The Geology of Grunehogna, Ahlmannryggen, western Dronning Maud Land

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A low-grade metamorphosed sedimentary sequence, 300 m thick, occurs at Grunehogna. The upper portion of the Schumacher and three members of the Högfonna Formation are described and their correlation discussed.

The sedimentary sequence is extensively intruded by mafic sheets and dykes, and seven possible phases of igneous activity are distinguished.

'n Laegraadse gemetamorfoseerde sedimentêre opeenvolging van 300 m dik kom by Grunehogna voor. Die boonste gedeelte van die Schumacher-formasie en drie lede van die Högfonna-formasie word beskryf en hulle korrelasie word bespreek.

Die sedimentêre opeenvolging is in groot mate deur mafiese plate en gange ingedring, en sewe moontlike fases van indringing word onderskei.

Introduction

Grunehogna (72°03'S, 2°45'W) is located in the central portion of the Ahlmannryggen, western Dronning Maud Land, Antarctica (Fig. 1). The first detailed geological mapping in the area was carried out during December, 1968 and January, 1969 by the author who was a member of the Ninth South African National Antarctic Expedition.

Accounts of previous investigations at Grunehogna and adjacent areas have been given by *Roots* (1953, 1969); *Butt* (1962, 1963) and *Neethling* (1964, 1969, 1970a, 1970b).

Physiography and Geomorphology

The topography of the Grunehogna nunatak group is characteristic of the Ahlmannryggen with its highly dissected and isolated rock exposures. The nunataks are often peaked, which is in contrast to the closely-spaced, flat-topped, block-like nunataks of the Borgmassivet, further to the south (*Swithinbank*, 1959). The highest point in the Grunehogna area is Kullen, which is 1 555 m above sea-level and rises to a height of more than 450 m above the surrounding snow.

Although some erratics as well as ice-striae on rock surfaces were found up to a few metres above the present snow surface, no evidence of any previous, large-scale overriding of the nunataks by the ice-sheet is exhibited by the present landforms.

Except for a few possible relicts of cirques, the basins of which are at present well below the snow-cover, no definite Alpine landforms occur in the Grunehogna area. Although peaks in the vicinity, such as Istind, resemble Alpine horns, they were shaped by scarp recession and not through cirque recession, and cannot therefore be considered to be true Alpine landforms.

Geology

The Sedimentary Sequence

A 300 m-thick sequence of typically low-grade metamorphosed sediments of the Ahlmannrygg Group (*Roots*, 1969), representing the top portion of the Schumacher Formation (defined by *Neethling*, 1964, 1970), and three members of the Högfonna Formation (defined by *De Ridder & Bastin*, 1968), is exposed in the western portion of Grunehogna. The contact between the two formations is sharp and clearly visible from a distance. Although each has distinctive features and can immediately be identified in outcrop, some genetically related sediments occur in both. No evidence was found to suggest a discordance or an unconformity between them. These sediments have a regional dip of 5° to the south-west.

1. SCHUMACHER FORMATION

Seen from a distance, the Schumacher Formation appears greyish and is characterized by well-defined bedding with good lateral continuity. Where exposed, the rocks usually occur in vertical cliff faces. Approximately 90 m of the Schumacher Formation is exposed at Grunehogna.

(a) Lithology

The quartzitic beds of this formation range from medium-grained arkosic in the lower horizons to fine-grained argillaceous towards the top. Purple mudstone makes up the finer fraction of graded bedding units in the upper 50 m of the sequence. Jasper and flat-pebble conglomerates (characteristic of the overlying formations) are conspicuously absent throughout.

