Aspects of the geology of northwest Spitsbergen

(Some results of recent Norsk Polarinstitutt expeditions)

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Contents

Abstract

The geology of the crystalline rocks in the Caledonian orogenic zone of northwest Spitsbergen is summarized.

Late Precambrian supracrustals were regionally metamorphosed during late Proterozoic or early Paleozoic. Migmatization commenced in (mid?-) Silurian, and as the last plutonic event a batholithic post-tectonic granite was intruded in late Silurian.

Several deformation episodes are distinguished, corresponding to various stages of metamorphism and intrusion.

Introduction

GENERAL

This paper summarizes some of the main results from the geological work of the Norsk Polarinstitutt expeditions 1963–75, considering the areas of map sheets A4, A5 and A6. Reports and publications concerning these areas, from the following geologists, are used without separate references in the text: T. v. AUTENBOER, D. G. GEE, T. GJELSVIK, A. HJELLE, Y. OHTA and E. TVETEN. The approximate areas visited by the various geologists are indicated in Fig. 1.

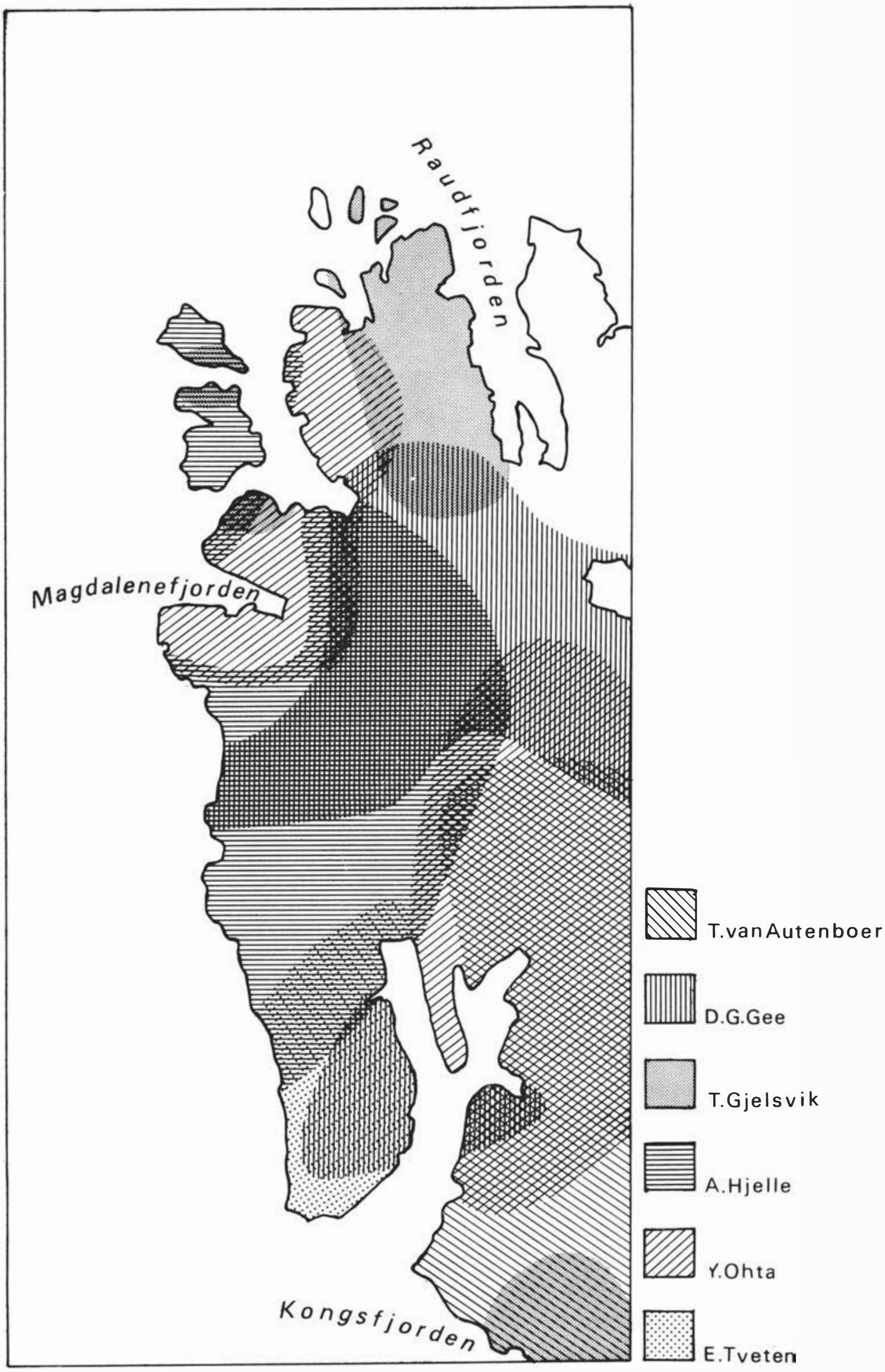

Fig. 1. *Areas visited by various geologists of Norsk Polarinstitutt expeditions 1963–75.*

GEOLOGICAL SETTING

The described area is situated north of Kongsfjorden, in the Caledonian orogenic zone of northwest Spitsbergen. Fig. 2. The areas adjacent to Kongsfjorden are largely made up of metasediments, whereas various gneisses, migmatites, and granites prevail in the central and northern parts.

The southern area (east and west of Krossfjorden-Möllerfjorden).

Except for a zone of migmatite and grey granite in the easternmost part, marbles and a monotonous sequence of pelitic rocks with subordinate quartzite and psammite make up most of the area. The calcareous rocks are overlying the main pelitic sequence both east and west of Krossfjorden. Primary sedimentary structures indicate a general lack of inversion.

The western transition area (between Førstebreen and Sjettebreen).

Though the rocks here have much of the character of metasediments as in the southern area, they are generally more gneissic, and to the north and east they grade into migmatites and syntectonic weakly foliated granite rocks.

The eastern transition area (west of the northern part of Monacobreen).

Conditions are much the same as in the western transition area, except that mobility and granitisation increase towards the west. The metasediments are separated from the Downtonian beds in the east by more or less continuous faults along Monacobreen and Isachensfonna.

The central and northern gneiss and migmatite area (mainly north of Sjettebreen to Louetbreen).

The bulk of the rocks are various gneisses, and migmatites with pelitic and psammitic restites, and with minor scattered marble bands. Grey granitic rocks occur widely, as dykes or more or less dome shaped bodies. As a last plutonic event the Horneman granite was intruded in the central part of the area. This red granite appears to have affected the regional structures considerably, however, in small scale it cuts the surrounding rocks discordantly.

Stratigraphy

In the central and northern gneiss and migmatite areas plastic deformation and differential melting have modified the supracrustal rocks to such an extent that it is impossible to establish all but scattered local stratigraphic sections. The best preserved beds occur in the metasedimentary areas of Kongsfjorden and Krossfjorden.

The absence of (macro-) fossiliferous strata and of rocks which are typical in Vendian or upper Riphean beds in Spitsbergen as tilloid rocks, oolithic rocks or black sulphurous limestone, suggests the beds in Kongsfjorden and Krossfjorden to be pre upper Riphean, or, in the terms established for Ny Friesland and Olav V Land, pre Akademikerbreen Group (HARLAND et al. 1966).

