The Straumsnutane Volcanics, western Dronning Maud Land, Antarctica

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The detailed mapping of the Straumsnutane Formation occurring on the Ahlmannryggen, western Dronning Maud Land, Antarctica, was undertaken during 1968 by the Ninth South African National Antarctic Expedition. This Formation has a total thickness of 860 m in the Straumsnutane, the type area, and may be divided tentatively into four conformable members, *viz* a lower member comprising 260 m of lava characterized by very large amygdales; a transitional member of 100 m thickness; a middle member consisting of 100 m of alternating amygdaloidal and non-amygdaloidal lava; and an upper member comprising 400 m of predominantly amygdaloidal lava, with subordinate dense lava and characteristic pillow structures. Minor intercalated sediments occur in the upper half of this member.

The volcanic rocks are intruded by dolerite and olivine-bearing basaltic dykes generally striking 0 – 25° true. The lava would appear to have had a source area lying to the west and north of the present exposures. Block-faulting, with some associated shearing, is the dominant structural feature of the area. Small amounts of copper carbonate staining are ubiquitous in the lavas. Petrographically the lava is a highly altered porphyritic andesite with varying proportions of a glassy mesostasis. Plagioclase has a composition An_{34} to An_{40}. Alteration to chlorite and epidote is extensive and in some cases complete.

Detailkartering van die Straumsnutane-formasie wat voorkom in die Ahlmannryggen, westelike Dronning Maud-land, Antarktika, is gedurende 1968 onderneem deur die Negende Suid-Afrikaanse Antarktiese Ekspedisie. Hierdie Formasie bereik 'n totale dikte van 860 m in die Straumsnutane, die tipegebied, en kan voorlopig onderverdeel word in vier konkordante lede, nl. 'n laagste lid bestaande uit 260 m lawa gekenmerk deur baie groot amandels; 'n oorgangslid van 100 m dikte; 'n middelste lid bestaande uit 100 m van afwisselend amandelhoudende en nie-amandelhoudende lawa; en 'n boonste lid bestaande uit 400 m oorwegend amandelhoudende lawa, met bykomstige nie-amandelhoudende lawa en kenmerkende kussingstrukture. Ondergeskikte tussengelaagde sedimente kom in die boonste helfte van hierdie lid voor.

Die vulkaniese gesteentes is ingedring deur doleriet en olivien-draende basaltiese gange, gewoonlik met 'n strekking van 0–25°. Blykbaar is die lawa afkomstig van 'n brongebied ten noorde en weste van die huidige dagsome. Die oorheersende strukturele eienskappe van die gebied is blokverskuiwing met geassosieerde skuifskeuring. Klein vlekke van koperkarbonaat kom oral in die lawas voor. Petrografies is die lawa 'n hoogs veranderde porfiritiese andesiet met afwisselende hoeveelhede van 'n glaserige mesostasis. Plagioklaas het 'n samestelling van An_{34} *tot* An_{40}*. Verandering in chloriet en epidoot is wyd verspreid en is plek-plek volledig.*

Introduction

Reconnaissance mapping (1:100 000-1:250 000) of the Ahlmannryggen, western Dronning Maud Land, was undertaken by geological field parties of South African National Antarctic Expeditions during the period 1960-1967. One of the many problems was the stratigraphy and correlation of the Straumsnutane Volcanics (*Neethling*, 1970). Their detailed mapping comprised a major part of the geological programme of the Ninth Expedition, 1968-69. The major occurrences lie between 71°31'S and 71°52,5'S and 1°0'W and 1°46'W, in the Straumsnutane on the north-eastern extension of the Ahlmannryggen (Fig. 1). Isolated outcrops of volcanic rocks also occur at Istind (72°6,5'S, 2°23'W) on the eastern central portion of the Ahlmannryggen and at Fasettfjellet (72°32,5'S, 3°0'W) in the north-eastern corner of the Borgmassivet (Fig. 1).

Geological investigation of these areas was completed during the course of two field seasons lasting from 28th January to 8th April, 1968 and from 21st September, 1968 to 6th January, 1969. Fieldwork was carried out with the aid of oblique aerial photographs and 1:18 000 enlargements of the 1:250 000 maps of the area published by Norsk Polarinstitutt, Oslo (1961).

Previous Investigations

The first geological investigation undertaken in the area under discussion was carried out by the Norwegian-British-Swedish Antarctic Expedition, 1949-52 (*Roots*, 1953, 1969). This constituted a reconnaissance survey of a very large area. No detailed work was done on the volcanic rocks.

The lavas of the Straumsnutane were investigated by the 2nd South African National Antarctic Expedition (*Butt*, 1963). During the 7th Expedition *De Ridder & Bastin* (1968) mapped the sediments and intrusions underlying the volcanics at Fasettfjellet in

