euhedral shapes like needles, skeletal and angular grains. Opaque minerals are the main source of brown or dark colours in fine-grained groundmass.

Anhedral biotite and epidote appear as well in some samples of the Ahlmannryggen, Heimefrontfjella and Mannefallknausane. They are caused by late magmatic alteration. Only in two cases veosicles were found partly filled with quartz or chalcedony.

The samples were divided into groups according to phenocryst composition, texture and grain size, the modal compositions of which are shown in Table 1. Group 1 to 3 represent olivine-bearing dolerites from Vestfjella. Group 1 contains fine-grained samples from Fossilryggen and Salryggen. Plagioclase and augite are intergrown subophitically, the groundmass is dark and cryptocrystalline. Samples from Plogen and Basen form group 2 being coarser grained than group 1. Additionally brown biotite occurs. Magnetite and ilmenite appear in skeletal aggregates. Group 3 is characterized by the dominance of mafic minerals, so augite surrounds plagioclase phenocrysts ophitically. Seladonite may occur as well in these coarse-grained samples. The dolerites from Plogen, which form group 4, show porphyritic textures according to chilled margins or thin dikes. Because dark cryptocrystalline groundmass dominates in these samples, only needles of plagioclase are otherwise distinguishable. Glomerocrysts, which were seldom found, consist of plagioclase and augite. Group 5 represents the olivine- and orthopyroxene-free equivalent to group 1.

Similar to the samples of Vestfjella, those from Ahlmannryggen, Heimefrontfjella, and Mannefallknausane can be separated into olivine-free and olivine-bearing groups. According to the average dike size, which is often smaller than in Vestfjella, the most frequent textures of the samples from Ahlmannryggen are fine-grained subophitic or porphyritic (group 6). Ophitic intergrowth of augite and plagioclase represents medium-grained group 7. Here the occurrence of titanaugite is also worth noting. Olivine-free group 8, being the textural equivalent to group 5, shows weak alterations which also affect the main components. This might correlate to the structural position, because nearly all samples belong to the second system of dikes striking SE to NW.

Vestfjella (23 samples)

components	group 1 vol.-%	group 2 vol.-%	group 3 vol.-%	group 4 vol.-%	group 5 vol.-%
plagioclase	50	50	45	21*	53
pyroxene**	30(5)	40(10)	40(5)	14*	36
olivine	5	3	5	—	—
groundmass	10	1	3	60	1
opaque minerals	5	3	5	5	5
acc. minerals	—	3	2	—	5
Total	100	100	100	100	100

Ahlmannryggen (26 samples)

components	group 6 vol.-%	group 7 vol.-%	group 8 vol.-%
plagioclase	40	40	50
pyroxene**	35(5)	50(10)	40(10)
olivine	15	5	—
groundmass	5	4	5
opaque minerals	4	1	5
acc. minerals	1	—	—
Total	100	100	100

Heimefrontfjella and Mannefallknausane (18 samples)

components	group 9 vol.-%	group 10 vol.-%	group 11 vol.-%	group 12 vol.-%
plagioclase	47	50	48	50
pyroxene**	35	35(1)	40(1)	31(8)
olivine	10	5	—	—
groundmass	5	8	3	12
opaque minerals	2	2	5	4
acc. minerals	1	—	4	3
Total	100	100	100	100

* phenocrysts
** orthopyroxene content in brackets

Tab. 1: Average petrographic composition of dolerites from each sampled region.

Tab. 1: Durchschnittliche modale Zusammensetzung der Dolerite jedes Untersuchungsgebietes.

Dolerites from Heimefrontfjella and Mannefallknausane, which form group 9, show characteristics similar to group 3. The samples from group 9 also contain biotite. Group 10 is comparable with group 2 although groundmass content is somewhat greater. The last two groups (11 and 12) represent olivine-free dolerites. While group 12 is similar to group 5, the coarse-grained, ophitic samples in group 11 show stronger alterations similar to those in group 8, as seen from the amounts of seladonite and green phyllosilicates. Alterations such as those oberserved in groups 8 and 11, since similar, could possibly stem from a single source.