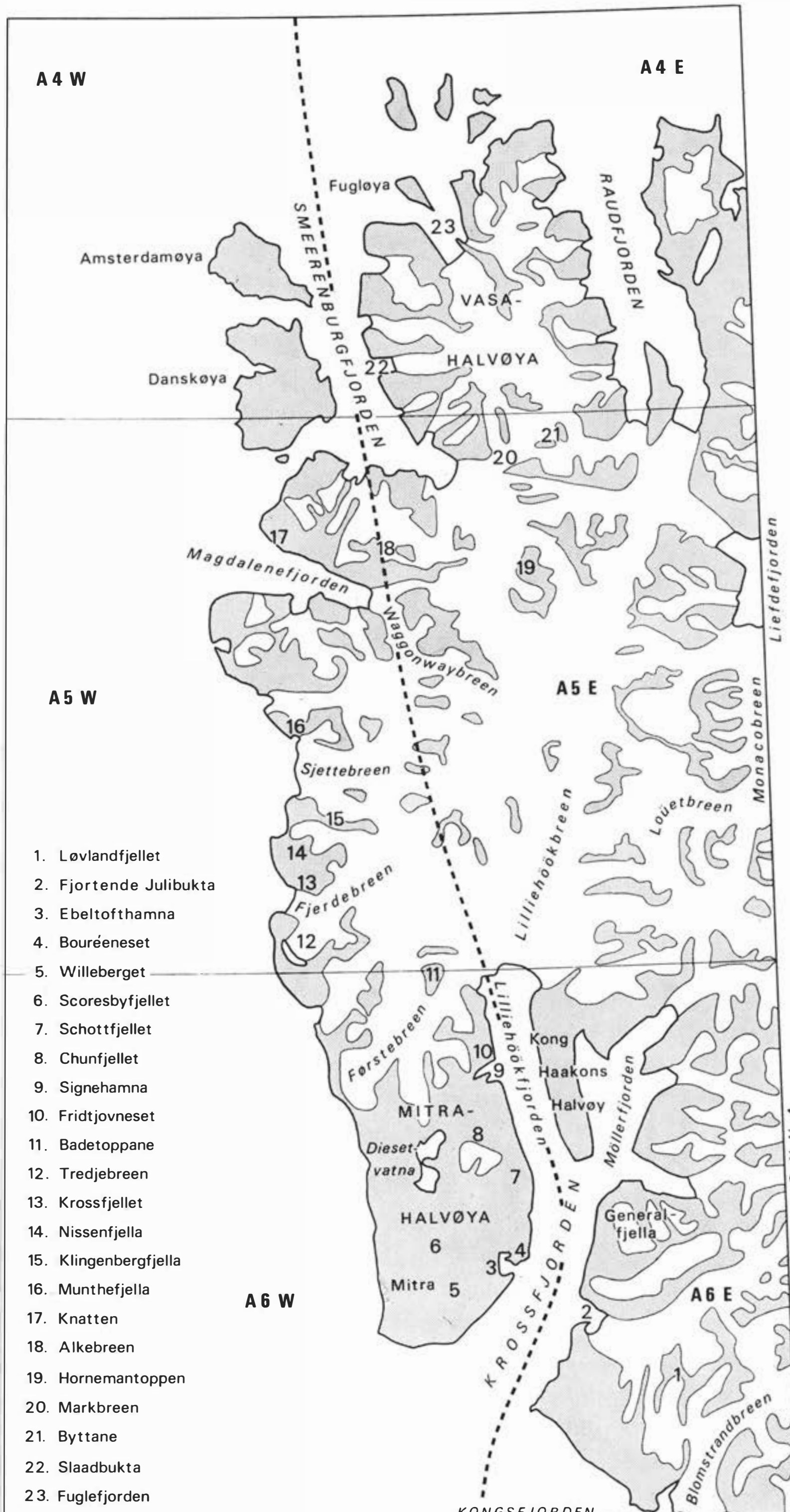

Fig. 2. *Location map for names used in the paper. The map also shows the division used in Fig. 7.*

In Ny Friesland several of the formations below the Akademikerbreen Group contain calcareous beds which might be possible correlatives to the calcareous beds described below:

Kingbreen Formation	Veteranen Group
Kortbreen Formation	
Lower part of Vildadalen Formation	Planetfjella Group
Rittervatnet Formation	Harkerbreen Group
Upper part of Smutsbreen Formation	Finnlandveggen Group

Considering the lithology and thickness of the beds north of Kongsfjorden, the author prefers to correlate the calcareous rocks to the lower part of the Vildadalen Formation and the various pelitic, psammitic and gneissic rocks below to the Flåen and Sørbreen formations below the Vildadalen formation. Variations in thickness and sedimentary facies due to different primary positions of Ny Friesland and the west coast area in a main geosyncline, or due to relative north-south movements would introduce considerable uncertainties in the correlation.

In the beds around Krossfjorden, the metamorphic grade generally decreases upwards and southwards and the lowest grade lithologies broadly coincide with the highest stratigraphic levels exposed.

The youngest beds occur east of Krossfjorden (the Generalfjella Formation, Gee and Hjelle 1966) (Fig. 3):

>400 m of light grey or buff marbles intercalated with subordinate phyllite
C. 1300 m of phyllite with subordinate marble and quartzite
C. 800 m interbanded marble, phyllite and quartzite

In the northern slope of Generalfjella, c. 3 km northwest of the main (855 m) peak, a section is obtained from the upper part of the Generalfjella Formation:

>150 m banded marble
60 m yellow, banded marble
30 m blue marble
12 m yellow weathering marble
2 m phyllite
7 m blue marbe
40 m silver grey phyllite
30 m marble, weathering blue in upper part, yellow in lower part
40 m silver grey phyllite, weathering dark red brown
25 m marble with thin quartzite bands at base
60 m silver grey phyllite, weathering dark red brown
10 m red stained quartzite
20 m dark grey quartzite
10 m (+ ?) silver grey phyllite
? m psammitic quartzite with subordinate phyllite

Further east, just north northwest of the 855 m peak another section is measured, which apparently belongs to a lower part of the Generalfjella than the section above (a fault with downthrow to the west divides the two sections):