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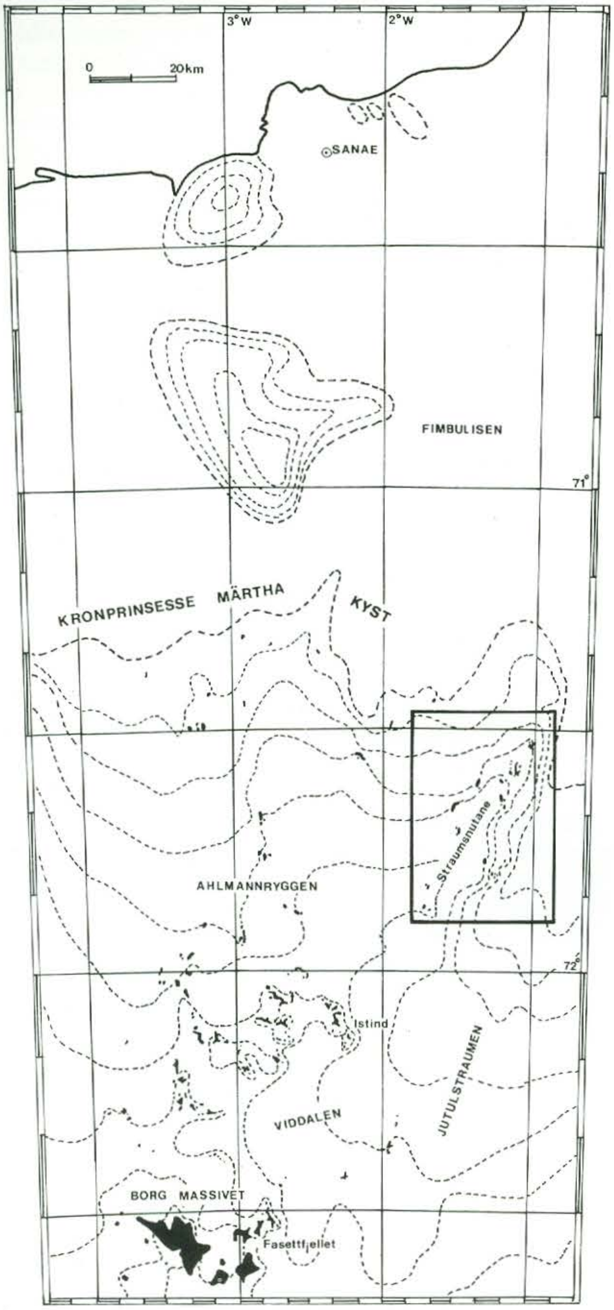

Fig. 1. Sketch map of western Dronning Maud Land. Oblong indicates locality of Fig. 2.

the Borgmassivet. The presence of volcanic rocks was inferred from lava scree.

Physiography

The dominant feature of present-day landforms is a system of blocks, ridges and valleys trending mainly north-east, an arrangement that is the result of glacial erosion superimposed on pre-existing structural features. On the northern part of the Ahlmannryggen, which includes the Straumsnutane, glacial denudation is at a very advanced stage and pyramidal forms are common; these represent the final stage in the breakdown of nunataks owing to the retreat of their walls (*Swithinbank*, 1959). The proportion of rock actually exposed in this area is extremely low, and outcrop accessibility is hampered by the uniformly steep slopes which have resulted from the continual removal by ice of debris falling from cliffs.

The Straumsnutane Volcanics

Macroscopic characteristics of the lava

The lava, andesitic in composition, displays varying but distinct textural characteristics when viewed in outcrop or hand-specimen. On the basis of these characteristics, which comprise mainly grain size, shape, size and arrangement of amygdales, and also colour, various distinct lava types have been recognised. Combinations of and gradations between them are, however, the rule rather than the exception. No particular order in the succession is implied by the following descriptions.

(1) Fine-grained amygdaloidal lava ranging in colour from dark green through greenish-grey to grey. The amygdales are fairly rounded and range in diameter from 6 to 12 mm. Where two or more vesicles coalesced whilst the lava was still in a liquid or semi-liquid state, larger irregularly-shaped amygdales have resulted. This lava type appears to be the most abundant in the sequence.

(2) Dark green to greenish-grey, fine-grained, non-amygdaloidal lava which may contain a few very small amygdales (3-6 mm in diameter).

(3) Dark green to greenish-grey, fine-grained, amygdaloidal lava. The amygdales are large and have various shapes, e.g. irregular spheroidal, flattened spheroidal, dish-shaped and pipe-like; they measure 3 to 40 cm in length and 6 mm to 8 cm in diameter.

(4) Fine-grained, banded amygdaloidal lava. This is a highly amygdaloidal type similar to (1) but in this case the amygdales, or coalesced amygdales, are arranged in bands. Very often these bands have a wavy character, a pattern which is reflected in linear undulations on the lava flow surface.

(5) Dark grey to grey-green medium-grained, non-amygdaloidal lava which is generally free of amygdales although occasional small ones are present. Not uncommonly this type of lava is porphyritic and in some instances, glomeroporphyritic. The phenocrysts are usually feldspar.

(6) Pillow lava, consisting of rounded pillows ranging in diameter from 20 cm up to 3 m or more, the general tendency being that they are wider than they are tall. Filling the inter-pillow spaces is highly amygdaloidal lava, or lava breccia, or large spidery fillings of secondary quartz, chalcedony and accessory epidote, chlorite, prehnite and feldspar. Unfilled cavities were also observed. The pillows consist of non-amygdaloidal or moderately amygdaloidal lava.

Characteristics of the flows

Sharp contacts between individual flows are relatively rare and are not always continuous, as such, if traced laterally. It would appear that the outpourings of lava followed one another closely with, in most cases, no appreciable time lapse to allow surface weathering to take place. An isolated band of pipe amygdales is