Comparing the three regions, there are some differences worth noting. Vestfjella provided the freshest samples, in which olivine only occurs in small amounts and epidote lacks completely. In contrast, alteration has affected two dolerite groups from Ahlmannryggen, Heimefrontfjella, and Mannefallknausane. This might correspond to differentiation during the intrusion process. Silica content also varies between the three regions, so the samples from the Ahlmannryggen show the lowest and trend towards ultrabasic. This is caused by better differentiation in thick dikes. Slight changes in chemical composition of the magma over Neuschwabenland might also have been of further influence. Thus as expected, the dolerites of Vestfjella, Heimefrontfjella, and Mannefallknausane demonstrate more similarities than those from Ahlmannryggen, as geographic distance would dictate.

7. GEOCHEMISTRY

Geochemical data were determined by X-ray fluorescence spectroscopy (PW 1400, Philips) on glass

	Vestfjella (22 samples)		Ahlmannryggen (27 samples)		Heimefrontfjella and Mannefallknausane (18 samples)	
weight %	mean	range	mean	range	mean	range
LOI	1.68	0.48 — 3.67	2.27	0.77 — 5.45	0.75	0.05 — 2.52
SiO_2	48.76	46.78 — 52.99	47.86	43.11 — 52.20	48.37	44.25 — 58.49
Al_2O_3	13.37	10.12 — 15.37	10.59	6.87 — 14.43	13.12	8.69 — 15.86
CaO	10.43	7.49 — 13.44	9.40	5.25 — 13.18	9.62	6.56 — 12.56
MgO	6.96	4.52 — 11.23	10.24	5.05 — 19.15	7.06	3.53 — 22.54
Na_2O	2.38	1.32 — 3.16	2.00	1.09 — 3.49	2.08	1.12 — 3.09
K_2O	0.53	0.14 — 1.06	0.52	0.12 — 0.97	0.72	0.13 — 1.92
TiO_2	1.78	1.24 — 4.00	2.72	1.39 — 5.51	2.45	0.92 — 4.53
Fe_2O_3	13.61	11.97 — 19.71	14.84	13.25 — 16.81	15.31	9.66 — 20.13
MnO	0.18	0.14 — 0.20	0.19	0.17 — 0.22	0.21	0.13 — 0.25
P_2O_5	0.19	0.10 — 0.51	0.29	0.10 — 0.73	0.28	0.07 — 0.54
Total	99.87		100.92		99.97	
ppm	mean	range	mean	range	mean	range
Ba	396.90	124 — 1101	272.85	101 — 641	235.75	122 — 516
Sr	269.45	131 — 378	302.89	36 — 757	277.61	187 — 518
Rb	19.83	21 — 34	30.23	21 — 47	38.56	20 — 78
Zr	137.32	85 — 304	180.70	89 — 503	169.22	55 — 283
Y	25.18	20 — 57	29.06	20 — 53	12.25	7 — 25*
V	288.59	221 — 389	395.78	301 — 507	388.83	188 — 594
Cr	275.23	42 — 974	665.78	94 — 1514	295.88	61 — 1462
Zn	72.86	53 — 147	127.33	111 — 184	127.05	91 — 184
Ni	149.18	46 — 407	480.70	57 — 1363	178.94	38 — 1238
Co	46.14	37 — 62	71.81	51 — 109	55.33	40 — 97
K/Rb	241.70	114.48 — 338.38	226.11	131.42 — 489.49	201.64	121.76 — 288.20
K/Ba	10.79	6.02 — 18.22	23.90	10.56 — 76.98	30.42	22.06 — 41.73

* For 14 samples Y was out of range

Tab. 2: Average geochemical composition of dolerites from each sampled region (Fe_2O_3 as whole iron).