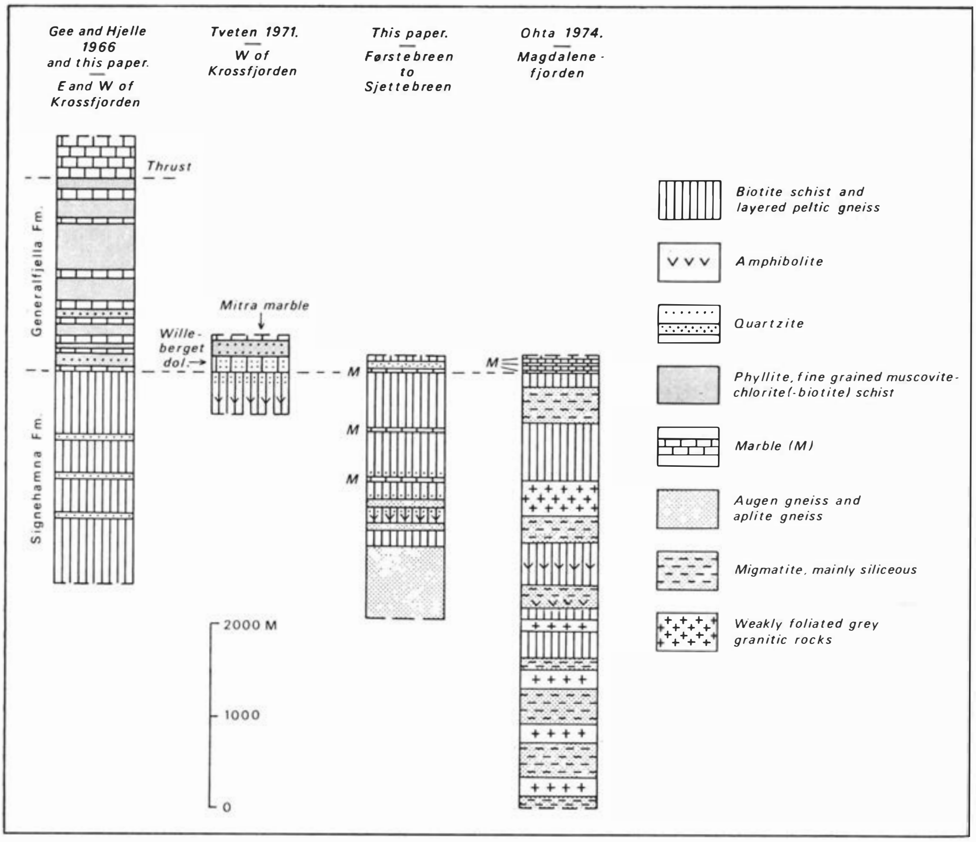

Fig. 3. *Local stratigraphical correlation, northwest Spitsbergen.*

? m thinly interbanded blue grey and white phyllite and quartzite
20 m phyllite
30 m psammitic phyllite
15 m buff marble
2 m blue marble
15 m buff marble
3 m silver grey phyllite and green sandstone
0.5 m brown sandstone
3 m purple grey phyllite
3 m black quartzite
3 m white quartzite and green phyllite, finely interbanded
1.5 m conglomerate and grey quartzite in the upper part, green and red purple phyllite in the lower part
7 m grey and white quartzite
3 m grey psammitic phyllite
0.5 m grey quartzite
5 m phyllite, purple red at top, green at base
3 m quartzite
c. 15 m black quartzite and phyllite (in scree)
c. 130 m silver grey phyllite with quartzite lenses
10 m blue banded marble
3 m phyllite
5 m quartzite

2 m buff banded marble
4 m dark blue marble
0.5 m buff quartzite
4 m blue grey marble
1 m silver grey phyllite
3 m banded blue grey and buff marble
0.5 m quartzite
0.5 m silver grey phyllite
10 m blue grey banded marble

West of Krossfjorden apparently only the lower 400 m of the formation occurs:

50 m of calcite marble (= Mitra Marble, TVETEN 1971)
C. 230 m of mica schist and phyllite, with some quartzite. Chloritoid occurs in the uppermost part and some minor inpersistent dolomite beds in the lower part.
C. 150 m of dolomite marble (= Willeberget Dolomite), with c. 1 m of quartzite in the middle part.
Max. 3 m of local basal conglomerate beds, recorded at two places in the southern part of Mitrahalvøya. The conglomerate consists of 7 or 8 beds, each 30–50 cm, of poorly sorted quartzite pebbles, 1–25 cm^2 in section.

Below this conglomerate, calcareous beds are fewer, and mica schist becomes predominant:

GEE and HJELLE 1966, this paper (Signehamna Formation)
2000–2500 m of pelitic and psammitic schist with subordinate quartzites and a few minor marble horizons. Small concordant lenses of amphibolite is recorded from two places.
TVETEN 1971
700 m of mica schist, with subordinate quartzite and minor amphibolite. Chloritoid occurs locally in the uppermost part.

Several occurrences of sedimentary structures, as quartzite to pelite transitions and current/ripple bedding, suggest that the beds around Krossfjorden in general are not inverted. Three observations, c. 2 km apart, in southern Mitrahalvøya, indicate a direction of transport from east to west. In the northern part of Mitrahalvøya and at the eastern shores of Lilliehöökfjorden, the lower mainly pelitic rocks of the Signehamna Formation makes up most of the area. A wedge of mica schist also extends towards the NNW from the inner part of Blomstrandbreen. A c. 25 m marble+quartzite horizon which crops out at various places from Førstebreen to Fjerdebreen suggests the pelitic sequence to extend almost to Nissenfjella, although the pelitic rocks are more gneissose in the northern part. Calcareous lithologies are very scarce in the inland area between Magdalenefjorden and Førstebreen.

Approaching the areas north and east of Sjettebreen, the general structure becomes more complex and the lithologies give evidence of a much greater mobility during deformation. Permeation of quartz-feldspathic material as schlieren or dyke and sheets increases towards the migmatites, and an estimation of the thickness of the Nissenfjella Formation (below Signehamna For-

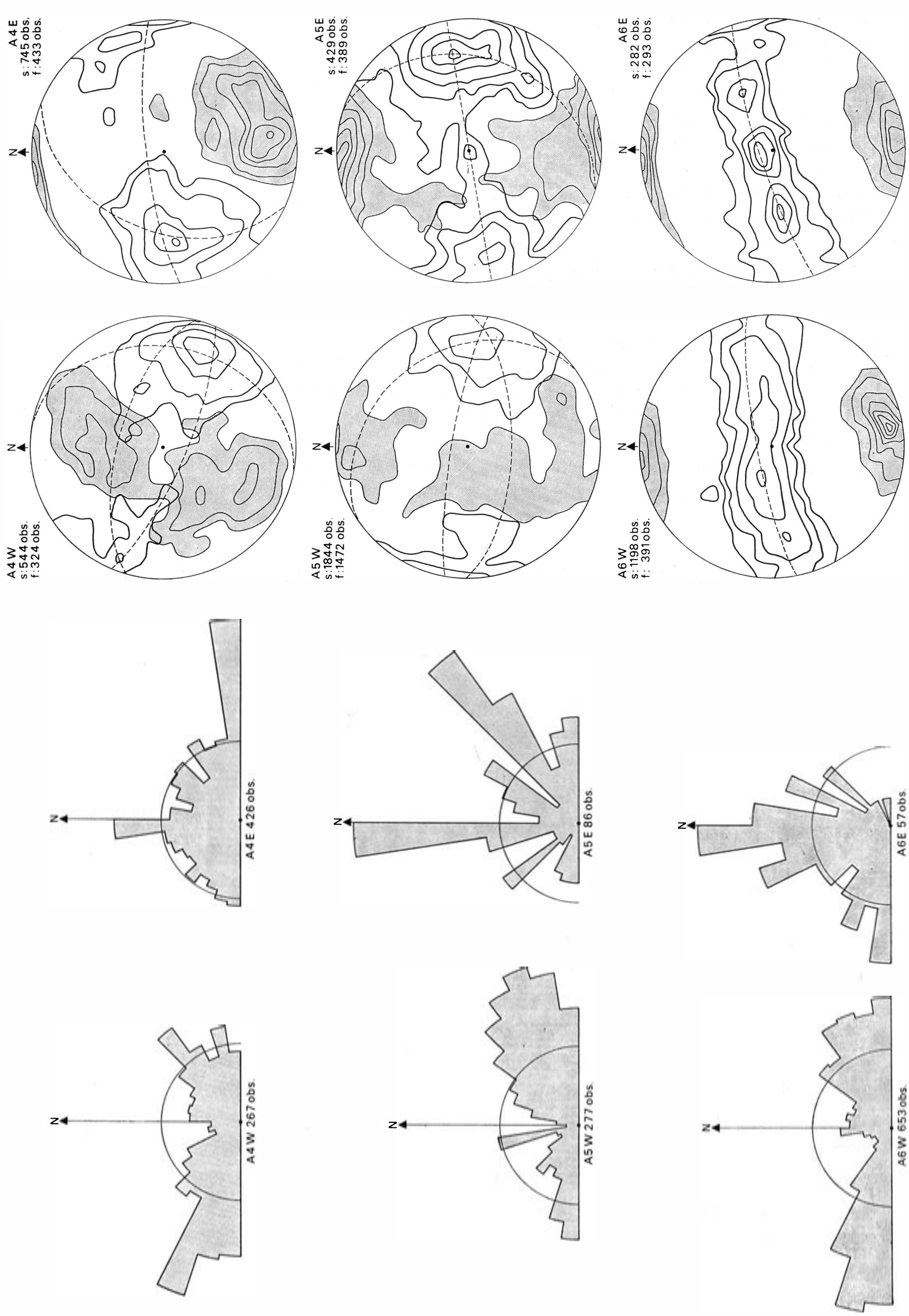
A4E
s: 745 obs.
f: 433 obs.
A5E
s: 429 obs.
f: 389 obs.
A6E
s: 282 obs.
f: 293 obs.
A4W
s: 544 obs.
f: 324 obs.
A5W
s: 1844 obs.
f: 1472 obs.
A6W
s: 1198 obs.
f: 391 obs.
N
A4E 426 obs.
A5E 86 obs.
A6E 57 obs.
A4W 267 obs.
A5W 277 obs.
A6W 653 obs.