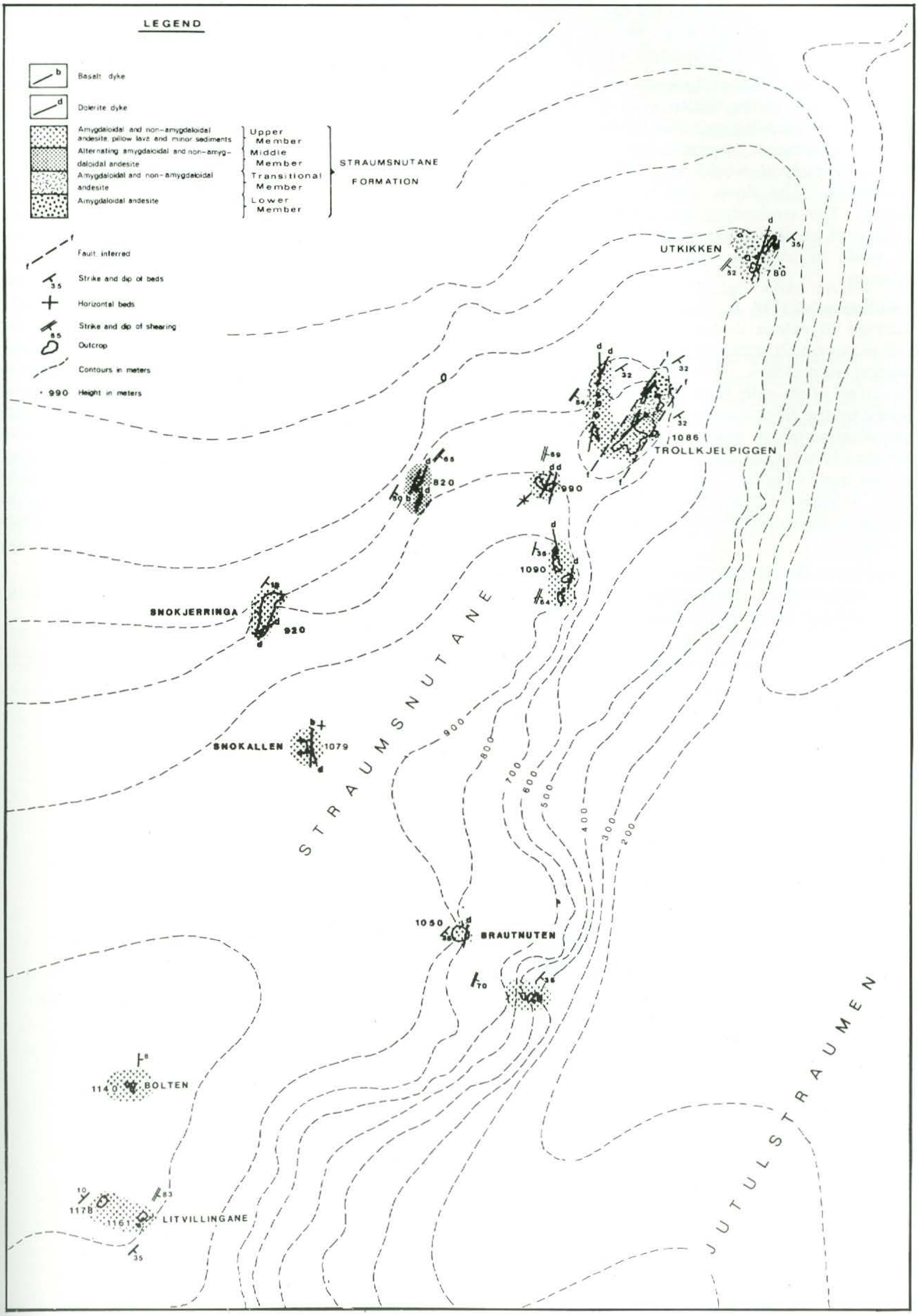

Fig. 2 Schematic geological map of the Straumsnutane.

usually a reliable indication of the base of a new outpouring and, as expected, flows become increasingly more vesicular towards their upper surfaces.

The lava flows range in thickness from less than 1 m to 55 m. Many of the thicker ones are undoubtedly composite but since the eruptions followed one another in rapid succession, contacts are diffuse and any further subdivision would be purely arbitrary and meaningless. The flows also tend to wedge out laterally. This tendency is not as obvious within the confines of an individual nunatak as when attempts are made to correlate individual flows over larger distances.

At Snökallen (Fig. 2), lava from the upper flow was observed to extend downwards into the underlying flow as a vein. It seems that before the event of the younger (upper) flow, there already existed a crack in the surface of the older flow. This crack was apparently caused by the flow movement of the lava just before consolidation which disrupted and broke the chilled and already solidified upper crust. The chilling would be even more enhanced if the lava were ejected underwater, as indeed ripple-marked sediments and pillow structures, developed at and above the contact, seem to suggest.

The lavas are all altered, with extensive epidotization, chloritization and sericitization. The more highly sheared lavas are more altered and many have a schistose appearance, bordering on the greenschist facies of low-grade metamorphism.

Petrography

The highly altered state of the lavas prevents accurate determination of the original constituents. However, the few least altered specimens selected from various levels in the succession indicated a feldspar composition in the andesine range, generally An_{35-38} Ab_{62-65}. The pyroxene in most cases would appear to be augite, sometimes with minor amounts of orthopyroxene, probably pigeonite. A glassy mesostasis is invariably present, often crowded with feldspar microlites, which are brown coloured and cloudy as a result of alteration.

The lavas are generally porphyritic and in a few cases glomeroporphyritic. Plagioclase feldspar laths usually form the phenocrysts but phenocrystic pyroxene was also observed. Generally the texture can be stated as porphyritic and intersertal if glass is present, or porphyritic and intergranular if it is not. Indistinct flow structures may also be present.

Alteration products are predominantly epidote, chlorite and sericite. Some of the lavas are altered to the extent where practically no traces of the original constituent minerals remain, the rock consisting almost completely of epidote, chlorite (frequently the penninite variety), prehnite and ore minerals.

Vesicles are filled by quartz, chalcedony, chlorite, prehnite, calcite and feldspar.