Tab. 2: Durchschnittliche geochemische Zusammensetzung der Dolerite der Untersuchungsgebiete (gesamt Eisen als Fe_2O_3 bestimmt).

beads. For major oxides a mixture of 5 g lithiumtetraborate (66:34) and 0.5 g rock powder was analysed; for trace elements 4 g lithiumtetraborate and 1 g rock powder were used.

In Table 2 the average composition of major oxides and their variance are listed. Compared to average dolerite composition in past literature, relatively low SiO_2- and alkali-contents are noted. In contrast Fe_2O_3 and TiO_2 contents show above average values. Variances between the three sampled regions are insignificant. The dolerites from Ahlmannryggen, Heimefrontfjella, and Mannefallknausane show higher contents in Fe_2O_3 and TiO_2 coinciding with lower values for CaO. Relatively high amounts of MgO in the Ahlmannryggen reflect the group with higher olivine content.

These characteristics are demonstrated equally well in the following diagrams (Fig. 14 and 15). In Fig. 14 SiO_2 is plotted against the sum of alkalis, and in Fig. 15 against the ratio of Zr/TiO_2. As indicated by the tholeiite-alkali basalt boundary in Fig. 14 according to MacDONALD & KATSURA (1964) the majority

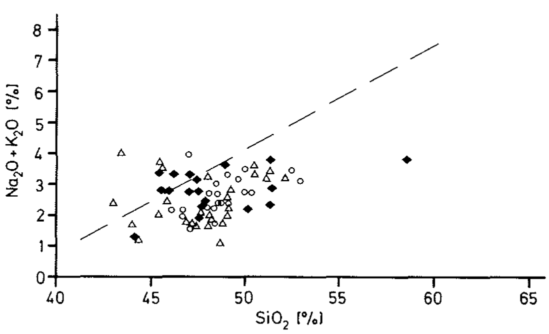

Fig. 14: Plot of (Na_2O + K_2O) versus SiO_2 for the dolerites from western Neuschwabenland. Nearly all samples show tholeiitic composition, that means they lie under the tholeiite-alkali basalt-boundary (MacDONALD & KATSURA 1964). Samples from Vestfjella (open circles), from Heimefrontfjella and Mannefallknausane (dark rhombs) demonstrate groups which are relatively homogeneous. In contrast those from Ahlmannryggen (open triangles) are divided into two groups. The group with low SiO_2 content represents samples which are olivine rich.

Abb. 14: (Na_2O + K_2O)/SiO_2-Diagramm der Dolerite von W-Neuschwabenland. Der überwiegende Anteil der bearbeiteten Proben zeigt tholeiitische Zusammensetzung, d. h. liegt unterhalb der Tholeiit-Alkalibasalt-Grenze (nach MacDONALD & KATSURA 1964). Während die Proben aus Vestfjella (offene Kreise) und Heimefrontfjella und Mannefallknausane (dunkle Rauten) jeweils eine relativ einheitliche Gruppe darstellen, fällt beim Ahlmannryggen (offene Dreiecke) eine SiO_2-ärmere zweite Gruppe auf, die die Proben mit hohen Olivin-Gehalten repräsentiert.