Fig. 4.

mation, GEE and HJELLE 1966) is doubtful. However, with an average plunge of mesoscopic fold axes of c. 12^g (Fig. 4), at least some of the rocks at the south side of Sjettebreen could represent stratigraphic levels c. 2000 m below the Signehamna Formation. The rocks include pelitic schists, amphibolites and various feldspathic lithologies. Amphibolites are most conspicuous in the western parts of Nissenfjella and Klingenbergfjella. The feldspathic rocks are mainly concordant, foliated aplites, and soda feldspar augen-gneisses transitional to mica schist.

North of Sjettebreen the south plunge of folds alternates with north plunge, and areas occur with apparently younger beds as the calcareous and pelitic beds in outer Magdalenefjorden, in parts of Danskøya and Amsterdamøya, and in western Vasahalvøya. These beds are tentatively correlated with the lower part of the Generalfjella Formation and the upper part of the Signehamna Formation.

In outer Magdalenefjorden distinct layers of marble occur in Knatten, at the northern entrance of the fjord:

100 m layered gneiss
10 m consisting of 3 marble layers in layered and fine grained biotite gneiss
80 m siliceous layered gneiss
100 m pelitic layered gneiss
50 m siliceous migmatite
several m unexposed
several m of layered gneiss with one marble layer

In the western part of Vasahalvøya the estimated thickness of the metasediments is about 5200 m, presuming there is no repetition by folding or thrusting.

In the area north of the innermost part of Kongsfjorden, a marble occurs, which in its southern part is in fault contact with mica schist, and in the north wedge out in grey granite and migmatite. Occurring as an isolated body in the migmatite, this marble is thought to belong to the lower part of the Generalfjella Formation. North of the marble a persistent zone of marble relics continues northwards in the migmatite as far as to the north coast. That all these marbles represent associated sediments of about the same horizon is testified to by their continuity on a regional scale parallel to the regional strike of the non-migmatitic metasediments. If a $5–10^g$ south plunge of the mesoscopic fold axes in this area (Fig. 4) also is representative of the regional folding, successively lower beds should be expected northwards. The persistency of the north-south trending zone of marble relics could be explained as being parts of a regional synclinorium of considerable amplitude, probably more than 5000 m.

←

Fig. 4. *Right: Mesoscopic fold axes and associated lineations (shaded, f) and bedding, layering and gneissosity (thick lines, s). Mainly bedding in the south (map sheet A6), mainly layering and gneissosity in the north (A4 and A5). Stereographic projection, lower hemisphere. Contours for 1, 2, 4, 6, 8, 10% per 1% area.*

Left: Directions of vertical or almost vertical joints ($\geqq 70^g$) Demicircle indicates 5% of total counts. For location of the areas see Fig. 2.

The mica schist and associated quartzites close to the head of Liefdefjorden underlie marble beds, which are in fault contact to the Downtonian beds in the east. The lithology of the schist-quartzite-marble unit, and the mutual stratigraphic relations, suggest a correlation with the upper part of the Signehamna Formation and the lowermost part of the Generalfjella Formation.

Thus rocks of possible similar stratigraphical position occur both along the west coast and in the eastern inland area as moderately deformed metasediments, as gneisses, or as more or less digested relics in migmatitic rocks. It is therefore likely that in northwest Spitsbergen differences in metamorphism or in degree of deformation do not necessarily establish relative age.

In general pelitic schists are the far most common sedimentary relics in the gneiss migmatite areas, and it is suggested that the bulk of the relics originated from the Signehamna and Nissenfjella Formations, and that calcareous rocks from the lower part of the Generalfjella Formation were preserved only in synclinorium areas.

Petrography

METASEDIMENTS

Calcareous rocks.

The main upper marble in the Generalfjella Formation continues south of the present map area to Blomstrandhalvøya. The calcareous rocks here are mostly rather inhomogeneous and the grain size varies from less than 0.1 mm to 10 mm, occasionally veins occur with large calcite crystals up to 10 cm (SIGGERUD 1963). The fine grained varieties often show signs of being on the point of recrystallization, i.e. larger crystals starting to grow in the fine grained groundmass. Extensive brecciation has taken place with subsequent calcite cementation. Some quartz can be found as layers of well rounded grains 0.1–0.3 mm.

In Generalfjella the marble units are rather homogeneous in texture, but the weathering colour varies considerably from light grey and yellow through buff to greyish blue and dark blue.

West of Krossfjorden the Willeberget Dolomite probably represents the lowermost part of the Generalfjella Formation. This dolomite generally possesses an even grained polygonal texture 0.06–0.1 mm, indicating a complete recrystallization. Occasionally quartz rich layers occur of a maximum thickness of 2 cm. The most completely recrystallized parts of the dolomite almost invariably contain small amounts of evenly distributed muscovite, and some 0.5 cm clusters containing quartz, minor actinolite and feldspar, and occasionally minor enstatite. The upper part of the dolomite which is flexure folded and imbricated, is of grey colour with accessoric magnetite, whereas the lower part, which often shows plastic deformation, is mainly of yellow or reddish colour, and contains accessoric hematite and pyrite.

The apparently uppermost lithologic unit west of Krossfjorden is the Mitra Marble which crops out in the southwestern Mitrahalvøya, and which constitutes the mountain Mitra. This calcite marble is of light grey colour, and often contains reddish calcite veins. The texture is generally somewhat deformed polygonal, with grain size 0.1–0.3 mm. Occasionally breccias accompany overturned folds of c. 20 m wavelength, the breccia fragments being up to 20 cm across, with white or reddish matrix. A weak foliation occurs in the marble due to a minor content of carbonaceous matter between the calcite grains. Up to c. 5 vol. % of recrystallized quartz is present.