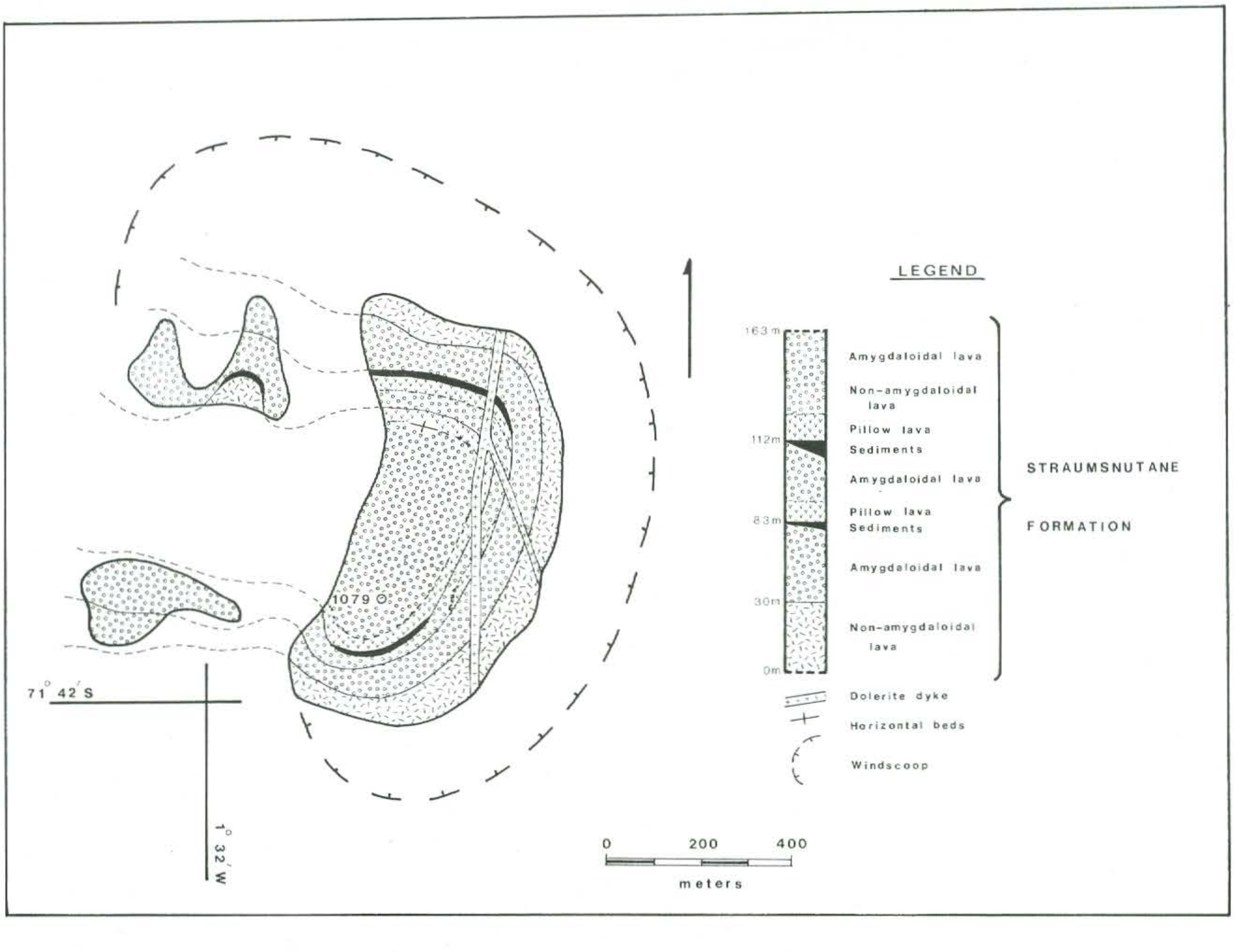

Fig. 3. Geological sketch map of Snökallen.

Direction of flow

Field evidence suggests that the prime source area for the lava was somewhere to the west and north of the present exposures. The most reliable indication of directions of flow is the shape and attitude of the pillows in many of the pillow lava horizons. If viewed parallel to the bedding but perpendicular to the presumed direction of flow, an overriding effect of successive pillows is evident, generally towards the south-east. Accurate measurements on pillow lavas of Nunatak 990* indicated a flow in a direction 118° (east-south-east). At Bolten, wrinkles or undulations in the upper surfaces of lava flows, striking 62°, could also indicate a flow in a direction 152° (south-south-east).

Determination of direction of flow by pipe amygdales, inclined to the base of the flow by the drag of a semi-liquid lava, was virtually impossible and certainly unreliable because of a post-consolidation re-orientation of the pipes by shearing action, which is very common throughout the lavas. However, a few outcrops which are relatively less sheared provide evidence of flow from the north and west. Although this is not conclusive on its own it does tend to strengthen the above evidence.

*All unnamed nunataks are referred to by their heights in metres as given on the 1 : 250 000 scale maps of the area published by Norsk Polarinstitutt, Oslo (Ed.).

Associated sediments

Sediments associated with the lavas are relatively rare in the Straumsnutane. At Snökallen, two sedimentary interbeds are present at different stratigraphic levels, both occurring immediately below bands of pillow lava (Fig. 3). These interbeds are not continuous in a lateral sense and in most instances the pillow lavas rest directly on the underlying lava with a sharp contact. Deposition apparently took place in shallow depressions in the surface of a preceding lava flow during a period of quiescence.

From the base up the sediments, at their maximum development, are composed of:

(1) Fine-grained, thinly bedded, often friable, calcareous, tuffaceous quartzite. Maximum thickness is 50 cm.

(2) Fine-grained, thinly bedded quartzite that has a conspicuous red and/or green colour. The thickness ranges from virtually nothing up to 50 cm but is more consistent than (1). Surfaces displaying indistinct mud-cracks were found. The upper surface is extensively ripple-marked.

(3) In the north-western part of the nunatak these horizons are overlain by a medium-bedded, reddish-brown quartzite which after approximately 50 cm becomes pale brown or buff coloured. This quartzite attains a maximum thickness of 8 m.