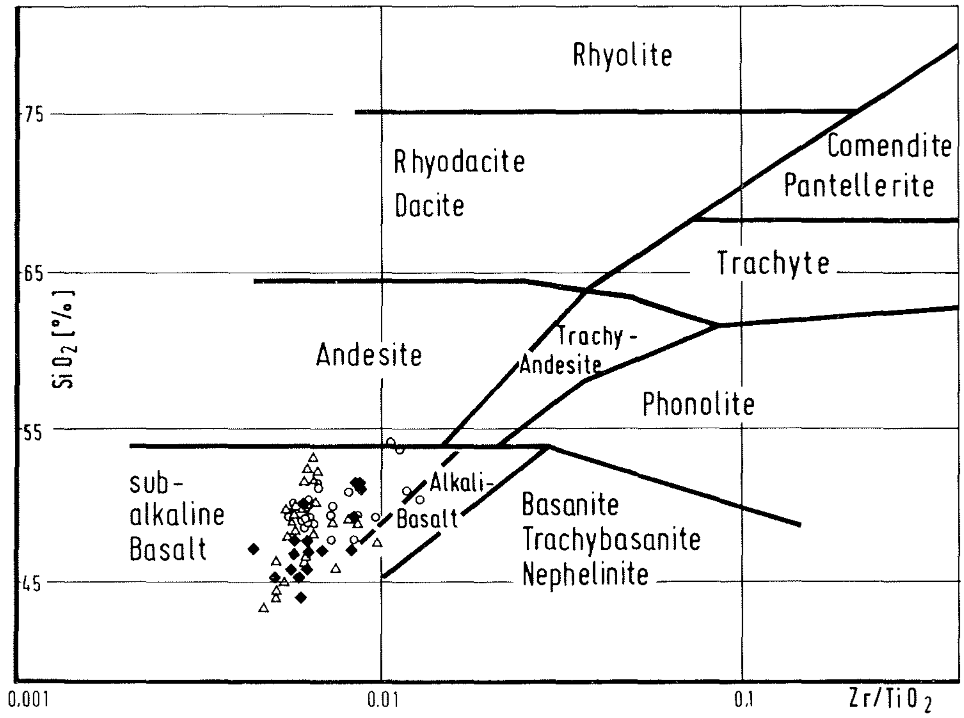

Fig. 15: The classification of WINCHESTER & FLOYD (1977) shows the samples of all working areas lying in the field of subalkaline basalt. Symbols used are equal to Fig. 14.

Abb. 15: Die Klassifikation nach WINCHESTER & FLOYD (1977) zeigt die Zuordnung der Proben aus allen Arbeitsgebieten zu subalkalinem Basalt. Tendenzen zu andesitischem und alkalibasaltischem Chemismus sind erkennbar. Die Symbole entsprechen denen in Abb. 14.

of samples belong to tholeiitic basaltic rocks which was also the result of previous petrographic analysis. Silica content can be used to separate the dolerites from Ahlmannryggen into two distinct groups, as noted above. In Fig. 15 this element-oxid combination was chosen to exclude coincidental correspondence on the one hand and influence of alteration on the other.

Regarding Fig. 16 and 17, the chosen trace elements demonstrate the geotectonic position of the dolerites. Based upon analyses of Ferrar dolerites, GUNN (1965) postulated a K/Rb ratio <250 for continental tholeiitic rocks. An average value of 223 (Fig. 16, see also Tab. 2) for all sampled dolerites fits well with GUNN's thesis. K/Ba ratios do not show distinct values as K/Rb, but they lie within GUNN's predicted range. Another interesting aspect for the K/Ba ratio is its increase with differentiation from 26 to 36. The

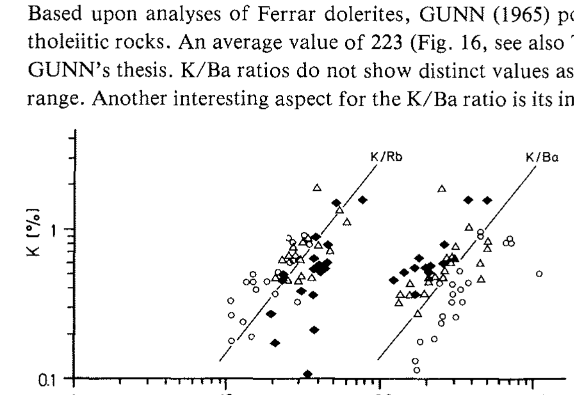

Fig. 16: K/Rb- and K/Ba-diagramm for dolerites from western Neuschwabenland. K/Rb ratio is 223 and then shows tholeiitic continental composition of the dolerites (GUNN 1965). The K/Ba ratio is variable with an average ratio of ZZ. Thus the samples from western Neuschwabenland indicate a low degree of differentiation. Symbols used are equal to Fig. 14.