In the gneiss and migmatite areas the calcareous beds are frequently split into numerous layers, pods, and lenticles which are very variable in thickness and persistence downstrike. The layers are commonly boudinaged and less than 10 × 100 m in outcrop. In the migmatites the calcareous inclusions are the most angular and show the greatest tendency to retain an orientation parallel to the original compositional banding. A banded nature of many of the marbles, with intercalated quartz rich horizons and pelitic schists, suggests that these rocks were primary limestones with sandy or silty, and pelitic beds. The siliceous layers are commonly accompanied by layers rich in diopside, wollastonite, vesuvianite and grossularite. Other common skarn minerals are scapolite, sphene and hematite. Some marbles have small graphite flakes among the calcite grains.

Some boudinaged layers of marble in mica schist and layered gneiss are recorded to continue into areas of highly mobilized rocks as migmatite and syntectonic granite where they wedge out, leaving pockets, layers or vague zones enriched in skarn minerals. From a small island southeast of Fugløya and from the western entrance of Fuglefjorden, a skarn paragenesis of forsterite, phlogopite, and spinel is recorded accompanying marbles in granitic migmatite.

East of the innermost part of Magdalenefjorden, in the migmatite area along Miethebreen, a shear zone occurs with skarn lenses associated with a pink aplite, which possibly is related to the red post-tectonic Hornemantoppen granite further east.

In the migmatite areas agmatitic or lensoid amphibolites may be followed for several kilometres, e.g. in the Magdalenefjorden–Danskøya area and in western Vasahalvøya. Frequently the amphibolites here are found in the vicinity of marble bands and migmatite may give evidence of amphibolitisation of marble.

Phyllite.

The occurrence of phyllite is mainly confined to the Generalfjella Formation in the southern area. The phyllite rocks are fine to medium grained with a greenish or greenish grey or silvery grey colour, and with a lustrous, sheeny look. The relatively low grade appearance of these rocks in outcrop is confirmed by microscopic examination; the main constituents are quartz, sericite, chlorite, and in the lower part of the formation occasional minor biotite. With increasing amount of quartz the phyllite grade into psammite and quartzite.

In Mitrahalvøya parallel oriented crystals of chloritoid are recorded in an intensely folded quartz-muscovite-chlorite phyllite which is thought to belong to the lower part of the Generalfjella Formation. The chloritoid occurs in the vicinity of thrust or fault zones, and the amount varies from 3 to 30 vol.%

Optical data from one thin section: α 1.714–1.720, β c. 1.72, γ 1.73; pleochroism α yellow green, β and γ pale blue green; mainly optical positive. Hematite occurs in small quantities in the phyllite.

Mica schist.

From the upper part of the Signehamna Formation and downwards biotite-muscovite schist gradually becomes more common and garnet begins to appear. Most of the rocks in the middle and lower part of this formation are schistose muscovite-biotite-quartz assemblages with small amounts of chlorite and plagioclase, and are usually garnetiferous. The original compositional banding and a weak graded bedding structure is sometimes preserved in the more psammitic schists.

In Mitrahalvøya the most common type of schist contains 50–70 vol.% mica with variable proportions of muscovite and biotite. Muscovite, which is the major platy mineral, is examined in 10 specimens. $2V_x$ vary between 43 and 45°, and N γ from 1.594 to 1.600. The structure is always of the 2M type.

Biotite show some variation, the most common pleochroism is: α colourless β and γ red brown. The red colour is most pronounced in biotites from the northern part of Mitrahalvøya. N_α varies between 1.56 and 1.58, independent of geographical distribution. Two generations of biotite can be distinguished in some thin sections, the older one being somewhat chloritized.

The garnets in the Mitrahalvøya schists show no visual zoning, and there is little variation in the refractive index. Ten garnets from various schists sampled north of the garnet isograde show N = 1.797–1.808; in the same garnets the unit cell (a) varies from 11.588 to 11.595 Å, with a/N 6.41–6.45, average 6.43.

Feldspar always occurs in small amounts, especially south of the garnet isograde. Almost all feldspar recorded are acid plagioclases, two thirds of these show an An content lower than 15%. Only a few schists contain potassium feldspar, mainly as clastic grains in quartzitic schists, in three cases post-tectonic orthoclase crystals were seen as joint fillings.

In general the amount of newly formed feldspar increases towards the north, 9 vol.% is found in a mica schist c. 5 km NNW of Signehamna. In the same schist 1–3 cm crystals of andalusite accompanied by some sillimanite are found bordering a head size pocket of post-tectonic quartz.

Only few details are recorded from the schists at the eastern shore of Krossfjorden and from Kong Haakons Halvøy, however in lithology and general appearance they seem to closely resemble the schists of the Signehamna Formation.

Although the mica schists retain their NNW–SSE trend and their clearly metasedimentary appearance in the area between Mitrahalvøya and Sjettebreen (Fig. 5, upper part), the texture of the rocks is generally coarser, and segregation and recrystallization of felsic material commence. Interfingering with, and transition to feldspar porphyroblastic schists occur, the newly formed feldspar being most abundant in schists with impure quartzite and psammite bands.

GNEISS AND MIGMATITE

Layered gneiss

In composition and mesoscopic structure, the layered gneiss lies between mica schist with quartzitic beds, and migmatite. Sporadic lenses and pockets of igneous textured feldspar rich rocks, less than half a meter across, occur sometimes in the mica schist as forerunners to layered gneiss. Although the layered gneisses are characterized by a generally higher proportion of feldspar than the mica schist group, the main part of them are of pelitic composition (Table 1). Compared to the mica schist and its felsic bands, the grain size has increased in the layered gneiss and the difference in composition between the mafic and felsic bands is smaller. The development of plagioclase porphyroblasts, both in the light bands and, more scattered, in the pelitic bands, and the common occurrence of accessoric cordierite and sillimanite, are other characteristic features.

The layered gneiss has developed a distinct axial plane gneissosity, and most of the detailed primary compositonal banding is usually lost. However, some granitic layers are evidently feldspathized beds of primary impure quartzites, and alternations of layered gneiss and migmatite is considered to reflect the original lithological successions of sediments. The thickness of the individual layers within the gneiss varies from a few cm. to several metres, the thickest can be followed along the strike direction for more than one hundred metres. The felsic layers are commonly boudinaged.

Typical compositions of layered gneiss are (C. modal %):

Mafic layer: Quartz 30, K-feldspar 5, plagioclase 35 (An 20–30), biotite 25, garnet+cordierite+sillimanite 2.

Felsic layer: Quartz 35, K-feldspar 15, plagioclase 35 (An 10–20), Biotite 10.

Corundum is found locally in layered gneiss east of Waggonwaybreen, and corundum and spinel in some of the gneisses east of Smeerenburgfjorden. The plagioclase porphyroblasts apparently developed during the last stage of the formation of the layered gneiss. Both the biotite and the plagioclase porphyroblasts are arranged parallel to the plane of gneissosity. In the west coast area, between Førstebreen and Tredjebreen, transitions from mica schist with quartzitic beds to layered gneiss occur frequently. While the lithology of the various layers clearly depends on the primary composition of the mica schist beds, the degree of recrystallization and mobilization is related to both the intensity of deformation and the stratigraphical depth as well as to the primary composition. Depending on the initial lithology, various layers occur:

Dark biotite mica schist→dark pelitic gneiss with more or less scattered plagioclase porphyroblasts.