(b) Sedimentary Structures

Several occurrences of slumped bedding were seen, usually in greenish-grey quartzite but also in purple mudstone. Graded bedding in units up to 7 m thick

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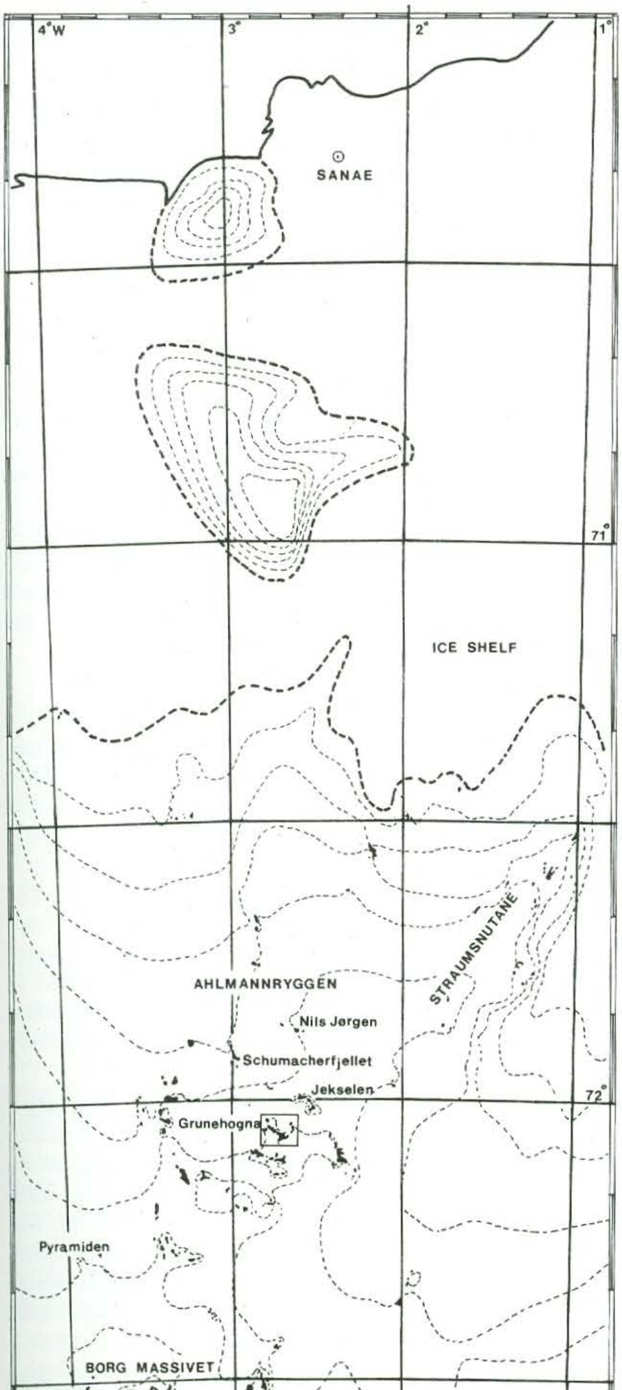

Fig. 1. Locality map, western Dronning Maud Land. Oblong indicates position of Fig. 3.

occurs in the upper 50 m of the formation. Cross-bedding is rare and units seldom exceed 50 cm in thickness.

Mud-cracks, which are rare in the lower portion, occur abundantly in the mudstones of the graded bedding units near the top. Intraformational breccias are also limited to the upper portion. The observed absence of mud-flake and shale-pebble conglomerate and the infrequent occurrence of ripple-marks and current-lineations are in contrast to the abundance of these structures in the Högfonna Formation.

(c) Depositional Environment

A low-energy, shallow-water environment with a distant shore is indicated by the fine-grained, even-bedded, graded nature of the beds and confirmed by the associated mud-cracks. The initial rate of sediment supply apparently slowed down with the increased erosion and planation of the provenance as the mature stage of the landscape was approached. Associated with this were the increased weathering of the feldspar-supplying rocks and a longer transportation period of the detritus, resulting in the presence of clay minerals instead of feldspar in the sequence as the basin filled up. During the last phases of sedimentation the basin floor dried up regularly, accounting for the multiple mud-cracks in the highest strata. The few measurements of cross-bedding that were made indicate predominant palaeocurrent directions from the west and south-west.

(d) Correlation

The lowest sequence of sediments at Grunehogna is similar in appearance and in lithology to the cyclic sequence at the northern end of Schumacherfjellet and to the lowest portion of the sequence at Veten in the Borgmassivet. It also fits the description by *De Ridder & Bastin* (1968) of the sediments at Framryggen.