Interbedded sediments also occur in the northern part of Nunatak 1090, immediately south of the Trollkjelpiggen (Fig. 2). Here the sedimentary rocks attain a maximum thickness of only 3 m and in the

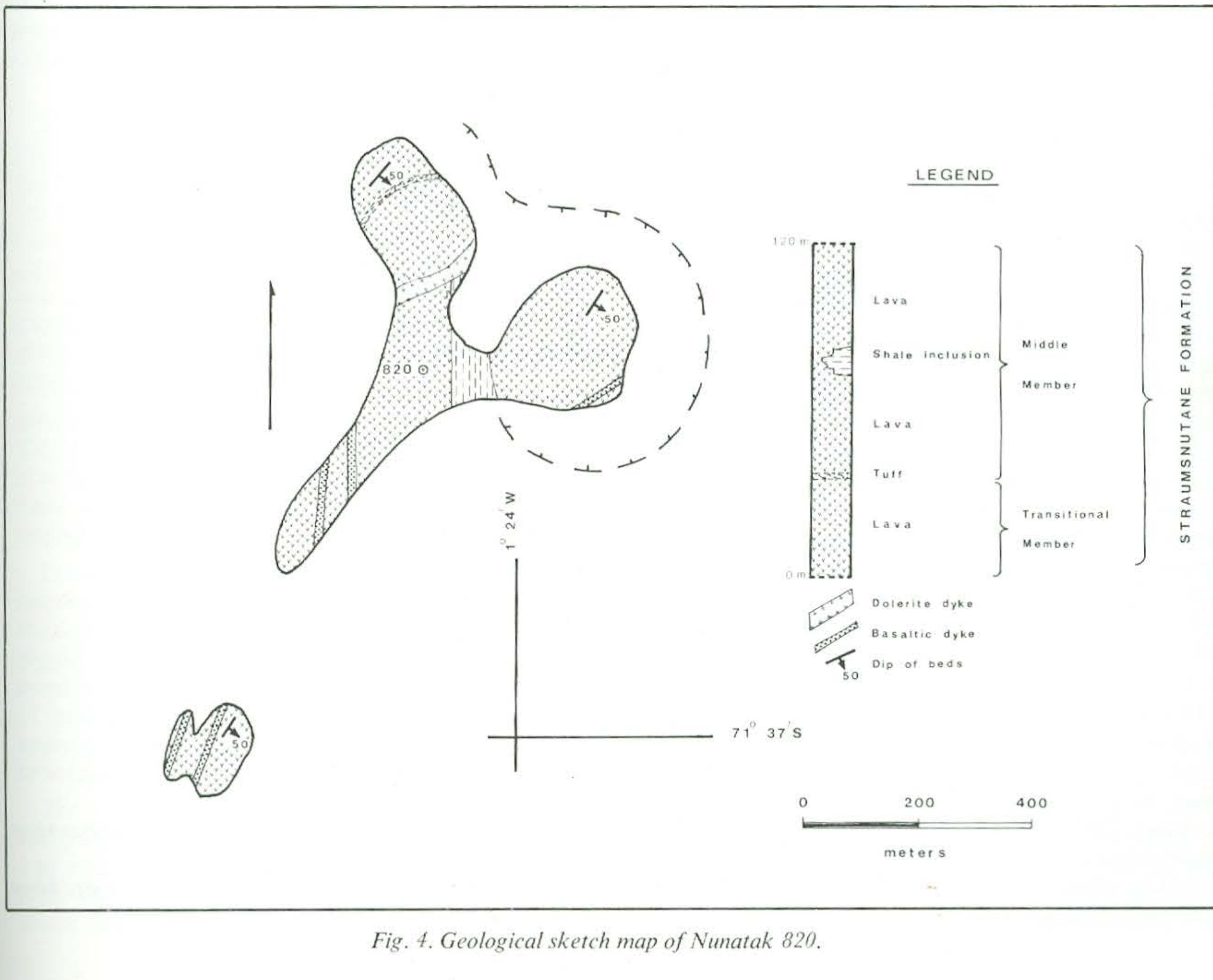

Fig. 4. Geological sketch map of Nunatak 820.

lower half consist of light-grey quartzite that has been severely sheared. The quartzite becomes finer-grained in its upper part. The dip conforms with that of the lava.

Approximately 12 km to the north-west of Nunatak 1090, at Nunatak 820, two types of sediment occur within the lava. The lowermost is a coarse-grained tuffaceous quartzite up to 1 m thick and ranging in colour from pinkish-brown to dark greenish-grey. The dip conforms with that of the lava (Fig. 4).

Higher up in the nunatak there occurs a 12-m thick bed of paper shale which displays irregular colour variations between red, maroon, brown and greenish-grey (Fig. 4). Near the western contact with the lava, interbedded lenses of medium-grained micaceous quartzite are present. The bedding of the sedimentary rocks is vertical and the strike is 167° which does not conform with that of the lavas. The nature of the upper and lower contacts does not suggest deposition on a lava surface. On the contrary, the contacts are baked, and the bed thins out northwards and terminates against a dolerite dyke. It is probable, therefore, that this sediment represents a block rafted or moved from elsewhere, not necessarily over any great distance, but it is nevertheless "foreign" in its present position.

Approximately half-way up the lava succession exposed at Brautnuten (Fig. 2) a quartzite inclusion 2 m^2 in size is present. The contacts are diffuse.

Igneous Intrusions

The only intrusions observed cutting the Straumsnutane Volcanics in the Straumsnutane were mafic dykes. Two types occur, *viz* a narrow set having a basaltic texture, and a set of greater average width having a doleritic texture.

The basaltic dykes are black when fresh, very fine-grained, and invariably contain phenocrysts of olivine up to 6 mm in length. These dykes are very susceptible to weathering and the weathered colour is a dark brown. Columnar-type jointing developed at right angles to the walls occurs without exception and this accelerates the rapid mechanical disintegration and removal of the rock, resulting in a decidedly negative erosional feature. The width of these dykes is about 1 m on the average and is never greater than 2 m. The attitude is vertical or near to vertical and a clean contact with the country rock is typical. These intrusions have not affected the country rock to any great extent; only a slight darkening and hardening of the latter for 2 cm or so from the contact is evident. The basalt, on the other hand, is noticeably chilled for a few centimetres from the contacts.