Pure quartzite→coarse glassy quartzite, mainly less than 10 cm thickness.

Feldspathic quartzite→coarse K-feldspar – quartz -albite gneiss with minor muscovite, sometimes of pegmatitic appearance and with weak foliation.

Table 1.

Modal and chemical analyses.

Modal and chemical analyses of northwest Spitsbergen rocks

	1	2	3	4	5	6	7	8	9	10
Quartz	36.7	28.7	36.2	26.0	33.8	26.5	22.9	0.9	34.0	32.8
K-feldspar	22.4	16.4	22.0	4.0	3.7	2.1	2.2	-	22.1	25.5
Plagioclase	33.4	43.9	31.9	33.8	34.1	54.3	54.6	28.5	31.0	27.9
Muscovite	-	-	4.7	-	0.8	-	1.4	-	4.1	2.5
Biotite	6.7	10.6	3.2	36.0	26.5	14.4	12.2	-	7.4	8.1
Chlorite	0.4	-	0.9	-	-	2.4	0.1	2.4	0.4	1.2
Amphibole	-	-	-	-	-	-	5.3	60.7	-	-
Epid.zois.	-	-	0.3	-	0.6	-	-	0.3	0.8	1.2
Apatite	-	-	-	-	-	-	0.2	-	tr.	0.3
Sphene	-	-	0.1	-	-	-	0.4	3.1	-	tr.
Ore mins.	0.5	0.3	0.5	0.3	0.4	0.3	0.7	4.2	0.2	0.4
Garnet	-	-	-	tr.	tr.	-	-	-	-	-
	100.1	99.9	99.8	100.1	99.9	100.0	100.0	100.1	100.0	99.9
%An in plag.	(15)	(15)	(21)	(35)	(15)	(20)	(30)	(50)	(33)	(30)

	1	2	3	4	5	6	7	8	9	10
SiO_2	70.70	69.15	70.80	67.70	65.15	63.60	64.71	56.70	69.99	69.93
TiO_2	0.22	0.47	0.18	0.73	1.20	1.15	0.59	2.48	0.40	0.38
Al_2O_3	17.00	16.32	16.24	14.44	15.32	16.97	16.18	11.87	15.24	15.31
Fe_2O_3	0.61	1.21	0.29	2.39	2.57	1.91	0.43	4.24	0.09	1.20
FeO	1.29	2.52	1.22	3.23	4.74	4.31	3.97	2.31	2.79	1.56
MgO	0.19	0.69	0.34	1.86	1.74	1.74	2.14	5.77	0.87	0.81
CaO	1.53	1.61	1.31	3.68	1.88	2.68	4.24	9.53	2.57	2.45
Na_2O	3.45	3.31	3.50	2.89	3.21	3.35	4.33	2.10	3.44	3.31
K_2O	4.20	4.68	4.03	2.05	2.48	3.00	2.85	1.60	3.49	3.90
H_2O	±0.36	±0.75	n.d.	±0.80	±1.58	±1.64	+0.74	±2.21	+0.79	+0.74
P_2O_5	0.05	0.12	0.06	0.11	0.07	0.08	0.07	0.30	0.08	0.05
	99.60	100.83	97.97	99.88	99.94	100.43	100.25	99.11	99.75	99.64

No.in Table	NP No.	°N	°E	Location	Type
1	66 YO 217	79°40.8'	11°24.5'	SW Vasahalvøya	Fine grained gneiss, felsic
2	66 YO 52-3	79°45.8'	11°17.4'	NW "	Layered gneiss, felsic
3	66 Hj 26 B	79°45.3'	10°40.8'	W Amsterdamøya	Migmatite, felsic part
4	66 YO 178-2	79°43.1'	11°12.7'	W Vasahalvøya	Fine grained gneiss, mafic
5	66 YO 449	79°41.3'	11°14.5'	" "	Layered gneiss, mafic
6	66 YO 394	79°43.6'	11°22.4'	" "	Migmatite, mafic part
7	66 Hj 82 A	79°43.1'	10°51.5'	N Danskøya	Amphibole bearing gn.
8	66 YO 284-2	79°45.1'	11°13.9'	NW Vasahalvøya	Amphibolite
9	64 Hj 230 A	79°38.9'	10°47.7'	SW Danskøya	Granitic dyke
10	64 G 118	79°39.0'	11°39.8'	S Vasahalvøya	Hornemantp. monzogranite

Nos. 1-6, and 8 analyst Y. Ohta
No. 7 analyst J. Røste, Norges geologiske undersøkelse
Nos. 9 and 10 analyst P.R. Graff, Norges geologiske undersøkelse

Pelitic feldspathic quartzite→homogeneous augengneisses of quartz diorite composition.

Some felsic layers are evidently mobilized, and granitic material penetrate. the surrounding layers concordantly parallel to the axial plane gneissosity. Occasionally dark micaceous lenses are entirely enclosed by granitic materials

Migmatite.

When the degree of feldspathization and mobilization increases in the layered gneiss, the granitic material begins to penetrate the layers and the axial planes of the small folds discordantly, and the layered gneiss grade into migmatites with ptygmatic granitic veins. As the mobility increases away from the layered gneiss, the migmatite metaster looses orientation related to earlier structures and the compositional banding becomes more diffuse.

The inclusions in the migmatite, on the basis of composition, fall into four groups — pelitic, psammitic, calcareous and amphibolitic. Pelitic masses are most typical in the migmatites and particularly in those not containing marbles. They are usually smaller than other coexisting masses and less angular.

Amphibolite masses (other than those of skarn association) are frequently found in migmatites in the vicinity of the marble bands e.g. in Danskøya. They give evidence of amphibolitization and induced foliation prior to migmatization. Hornfelsing of these masses is usual, with margins of c. 1 cm around the xenoliths. Pyroxene-bearing xenoliths are found on each side of the Horneman granite north of Markbreen.

The migmatite inclusions occur in different stages of assimilation, some rotated and some in parallel orientation with the country rock. Several observations of transitions from agmatitic to streaky and nebulitic migmatite, suggest a progressive assimilation process, beginning with formation of agmatitic migmatite by injection and ending with nebulitic migmatites and ghost granites.

The metaster often shows preservation of folds and a penetrative schistosity which clearly developed prior to the superimposition of hornfelsed margins during migmatisation. This suggests that the migmatisation occurred after the first main folding and regional metamorphism of the rocks.

The migmatites are rarely homogeneous over long distances, and discontinuous masses of mica schist, layered gneiss, amphibolite and marble occur as bodies, c. 10–200 m across within the migmatite. Persistent rocks as amphibolite and marble show least alteration, and they may be followed as broken up and boudinaged layers for several hundred metres.

There is much variation in the composition of the metatect, particularly adjacent to the metaster, however the bulk composition is that of a granite or granodiorite. Although locally massive, these rocks often posess a flow structure and are somewhat foliated concordant to the metaster throughout most of the area. Biotite is the dominant mafic constituent of the metatect, however when the migmatite has originated from gneisses with amphibolitic and/or calcareous layers hornblende frequently occurs together with biotite.

Typical compositions of migmatites are (C. modal %):

Metaster (pelitic type): Quartz 25, K-feldspar 5, plagioclase 45 (An 20–30) biotite 20, garnet, sillimanite, cordierite 2.

Metatect: Quartz 30, K-feldspar 17, plagioclase 40 (An 15–25), biotite 8.