2. HÖGFONNA FORMATION

(a) Lithology

An abrupt change in the lithology and in the nature of the depositional structures in the sedimentary sequence is considered to mark the upper limit of the Schumacher Formation. At present, Grunehogna is the only locality where a distinctive, unambiguous contact between the Schumacher and the Högfonna Formations has been observed.

The Högfonna Formation was defined by *De Ridder & Bastin* (1968) as comprising all the sediments between the two polymict jasper-rich conglomerates at Högfonna, the type locality. Two widely spaced conglomerates also occur at Grunehogna, but they need not be stratigraphic equivalents of those at Högfonna. At Grunehogna, the sediments between the conglomerates, as well as the sedimentary units above and below them, have related characteristics and all are included in the Högfonna Formation. The Högfonna Formation in the Grunehogna area thus includes all the jasper-bearing and associated non-jasper-bearing sediments of the Ahlmannrygg Group.

No basal conglomerate is present above the contact. The first obvious feature distinguishing the Högfonna Formation from the underlying purple mudstones of the Schumacher Formation is the occurrence of cross-bedded units, up to 1,4 m thick, of feldspathic quartzite with lenses and layers of shale-pebble conglomerate.

On the whole the Högfonna Formation is more feldspathic than the Schumacher Formation, with the feldspar content at times reaching arkosic proportions, and the sediments are generally coarser-grained. Bedding units are thicker and often exhibit less lateral continuity than those of the underlying Schumacher Formation. Abundant occurrences of cross-bedding, ripple-marks, current-lineations and large mud-cracks are all distinguishing features of the sediments above the contact.

The Högfonna Formation at Grunehogna may be subdivided into three members, demarcated by the two jasper-bearing conglomerates.

(1) The Lower Member (80 m) — This member comprises mainly lens-like, discontinuous, current-bedded quartzite and arkose, interspersed by shale-pebble conglomerates up to 50 cm thick. The middle 25 m forms a distinctive zone with more even-bedded units in relatively thinner layers. Shales are abundant and contain many well-preserved current-lineations, flute-casts, ripple-marks, and mud-cracks with polygons up to 85 cm across. Epidotized layers of shale-fragment conglomerate occur together with beds of reddish, highly silicified quartzite. It should be noted that similar epidotized beds are reported to occur at several localities in the Borgmassivet (*De Ridder & Bastin*, 1968).

Towards the top of this member, the sediments become more reddish to purple in colour and somewhat finer-grained. Some layers contain abundant concretions of specularite. These sediments are considered to be the equivalent of the Basal Red-Beds (*Neethling*, 1964) at Nils Jörgennutane.

In the western part of Grunehogna the highest 2 m of this Lower Member consists of fine-grained, laminated, purple to brown-red shale. Fragmented quartz grains and typical ash-particles are visible under the microscope, suggesting that these red shales might be tuffaceous in origin. Towards the east these beds are laterally replaced by poorly consolidated, grey-coloured, medium-grained rock containing dark oval-shaped fragments up to 10 cm in diameter, which are probably of pyroclastic origin.

(2) The Middle Member (60 m) — There is a remarkable similarity in the lithology of the Middle and Lower Members of the Högfonna Formation. The deduced depositional environment of these two members is also similar. As in the case of the Lower Member, the main rock type of the Middle Member is cross-bedded quartzite which is somewhat more gritty, darker in colour and less feldspathic than those lower down. This is interspersed by lenses and layers of shale-pebble and mud-flake conglomerate. A few prominent beds, up to 1 m thick, of black, fine-grained quartzite appear scattered throughout the sequence. Similar dark quartzite beds also occur in the Upper Member.

The lowest known occurrence of jasper in the Högfonna Formation at Grunehogna is the polymict, chert-jasper conglomerate that constitutes the base of this Middle Member. The constituent pebbles are generally small and do not exceed 2,5 cm in diameter. They are loosely packed in a well-sorted, medium-grained matrix containing minute grains of red jasper. The pebbles seldom occur more than 1 m above the base of the conglomerate as it grades into cross-bedded, gritty, jasper-bearing quartzites. The jasper content of the sediments diminishes rapidly until it is totally absent 3 m above the base of the conglomerate. Minute grains of jasper, however, again occur in quartzite, 35 m higher.