Abb. 16: K/Rb- und K/Ba-Diagramm für die Dolerite aus W-Neuschwabenland. Das K/Rb-Verhältnis, das nach GUNN (1965) für kontinentale, tholeiitische Gesteine <250 ist, erfüllt mit einem Durchschnittswert von 223 für alle Proben diese Forderung. Das K/Ba-Verhältnis weist eine größere Streuung auf. Der Durchschnitt liegt bei 22 und zeigt somit auch den niedrigen Differentiationsgrad der Proben an. Die Symbole entsprechen denen in Abb. 14.

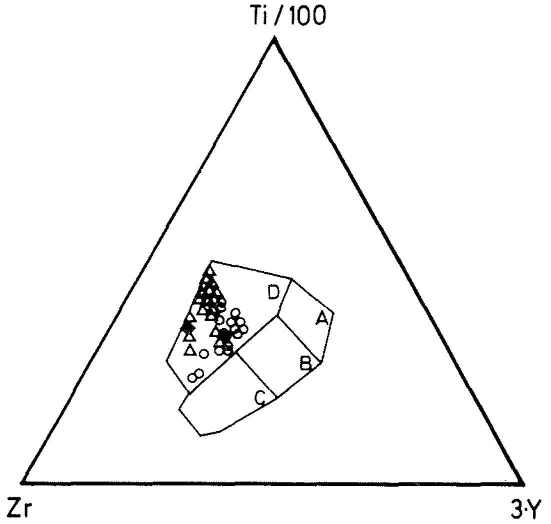

Fig. 17: Discrimination diagramm Ti-Zr-Y for basalts. Ti, Y and Zr show the dolerites of the working areas belonging to continental basaltic magma, because all samples lie in field D. This field represents continental basalts, tholeiites and alkali basalts, described by PEARCE & CANN (1973) as "within-plate" basalts. Symbols used are equal to Fig. 14. The black rhomb represents four samples.

Abb. 17: Diskriminierungsdiagramm Ti-Zr-Y für Basalttypen. Ti, Y und Zr zeigen deutlich die Zuordnung der Dolerite zu kontinentalem, basaltischen Magma. Alle Proben liegen in Feld D (nach PEARCE & CANN 1973), das kontinentale Basalte, Tholeiite und Alkalibasalte umfaßt. Die Symbole entsprechen denen in Abb. 14. Die schwarze Raute repräsentiert vier Proben.

average K-Ba ratio from all samples of western Neuschwabenland is 22 and indicates low degree of differentiation.

Being immobile during alteration, Ti, Zr and Y are used for discrimination in Fig. 17. All samples are lo-