AMPHIBOLITE

Concordant lenses and bands of amphibolite have been recorded at four places in Mitrahalvøya:

(1) C. 0.5 km west of nordre Diesetvatnet, as several lenses of c. 0.5 m thickness, extending c. 30 m north-south. The main minerals of the amphibolite are hornblende, quartz, biotite, chlorite, magnetite and apatite. Plagioclase (An 10–20) occurs as an accessoric mineral. The hornblende has $Z \wedge c = 18°$ and $2V = 74°$ with pleochroism: α brownish yellow, β and γ blue green. $N_y = 1.635$.

(2) C. 0.5 km north of Fridtjovneset, Signehamna. This amphibolite contains garnet; the hornblende closely resembles that in No. 1.

(3) In the coastal section north of Bouréeneset. Several small lenses of less than 0.3 m thickness.

(4) Below the marbles on the northwest side of Scoresbyfjellet. Only one small amphibolite lens was recorded.

Further north amphibolites are recorded both in supracrustal rocks and in gneisses and migmatites. Conspicious amphibolites occur in the western and central Nissenfjella, as lenses and boudins up to 5 m across. These bodies in general conform to the regional structure, and their planar structures are parallel to the lithologic layering and/or gneissic structure of the enclosing rocks, and like them they are locally folded. Foliation is highly developed in the thinner amphibolite layers, whereas in the central parts of some of the larger bodies it is indistinct and the rocks appear massive. Where the amphibolite shows little sign of shearing, garnet is stable; retrogression of both garnet and biotite is to be found in most outcrops.

Similar amphibolite and amphibolite interbanded with pelitic rocks are also contained in the core of the antiform in the eastern part of Hesteskoen, close to the head of Liefdefjorden.

The zone of amphibolite-bearing migmatites and gneisses extending N to NNW from the central Magdalenefjorden area is, as a whole, slightly oblique to the general NNE structural trend of the surrounding rocks, however it broadly coincides with the regional trend of the marbles and amphibole-bearing biotite gneisses in Danskøya and Amsterdamøya, which probably represent the trend of the strata of the pre-metamorphic rock sequence. This suggests that the amphibolites originated from rocks which primarily paralleled the supracrustal beds as volcanics or as sills, and that the NNE layering and foliation which is especially well developed in the pelitic rocks, to a great extent were produced by tectonic transposition and intercalation during intense deformation. The absence of primary structures in the amphibolite makes it difficult to decide whether the amphibolite were originally dykes or extrusive sheets.

GRANITIC ROCKS

Weakly foliated grey granitic rocks

Nearly all of these rocks are closely associated with the migmatites. The contact against the surrounding rocks are mainly gradual, although there are some cross-cutting contacts. In Danskøya, vaguely defined dome structures are observed with central bodies of massive or weakly foliated granitic rocks containing small and scattered shadowy metaster. The granitic rocks grade outwards into migmatite and layered biotite gneiss. This evidence shows that these granitic rocks could be considered as "mature" migmatites with a high metatect/metaster ratio.

Several granite bodies of considerable size occur within or adjacent to the migmatite area:

(1) The granite east of Krossfjorden–Möllerfjorden. Fault contact occurs against the metasediments in the west, and transitional or intrusive contacts towards the eastern migmatite. The composition is mainly monzogranitic.

(2) The dyke-like granite extending northwestwards from Sjettebreen. This is a monzogranite of medium grained homogeneous texture, and with a faint foliation. Inclusions are rare except when approaching the migmatite in the north and east. Although migmatite varieties occur within this granite, its general appearance shows many similarities with a discordant dyke intrusion.

(3) The granitoid at the middle and inner part of Magdalenefjorden. With a relatively low content of potassium feldspar, this is rather a granodiorite with transitions to quartz diorite than a granite. The texture is medium grained homogeneous, and the main body occurs as a wedge-shaped intrusive layer sub-concordant with the surrounding gneisses, the eastern contact being relatively sharp. A faint, but consistent foliation also conforms with the structures outside.

(4) The plagioclase porphyroblastic granite east of Smeerenburgfjorden, extending southeastwards from Slaadbukta. This is a monzogranite with transitions to granodiorite, and the body fills the core of a synform structure in the metamorphic rock. In the northwest sharp drag contacts occur against the metamorphic rock, while in the east the granite has a sharp but intrusive contact to layered gneiss.

Below the general characteristics of the weakly foliated grey granitic rocks are summarized:

(a) All locations of these rocks are in or adjacent to the migmatite area.

(b) The lithology of the granites is about the same as in the migmatite metatects and the granitic layers in the layered gneiss.

(c) Structurally the granitic rocks conform to the flow structures and the open folding of the migmatites rather than to the older tight isoclinal folding of the gneisses.

(d) The contact to migmatite is mainly transitional, to the gneissic rocks often sharp, with signs of emplacement by liquid intrusion.

Thus, the observations suggest a late tectonic origin of the granites, closely connected in time to the development of the migmatites. The granites may be regarded as the mobilized and homogenized end products of the granitization of the regional metamorphic rocks.

Grey granitic dykes

The grey granitic dykes occur in two generations:

(1) When approaching the migmatite areas, e.g. just south of Sjettebreen, aplite and pegmatite sheets begin to appear in the metasediments. Their positions are mainly concordant, but some are also discordant to the foliation. These latter cut only the metasediments, and belong to the initial stage of agmatitic migmatites. However, dyke activity is recorded as far southwest as in Schottfjellet and Chunfjellet (west of Lilliehöökfjorden), where scattered light coloured intrusive sheets of 3–5 m thickness traverse the mica schist obliquely with a c. 40^g dip towards the ENE. The dykes are folded, and were emplaced before the main folding ceased in this area.

(2) The predominating dykes are those cutting both metasediments, grey late tectonic granites and the migmatites. They include aplitic and pegmatitic varieties and are almost wholly confined to the migmatite area. These rocks occur as sharp cut dykes, and only in rare cases are they transitional to larger masses of grey granite. The bulk of the dykes, therefore, was intruded after the consolidation of the migmatites.

The granitic dykes referred to below, all belong to group (2).

The composition of the aplitic dykes is rather homogeneous, monzogranitic to granodioritic, with a compositional range between that of the migmatite metatect and biotite gneiss, i.e. it approximates the bulk composition of a common migmatite (Table 1, No. 9). The aplitic dykes also show compositional similarities with the Hornemantoppen monzogranite.

The pegmatite veins and dykes are usually more felsic than the aplitic ones, and when the two types occur together, the pegmatites are commonly the younger.

In Danskøya and Amsterdamøya a comparison between the directions of dykes and joints, showed a close similarity, indicating a preferred direction of intrusion parallel to the jointing. Of the pegmatite dykes in this area only c. 10% exceeded 1/2 m in width, compared to c. 65% of the aplitic dykes.

Regarding the granitic dykes in northwest Spitsbergen as a whole, there appear to be two main maxima of directions: c. 90^g and c. 150^g, i.e. close to the directions of cross joints which could be expected in the mainly N or NNE trending zone of gneiss and migmatite.

Post-tectonic red granite.

The Hornemantoppen granite forms an outcrop pattern, elongated NNW, within the migmatite area. The granite is centered on Hornemantoppen, and the ridges and nunataks cover an area of more than 150 km², including ice cover. Within this area are found a variety of granites, the far most conspicious of which is a coarse to medium grained red granite.