(3) The Upper Member (70 m) — A second chert-jasper conglomerate bed, similar in appearance to the one at the base of the Middle Member, occurs at the base of the Upper Member; it grades into overlying gritty and coarse-grained, brown to purplish-red quartzite, with cross-bedded units up to 1 m thick. Jasper occurs in gritty horizons and as small lenses of pebbles scattered throughout this member. No mud-cracks were seen and ripple-marks are rare. In general these quartzites contain less feldspar and more iron oxides than the quartzites of the two lower members.

(*b*) *Depositional Environment*

The predominantly fine-grained argillites of the Schumacher Formation are replaced in the Högfonna Formation by a mainly clastic assemblage. This, together with the abundance of high-energy sedimentary structures in the Högfonna Formation, would suggest uplift in the provenance area, resulting in a faster inflow of freshly eroded clastic material. The shallow-water environment of the Schumacher Formation was, however, maintained throughout the Lower and Middle Members of the Högfonna Formation as mud-cracks occur intermittently. In the Upper Member the rate of sediment inflow increased, as suggested by the abundant cross-bedding.

The observed co-existence of mud-cracks with large-scale cross-bedding and the occasional though wide-spread occurrence of erosion channels suggests an environment approaching deltaic conditions. This would account for the high degree of lateral discontinuity of beds that was seen to occur in the area. Stratigraphic correlation of individual beds or members of this formation should thus be done with caution, especially over great distances.

Indications of volcanism in the provenance area were found low down in the Högfonna Formation. The lowest of these are in the red-beds that constitute the top of the Lower Högfonna Formation.

Palaeocurrent measurements (Fig. 2) indicate inflow of sediments from the west and north-west during the deposition of the Lower and Middle Members.

(*c*) *Correlation*

Red jasper, occurring as rounded pebbles and as small grains, is a prominent feature of the sediments of the Högfonna Formation at Högfonna, the type locality (*De Ridder & Bastin*, 1968), as well as at numerous other sedimentary outcrops of a similar appearance throughout the Ahlmannryggen and Borgmassivet. Despite a careful search by the author, no jasper was found in the sediments of the Schumacher or Pyramiden Formations (*Neethling*, 1970).

If the occurrence of jasper is used as the prime criterion for correlation with the Högfonna Forma-