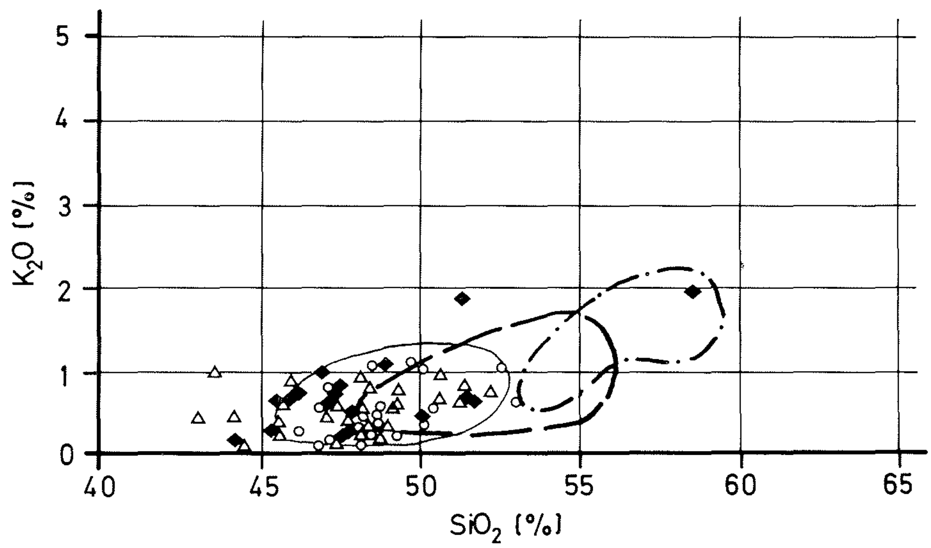

Fig. 18: Plot of K_2O versus SiO_2 for the dolerites of the working areas and further regions of Gondwana. Data from southern Vestfjella (JUCKES 1968, HJELLE & WINSNES 1972, continuous line), Transantarctic Mountains (FAURE et al. 1972, dashed-point-dashed line), Karoo basin (WALKER & POLDERVAART 1949, dashed line). Samples from western Neuschwabenland have the lowest amounts of SiO_2 and K_2O. Those from the Karoo basin indicate a relatively near former position of both regions in Mesozoic times. Ferrar Dolerites show nearly andesitic composition. Symbols used are equal to Fig. 14.

Abb. 18: K_2O/SiO_2-Diagramm für die Dolerite der Arbeitsgebiete und weiterer Regionen von Gondwana. Daten aus Vestfjella-Süd (JUCKES 1968, HJELLE & WINSNES 1972; durchgezogene Linie), Transantarktisches Gebirge (FAURE et al. 1972; strichpunktierte Linie), Karoo-Becken (WALKER & POLDERVAART 1949; gestrichelte Linie). Die durch niedrige K-Gehalte gekennzeichneten Karoo-Dolerite sprechen für ein relativ nahes ehemaliges Nebeneinander des Karoo-Beckens und des westlichen Neuschwabenlands im Gegensatz zu den SiO_2-reichen Ferrar-Doleriten mit fast andesitischem Charakter. Die Symbole entsprechen denen in Abb. 14.

cated in field D which is described as "within-plate" basalts (PEARCE & CANN 1973) i. e. continental basalts, tholeiites and alkali basalts. Dolerites from Vestfjella show lower content of Ti (22%—42%) and are slightly Y-richer (20%—25%) than those from the Ahlmannryggen (10%—20%). By far the lowest Y values can be seen in the samples from Heimefrontfjella and Mannefallknausane with amounts of 15%.

Finally it is noted that alterations described by petrography have no visible influence on geochemical composition.

8. COMPARISON WITH OTHER DOLERITES FROM GONDWANA

Comparing western Neuschwabenland to other regions of the Gondwana supercontinent, a similar type of rock can be found as well in the Transantarctic Mountains (Victoria Land), in the Karoo basin (southern African shield) and in Tasmania (Australia). Fig. 18 demonstrates the significant differences as well as the similarities of the above-mentioned dolerites using $Si0_2$ and K_20 as discriminators. The samples from western Neuschwabenland, which include those from JUCKES (1968) and HJELLE & WINSNES (1972) from southern Vestfjella, present the lowest amounts in $Si0_2$ and K_20. Those from the Karoo basin, which show many similarities to the dolerites from Neuschwabenland, are somewhat richer in $Si0_2$. Regarding the field, which contents samples from Ferrar dolerites analysed by FAURE et al. (1972), an increase of $Si0_2$ on the one hand and K_20 on the other is to be noted. This phenomenon indicates by means of petrographic and chemical data a relatively close geographic position of the Karoo basin and western Neuschwabenland in Mesozoic times, thus being postulated equally well by structural analysis. Although the dolerites of all mentioned regions coincide with probably the same geotectonic event, the great compositional differences between the Karoo basin and Neuschwabenland with basaltic composition on the one hand and Ferrar dolerites with nearly andesitic composition on the other hand, are obvious and worth to further discussion. FAURE et al. (1972) conclude that the dolerites of Antarctica, especially those from the Transantarctic Mountains, have been affected by mixing with granitic material, because the varieties cannot result only by magmatic differentiation.