The larger dykes, which range in width from 2 to 14 m, have a typical doleritic appearance, are fine to medium-grained and dark grey in colour. Although these dykes do not weather as readily as the basaltic ones, they also tend to form slightly negative erosional features. The weathered colour is a distinctive bright red-brown. They are also vertical or very nearly so in all cases. Small off-shoots and rounded projections into the country rock are common.

Age relationships between the dykes are not very clear although they are obviously both younger than the Straumsnutane Volcanics. Only at Snökallen were the two types of dyke found in contact. Here the basaltic dyke appears to be the younger of the two intrusions but unfortunately the contact is not very well exposed.

From the available field and laboratory evidence it would appear that the dykes are younger than the lavas and not merely a late phase of the same period of igneous activity. Both types of dyke cut the very prominent shearing that has affected the lavas and are themselves not at all sheared. Alteration of the lavas has been much more severe and the dykes are also more basic in composition than the lavas.

A small but very definite difference in the trend of the dykes and the strike of the shearing indicates that the direction of intrusion cannot be attributed to that of the shearing forces (Fig. 5).

The remarkably small variation in the strike direction of the dykes requires, however, that there be some sort of structural control and it seems likely that the direction of the intrusions was influenced by the tensional forces giving rise to the vertical joint set striking 10° (see following section).

Structural Geology

The general tectonics for this part of western Dronning Maud Land have been summarized by *Neethling* (1968, 1969, 1970a, 1970b) who states that "the outstanding tectonic feature of the region is the presence of large-scale, mainly tensional structures, indicating that the Borg-Ahlmann upland has been subjected to mainly epeirogenic movements . . . "