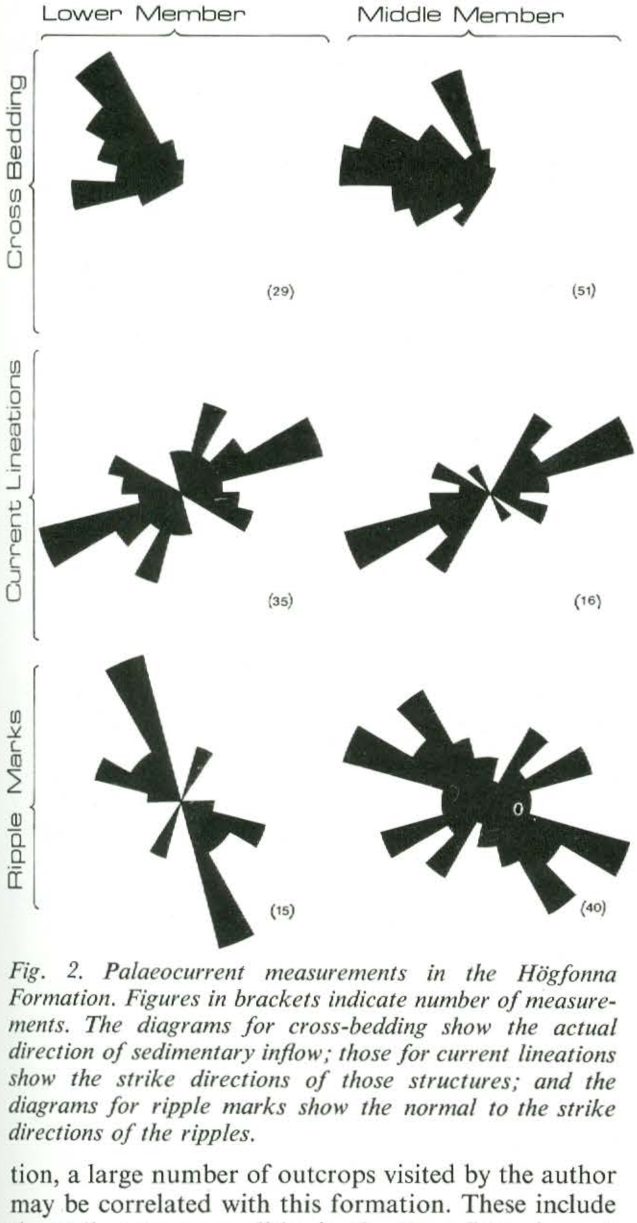

Fig. 2. Palaeocurrent measurements in the Högfonna Formation. Figures in brackets indicate number of measurements. The diagrams for cross-bedding show the actual direction of sedimentary inflow; those for current lineations show the strike directions of those structures; and the diagrams for ripple marks show the normal to the strike directions of the ripples.

tion, a large number of outcrops visited by the author may be correlated with this formation. These include the sedimentary xenoliths in the Borg Intrusions at Nils Jörgennutane and at Jekselen, as well as the sediments of Fasettfjellet, Vindegga, Stridbukken, Framrabben, Trioen, and the upper portion of the sequence at Veten, in the Borgmassivet.

Intrusive Rocks

The sedimentary sequences at Grunehogna have been invaded by possibly as many as seven phases of igneous activity. The most significant of these, constituting a tremendous volume of rock, are the layered sheets of the Borg Intrusions, discovered by the geologists of the Norwegian-British-Swedish Antarctic Expedition and first described by *Roots* (1953).

1. PRE-BORG INTRUSIONS

Two dykes older than the Borg Intrusions occur at Grunehogna. A 10 m-wide near-vertical dyke intrudes the sedimentary sequence at locality 4 (Fig. 3). Very little contact metamorphism is evident. The dyke is poorly exposed as it has been weathered away to form a deep gully, now filled with scree. It was sampled near the top of the mountain, where it is a fine-crystalline dolerite. The actual area of contact between this dyke and the Borg Intrusions is obscured by scree. Despite a careful search, no trace of the dyke could be found within the sheet lower down. The possibility that this dyke could be a branch of the sheet is also excluded as it does not conform to the pattern set by several such dykes that occur at other localities at Grunehogna.

A fine to medium-grained mafic dyke, approximately 15 m wide, occurs at locality 8 (Fig. 3) where it is exposed in a cliff face. The thick Borg Intrusion can clearly be seen to cut across the dyke which is highly altered, probably due to the emplacement of the later, adjacent dyke, associated with the Borg Intrusions. The earlier dyke could, however, represent an early phase of the Borg intrusive event.

2. THE BORG INTRUSIONS

(*a*) *Diorite-Dolerite and Syenitic Intrusions*

Underlying virtually all of the sediments at Grunehogna is the upper part of a differentiated diorite-dolerite sheet belonging to the Borg intrusive suite. The greatest exposure of this body, estimated to be more than 200 m thick, is at Kullen peak. The upper contact with the sediments is often transgressional and generally inclined towards the west. At locality 3 (Fig. 3), this contact is trough-shaped, but the lowest portion is covered by scree and snow.

At several localities the upper portion of the sheet branches off into the overlying sediments (localities 2, 5, 7, and 8, Fig. 3) intruding upwards at ever-increasing angles to form dykes.

The lower part of the sheet is a medium-grained dolerite. Upwards it grades into a coarse-grained diorite which is granophyric in places near the top. The differentiation is exceptionally well developed in the northern cliff faces at Kullen, and at peak 1390, where rhythmic layering and possibly also multiple intrusion occurred. Unfortunately no detailed sampling could be done on account of the sheer and inaccessible nature of the exposures.

A small inclusion of sediments, approximately 8 m across, occurs within the sheet at locality 13 (Fig. 3). Although the sediments are baked and highly altered, virtually no assimilation by the surrounding diorite is visible.

Bodies of a reddish-brown syenitic rock measuring up to 30 m across occur in the upper portion of the sheet at localities 6 and 9 (Fig. 3). There is no definite contact between them and the surrounding diorite. Provisionally, these syenitic rocks are considered to be assimilated sediments.