9. GEOTECTONIC SIGNIFICANCE OF THE DIKES

The majority of the dolerite dikes in western Neuschwabenland has a NE-SW strike direction and thus runs parallel to most of the observed small normal faults and to the suggested large scale tensional features, which have been inferred form the subglacial bedrock topography (HJELLE & WINSNES 1972) (Fig. 2). The crustal extension during the Jurassic, as indicated by the dikes and fracturing, acted in NW-SE direction. A subordinate extension perpendicular to this direction also occurred. However, this rifting in western Neuschwabenland, although very intensive in some localities (Vestfjella) with diminishing trend towards the east did not lead to an oceanic spreading centre.

Further it is worth noting that the orientation of the dikes and of the Mesozoic and post-Mesozoic fractures seems to be controlled by Precambrian and possibly by Early Palaeozoic tectonic features (shear zones). This emerges from the comparison of the orientation diagrams (pole diagrams) for the northern Ahlmannryggen seen in Fig. 2. It can be assumed that weak zones in the crust guided the Mesozoic rifting, as mentioned by SPAETH & FIELITZ (this volume) and as supposed by KYLE et al. (1981) for other Antarctic areas.

Western Neuschwabenland can be regarded as an excellent example for a continental margin fractured by rift processes (Fig. 19). The Mesozoic magmatic and tectonic events and the post-Mesozoic block faulting resulted in a strong dissection of the continental margin. The dissection continues to the west in a distinct fracturing of the shelf with subsidence of a thick rock sequence, interpreted as a stack of Jurassic basaltic lava flows (Fig. 19). The total downthrow of the basaltic lavas from western Neuschwabenland for more

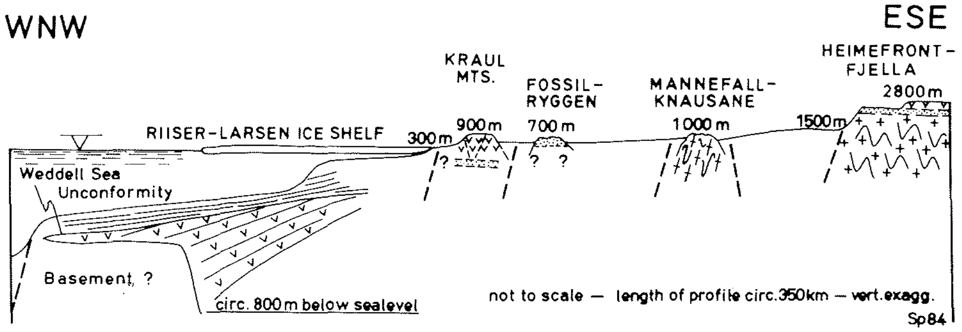

Fig. 19: Schematic section through the continental margin of western Neuschwabenland. Left part (shelf) drawn after HINZ & KRAUSE (1982). Symbols as in Fig. 3.

Abb. 19: Schematisches Profil durch den Kontinentrand von West-Neuschwabenland. Profil im Schelfbereich gezeichnet nach HINZ & KRAUSE (1982). Zeichenerklärung wie in Abb. 3.