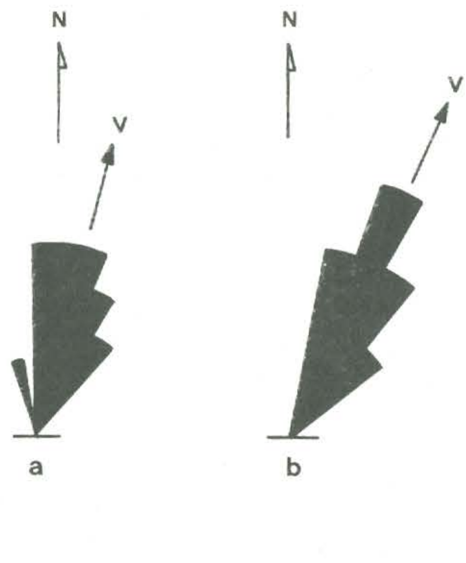

Fig. 5 a. Azimuthal distribution of dyke trends. Mean Vector (V) = 13°

Fig. 5 b. Azimuthal distribution of shearing trends. Mean Vector (V) = 26°

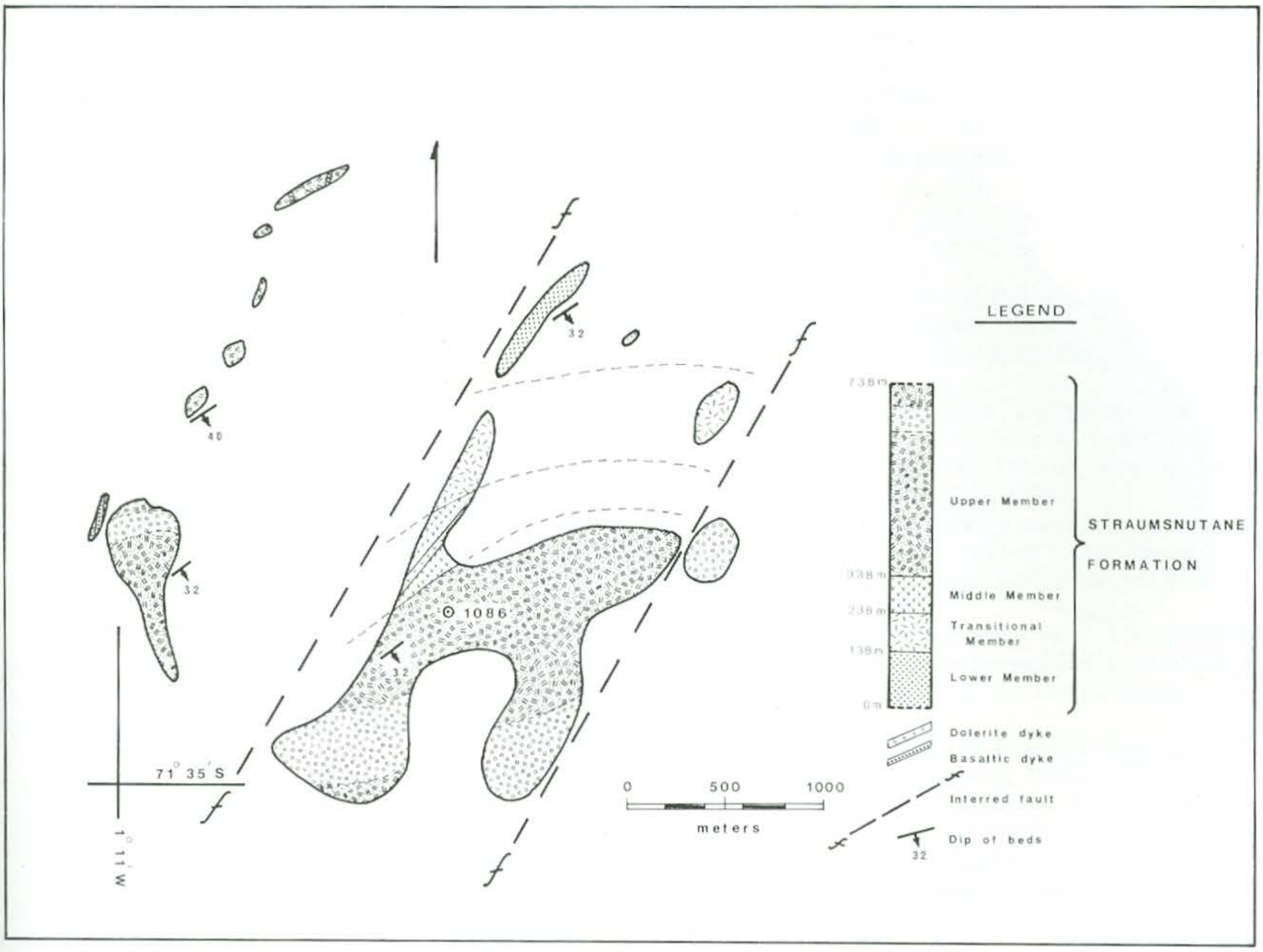

Fig. 6. Geological sketch map of the Trollkjelpiggen.

The Ahlmannryggen consists of relatively undeformed blocky massifs and ridges bounded by normal faults. The main trend of these large-scale faults is north-east, resulting in parallel ridges, blocks and valleys of the rift type trending in the same general direction. A certain amount of step faulting trending east-west must also have taken place, resulting in a progressive downthrow of blocks to the north, from the Borgmassivet towards the Kronprinsesse Märtha Kyst (Fig. 1).

(*a*) *Faulting*

To the east of Straumsnutane the landscape falls away sharply toward the Jutulstraumen. Undoubtedly this steep slope marks a zone of normal faulting of considerable magnitude.

Local inter-nunatak faulting has also taken place as indicated by the variation in stratigraphy. For instance, two normal faults cutting through Trollkjelpiggen have been inferred (Fig. 6) to account for the present relative positions of a very well defined band of pillow lavas. These faults probably both trend approximately north-east, paralleling the regional structural pattern.

The only fault zone actually exposed occurs at Litvillingane and is represented by a breccia zone 1 m wide, trending 17° and dipping 85° west. However, this would appear to be a fault of relatively minor displacement.

(*b*) *Shearing*

In the Straumsnutane there is a high degree of shearing, tending to schistosity in some localities. The shearing increases from west to east (*Butt*, 1962). In western nunataks such as 1178, Bolten, Snökallen and Snökjerringa, shearing is virtually non-existent, and it is moderate in the western Trollkjellpiggen and Nunataks 990 and 820. In contrast, however, shearing is very severe in eastern nunataks bounding the Jutulstraumen such as at Utkikken, eastern Trolljkelpiggen, Nunatak 1090, Brautnuten and Litvillingane (Fig. 2). The general trend of the shearing is approximately 27° and it dips about 65° to the east-south-east.

(*c*) *Slickensiding*

This feature is very common throughout the lavas and it would appear that a lot of very minor local movement has taken place by this mechanism. The planes of movement are always thickly coated with epidote, have an attitude from horizontal to vertical but invariably dip at steep angles to the east-south-east with a movement in the same direction. Use was often made of flow contacts or highly vesicular bands for ease of movement.

(*d*) *Folding*

Folding is practically non-existent in the lavas. A gentle synclinal structure with axis trending 48° and dips of 13° – 14° south-east and north-west is evident at Nunatak 990 (Fig. 7). Local basins which may