The syenitic rocks occurring on the eastern arm of Grunehogna and named the Jörgen Intrusions (*Neethling*, 1969; *Allsopp & Neethling*, 1970) were not visited by the author, but in hand-specimen they seem very similar to the syenitic bodies described above. It thus seems possible that these might also represent assimilated sediments.

(*b*) *Granodiorite Intrusions*

The largest occurrence of this kind is in the central part of Grunehogna where a 300 m-wide body of granodiorite cuts through the Borg Intrusions and into the overlying sediments. At this locality and also further to the west (Fig. 3, locality 10) folding and overfolding of the sediments as a result of their down-wedging by the intruding granodiorite, and assimilation of both the sediments and portions of the Borg

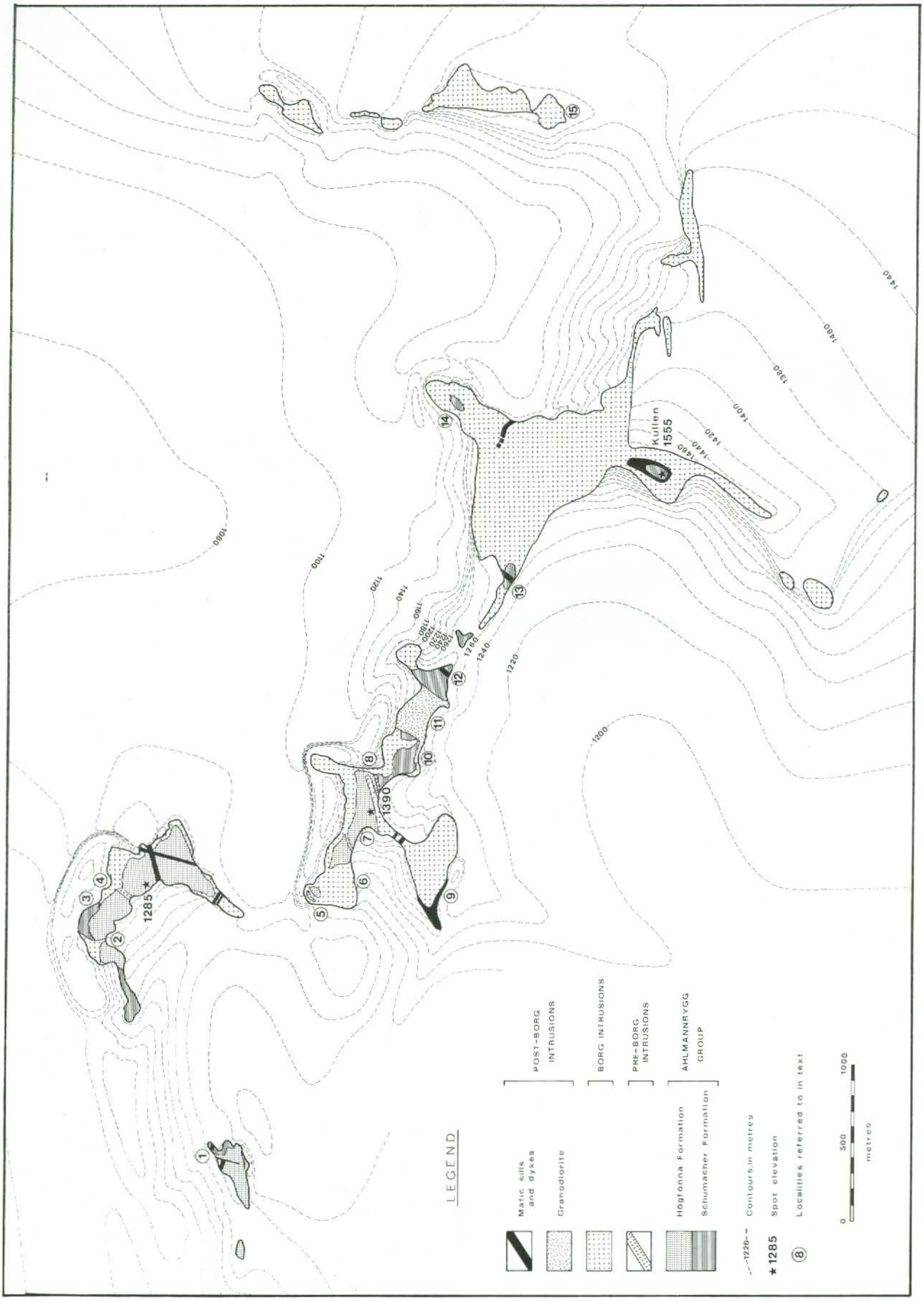

Fig. 3. Geological map of Grunehogna.