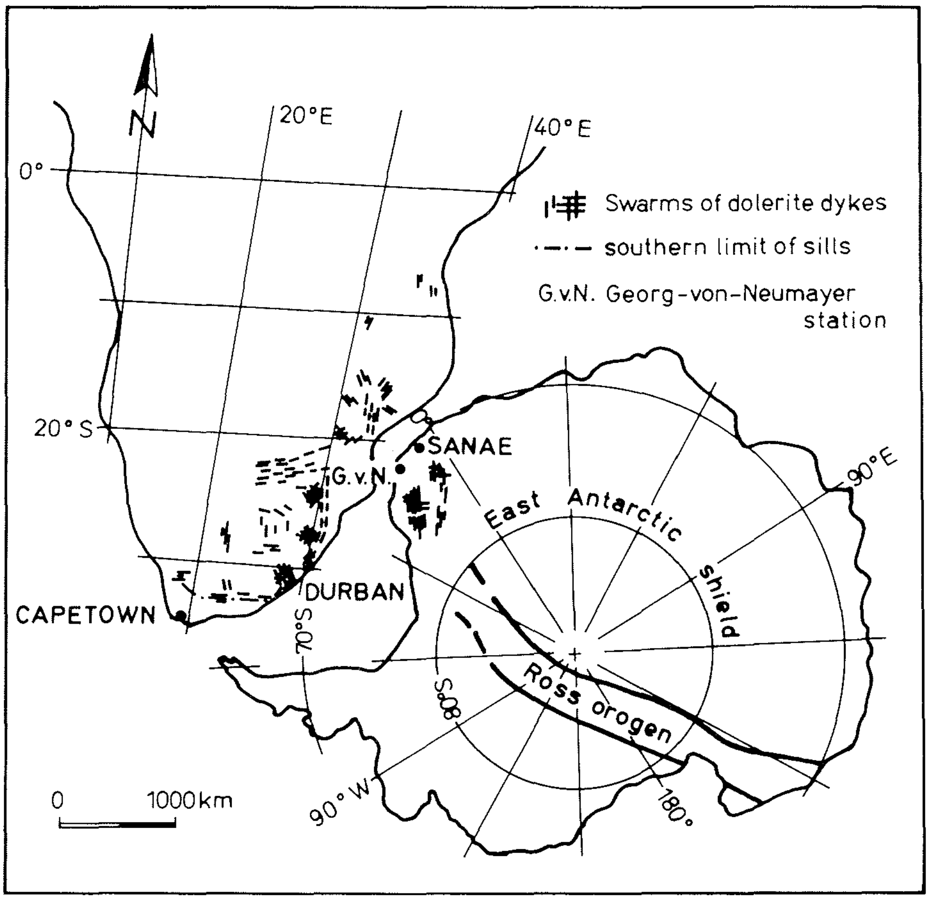

Fig. 20: Reconstruction of Gondwana regarding the juxtapostion of Antarctica and Africa. The main trends of dolerite dikes in western Neuschwabenland and southern Africa are shown. Reconstruction from McELHINNY (1973), dike swarms in Africa after VAIL (1970).

Abb. 20: Rekonstruktion des Gondwana-Zusammenhangs zwischen Antarktika und Afrika mit Darstellung der Hauptrichtungen der Doleritgänge im westlichen Neuschwabenland und südlichen Afrika. Gondwana-Rekonstruktion aus McELHINNY (1973), Gangschwärme in Afrika nach VAIL (1970).

than 3000 m (Fig. 19) is indicated by the results from geophysical investigations in the eastern Weddell Sea (HINZ & KRAUSE 1982).

The rifting has to be seen from its age and palaeogeographic constellation in connection with the break-up of the Gondwana supercontinent. Antarctica separated from southern Africa suggesting a comparison of the basic dike swarms from Neuschwabenland with those from the Karoo Supergroup (VAIL 1970) of Africa. Many geotectonic models exist for the reconstruction of the former position of southern Afrika and Antarctica with respect to each other. In Fig. 20 we used a model from McELHINNY (1973), which gave a good correlation for the directions of the dike swarms in the reconstructed juxtaposition of these segments of Gondwana. Two main dike directions occur: N-S and E-W. Because of the extensive distribution of the basic dikes in both parts of the Gondwana continent the reconstruction of the exact original juxtaposition cannot be done alone by using these dikes. It needs more detailed work on these dikes in East Antarctica and also the use of other geological features, for example structural trends of the Precambrian rock units (see SPAETH & FIELITZ, this volume).

10. ACKNOWLEDGEMENTS

We wish to thank the Alfred-Wegener-Institut, Bremerhaven, which provided logistic support for the expeditions. We also thank the Deutsche Forschungsgemeinschaft for financial support of these studies. We owe our gratitude to G. Friedrich and W. L. Plüger, Institut für Mineralogie und Lagerstättenlehre, RWTH Aachen, for making available their laboratory facilities. Furthermore, we are grateful to W. Fielitz (expedition member 1985—86) for assistance in the field work and in preparing this paper.

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