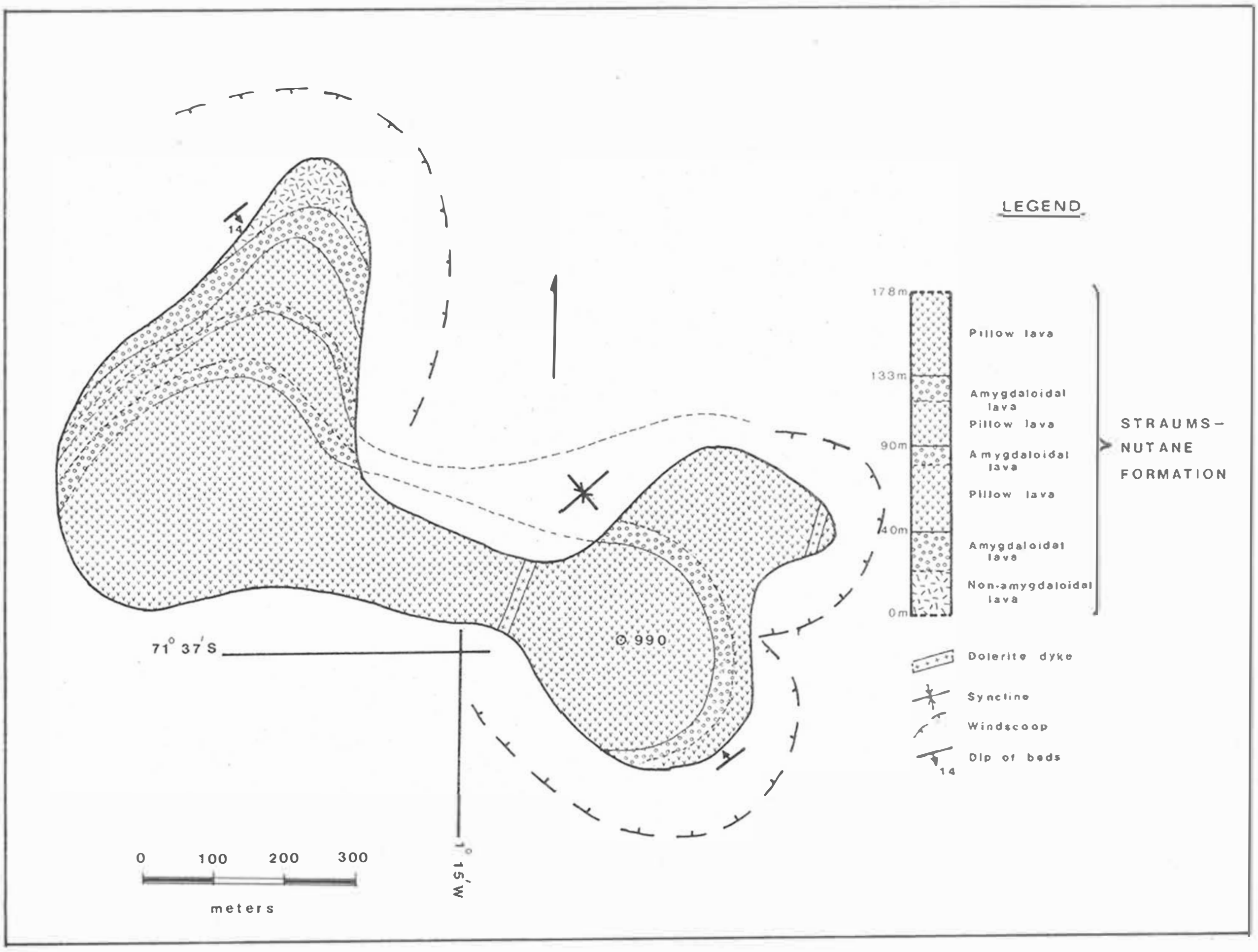

Fig. 7. Geological sketch map of Nunatak 990.

contain sediments, as at Snökallen Nunatak, are also present but these almost certainly represent hollows existing on the lava surface at the time of deposition and were not necessarily imposed by any secondary deformation.

(*e*) *Present attitude of the lava flows*
Adjacent to the Jutulstraumen the dips of lava flows are always 30° – 35° to the south-east and east-south-east, whereas on the western and central part of the Ahlmannryggen the flows are either essentially horizontal, as at Snökallen, or dip at low angles (8° – 13°) to the south-east as at Snökjerringa and Bolten. Exceptionally, the lavas of Nunatak 1178 dip 8° to the north-west; the synclinal structure of Nunatak 990 has already been mentioned.

(*f*) *Jointing*
An insufficient number of measurements were taken for reliable interpretation of the forces operating in the region to produce the present joint systems. However, a stereographic plot of available data indicates two major vertical joint patterns, at right angles to one another, striking 5-10° and 95-100° respectively.

Geological Interpretations and Correlations

In the Straumsnutane a total thickness of approximately 860 m of lava and minor intercalated sediments is exposed. Since neither the base, nor the top of the succession is exposed this must be regarded as a minimum thickness. These rocks, collectively named the Straumsnutane Formation by *Neethling* (1970), have been subdivided into four members having a transitional relationship to one another (Fig. 2). The large degree of lateral variation in the flows and the absence of suitable marker horizons do not allow the compilation of a reliable stratigraphic profile. However, the following sequence is tentatively suggested:

(*a*) *Lower Member* (*260 m*)
This Member consists of flows of aphanitic to fine-grained, greenish-grey lava, which in the lower two-thirds of every flow contains very large amygdales filled mainly with white quartz and accessory epidote. These amygdales may be egg-shaped, dish-shaped, or pipe-like. The upper parts of the flows are highly amygdaloidal and crowded with small rounded amygdales. This part of the succession is exposed at Utkikken (the type area) and in the north-eastern part of the Trollkjelpiggen.

(*b*) *Transitional Member* (*100 m*)
Flows of the Lower Member are gradually replaced by lavas of the Middle Member. The type area is in the eastern Trollkjelpiggen.

(*c*) *Middle Member* (*100 m*)
Highly amygdaloidal lava alternates with non-amygdaloidal or only slightly amygdaloidal flows. The

lava is fine to medium-grained, typically greenish-grey, and the amygdales may be arranged in bands. The type area is in the eastern Trollkjelpiggen.

(*d*) *Upper Member (400 m)*

The lower half consists predominantly of lava similar to the Middle Member. Pillow lavas also occur typically and become more abundant towards the top of the succession. The amygdaloidal flows of this Member often have amygdales arranged in either wavy or straight bands and there is a definite association and often a gradation between pillow lavas and wavy banded amygdaloidal lava. Thin intercalated sedimentary horizons also occur within the upper half of this Member. Between 10 m and 130 m of this Member may consist of pillow lava, depending on the locality of the outcrop. Maximum development occurs mainly on the western side of the Straumsnutane in the vicinity of Nunatak 990, western Trollkjelpiggen, Snökjerringa and Snökallen. A particularly persistent pillow lava horizon occurs approximately 30 m below the top of this Member.

Age determinations by the Rb-Sr whole rock method were done on a series of samples collected from Bolten, Snökallen, Snökjerringa, and Nunatak 820, and an age of 856 $\pm$ 30 m.y. was reported by *Eastin et al.* (1970).

Basic to intermediate lava, which by description bears a remarkable resemblance to the Straumsnutane Volcanics, occurs in two isolated outcrops. One of these lies approximately 150 km south-south-east of Istind at Sistenup (*Soloviev*, 1965), and the other in the Vestfjella some 450 km to the west of the Ahlmannryggen (*Juckes*, 1968). These widespread occurrences of lava may belong to the same volcanic episode and may be correlates of the Straumsnutane Formation occurring on the Ahlmannryggen.

Economic Geology

Small amounts of an unknown copper mineral stain the lavas in isolated patches, which become more abundant adjacent to the larger dolerite intrusions.

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