Intrusions by the granodiorite can be seen. At one locality the folding of the sediments extends upwards from the contact with the Borg Intrusions for approximately 17 m. The general strike direction of the axes of the folds is north-south.

A much smaller, but more genetically significant, intrusion of granodiorite occurs at locality 3 (Fig. 3). Here the sediments immediately above the Borg

Intrusions are intensively folded and are intruded by granodiorite (Fig. 3). The folding is, however, due to the intrusion of the Borg diorites and not of the granodiorite. Up to a height of 55 m above this zone of folding and intrusion the sediments are riddled by small veinlets. These are granodioritic in composition, and create the impression of having been isolated recrystallization centres in the sediments during a period of metasomatism. These veinlets usually cut across the bedding-planes but often spread laterally into strata containing more feldspar, creating the impression that the feldspar-rich layers were more susceptible to recrystallization than the rest.

The intimate association of the granodiorite with folding as a result of the implacement of the Borg Intrusions can only be explained by a genetic relationship between these rocks. The granodiorite is therefore considered to be a late magmatic phase of the Borg Instrusions.

No detail is available on the occurrence of granodiorite at locality 5 (Fig. 3) as it was seen only from a distance.

3. POST-BORG INTRUSIONS

The igneous rocks intrusive into the Borg Intrusions at Grunehogna can be classified into five distinct groups *viz* dolerite dykes, sills and sheets; andesitic dykes; pyroxenite dykes; olivine-dolerite dykes; and mafic aphanitic dyke material found in certain fault-zones.

At present it is not clear to what extent the mafic, post-Borg intrusions are genetically related to each other. Neither has it been possible to establish age relationships between any of these groups from observable field relations.

(a) Dolerite dykes and sheet-intrusions

At locality 9 (Fig. 3), a fine to medium-crystalline dolerite sheet, reaching a maximum thickness of 95 m, cuts through the Borg Intrusions. Its lower contact is not exposed above the snow-cover. The upper contact dips at 30° to the south-south-east.

Chill zones in the later dolerite and some baking and alteration of the older sheet indicate emplacement after the Borg Intrusions had consolidated and cooled down.

(b) Quartz Diorite Dykes

A near-vertical, aphanitic dyke cuts through the Borg Intrusions and the small inclusion of altered sediments mentioned earlier (Fig. 3, locality 13). The dyke is approximately 3 m wide and exhibits glassy chill zones. Petrologically this dyke corresponds to the composition of the andesitic Straumsnutane Volcanics (*Watters*, 1969), and it could thus represent an intrusive phase or be a feeder dyke of these volcanics.

(c) Pyroxenite Dykes

A steeply-inclined pyroxenite dyke, approximately 8 m wide, cuts through the Borg Intrusions and overlying sediments (Fig. 3, locality 12). Pyroxenite and peridotite dykes and sills were found to be widespread throughout the Ahlmannryggen, but no indications of their age relation other than their being of post-Borg age could, as yet, be deduced from known field relations.

(d) Olivine-Dolerite Dykes

Several olivine-dolerite dykes cut through the Borg Intrusions and sedimentary sequences at Grunehogna. Although they do not constitute a large volume of rock, these dykes are the most widespread of all the post-Borg rocks in the Grunehogna area. They are not very persistent, but they do show a preferential strike direction (Fig. 4). They range in width from 30 cm to 16 m and often occur in groups of two or three. The attitude is vertical or near-vertical and a clean contact with the wall rock is typical.

Very little baking of the wall rock is evident and chill zones are limited in extent, although they tend to vary in proportion with the width of the dykes.

The texture is generally fine to medium-grained dolerite with abundant phenocrysts of olivine. These dykes are susceptible to chemical weathering resulting in decidedly negative erosional features.

A set of olivine-dolerite dykes, 3 m apart, and dated as 191,5 ± 3,7 m.y. (G. Faure, personal communication) occurs at a small nunatak, 2 km north-west of Nils Jörgennutane. A close similarity in the petrology, preferential strike direction (Fig. 4) and general mode of occurrence would suggest that this set of dykes and the olivine-dolerite intrusions at Grunehogna belong to the same phase of igneous activity. A Triassic/Jurassic age is thus assumed for all the olivine-dolerite intrusions in the area, and they are considered to be intrusive correlates of the Jurassic lava which caps the Upper Beacon sediments of the Kirwanveggen (*Aucamp et al.*, 1970) and Heimefrontfjella (*Juckes*, 1970). This suggests that the Jurassic lavas may have extended over the sedimentary sequences that are at present exposed in the Ahlmannryggen.

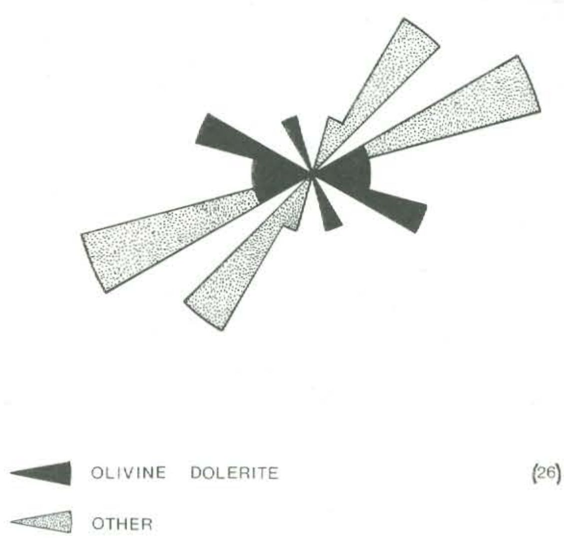

Fig. 4. Strike directions of dykes at Grunehogna.

(e) Mafic Intrusives, Associated with Faulting

Aphanitic, mafic, intrusive rocks occur in fault-zones at Grunehogna and Nils Jörgennutane. At Grunehogna they were found intrusive into strike-slip faults which displace an olivine-dolerite dyke. Large amounts of calcite, epidote and crystalline quartz occur in association with these intrusives.

Structural Geology

1. FAULTING

The most significant faulting in the Grunehogna area occurs at the westernmost nunatak of the group (locality 1, Fig. 3). Here a series of sinistral strike-slip faults displaces a 16 m-wide olivine-dolerite dyke over a total horizontal distance of 55 m. There is virtually no vertical displacement of the sediments. The brecciated fault-zone is partly filled with fine-grained mafic dyke-material (mentioned above) associated with large amounts of calcite, epidote and crystalline quartz.

Indications of movement (thrusting?) along sedimentary bedding-planes were found at the eastern face of Grunehogna peak 1285 where a thin olivine-dolerite dyke is displaced approximately 1,2 m horizontally.

Faults having a large displacement have seldom been seen in outcrop anywhere in the Ahlmannryggen. Differences in the altitude of the upper conglomerate horizon that occur at peaks 1285 and 1390 point to such faulting, with relative downward displacement of peak 1285. Glacial erosion has obviously exploited the weak zones associated with the more significant large-scale faults until all indications of their presence have disappeared beneath the snow-cover.

2. JOINTS

All of the sedimentary sequences and some of the intrusive rocks in the Ahlmannryggen are characterized by an extreme abundance of well-developed joints occurring in distinct sets.

Secondary mineralization, mainly tourmaline, epidote and actinolite, occurs along some sets of joints. The extent and nature of the mineralization varies with the distance above the Borg Intrusions suggesting (a) that the mineralization is related to the emplacement of the Borg Intrusions, and (b) that the joints containing the mineralization are older or genetically closely related to the emplacement of the Borg Intrusions.

The majority of the joints are, however, free of mineralization and are probably of post-Borg age.

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