Except for minor border facies rocks the pluton is a nonfoliated mass of monzogranite composition, and the rocks contrast markedly with the adjacent metamorphic rocks into which they are intruded. The texture is hypidiomorph equigranular, sometimes with transitions into more porphyritic varieties. Potash and plagioclase feldspars occur in about equal proportions, potassium feldspar as large grains up to 2 cm across, plagioclase somewhat smaller. The remainder is mostly made up of aggregates of quartz grains and more or less evenly distributed biotite, which is the dominant ferrogmagnesian mineral in all examined specimens. In five specimens of the most common variety, the modal range was: Quartz 29.7–34.7%, potassium feldspar 24.6–26.3%, plagioclase (oligoclase-andesine) 21.7–30.0%, biotite 4.1–8.1%, and chlorite 0.7–2.6%. The plagioclase grains are often strongly decomposed to sericite and zoisite. When fresh, the plagioclase often shows grading from andesine cores to sodic oligoclase rims, with strong oscillatory zones. Considering the volume, an average plagioclase composition of An 25–35 is common. Fine grained, late crystallized potassium feldspar and quartz fill interstices between other minerals.

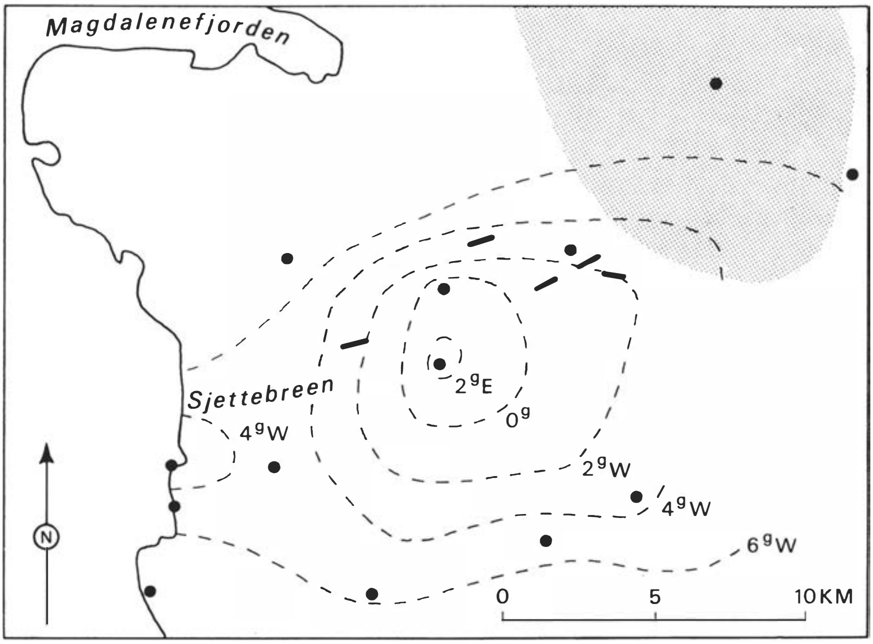

Fig. 5. *Magnetic declination west of Sjettebreen. (Difference in mirror compass bearings and directions, measured on 1: 100 000 map, Magdalenefjorden, Norsk Polarinstitutt 1969). Dots: observations. Thick lines: basic post-tectonic dykes. Shaded: post-tectonic granite.*

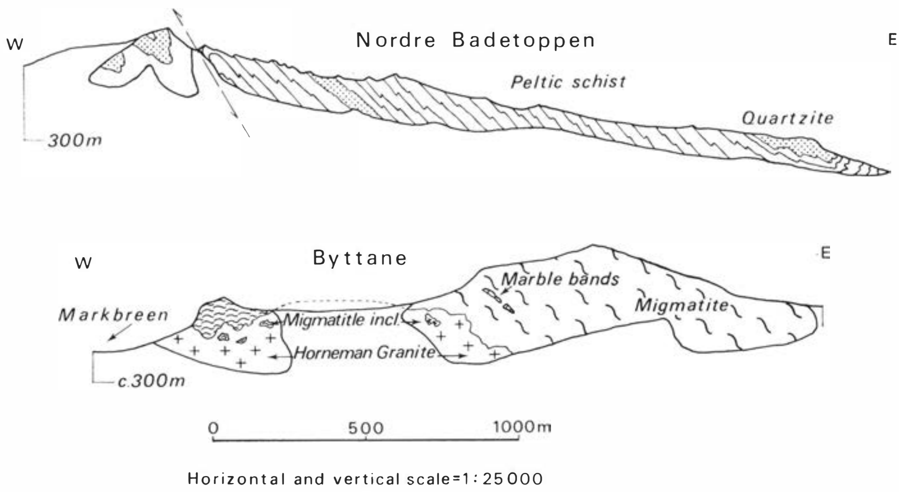

Fig. 6. *Typical outcrops, in the mica schist area (upper) and at the northern part of the Hornemantoppen granite (lower).*

Common accessoric minerals are sphene, apatite, pyrite and magnetite. The magnetite content is generally slightly higher than in the surrounding metamorphic rocks, and a magnetic anomaly in central Albert I Land, with amplitude c. 200 γ might be related to this higher magnetite content (ÅM 1975). Magnetic declination measurements made by the author in 1975 show anomalies east of Sjettebreen (Fig. 5). In this area, several post-tectonic basic dykes are recorded, and it is considered possible that the anomaly arises from basic differentiation products from which the dykes might have originated, and which is related to the Hornemantoppen granite intrusion. The basic dykes are nowhere seen to cut the granite.

Away from the contact area, the granite contains a very subordinated amount of xenoliths, typically rounded and smaller than $\frac{1}{2}$ m in diameter. Closely associated with the granite are pink or red aplites and pegmatites which are recorded from several contact areas. The latter are typically quartz potassium feldspar intergrowths with muscovite and occasional pyrite. The aplites contain up to 10% biotite. Pink aplitic veins and dykes, up to 3 m thick, occur also further west, in the east side of Alkebreen. The dykes, which seem to be closely connected with the emplacement of the granite are associated with skarn masses.

The Hornemantoppen granite is eroded to a depth of more than 700 m to form a rugged topography. The depth of erosion indicates that the granite is probably not a laccolith or sill-like mass. The foliations marginal to the granite, which generally dips away from the contact, seem to confirm the suggestion of a batholitic intrusion.

The main part of the granite is intruded only into migmatitic lithologies, and occurs as a north-south elongated core in the migmatite domain. In all examined localities the granite contacts were unsheared and intrusive, the granite prominently cutting the foliation in the migmatite rocks. Hornfelsing in the contact rocks has not been observed, however it should not be expected either, considering the near magmatic conditions during migmatisation.

In the northern part of the granite, north of Markbreen, where the roof zone is well exposed (Fig. 6, lower part), large xenoliths and large projecting masses of horizontally foliated migmatite gneiss from the overlying country rock are immersed in granite, and apparently the surface of erosion here corresponds closely with the roof of the batholith.

As the Hornemantoppen granite injected after the main metamorphism and deformation, it could (1) have been emplaced into a pre-existing major antiform or (2) have arched the metamorphic rocks into an antiform, which was possibly initiated already during the formation of the migmatite. The homogenity of the granite and the relative lack of xenoliths seem to favour the latter. So do also the fact that the migmatite — metasediment contact southwest of the granite roughly parallels the granite contact rather than the general north-south structures in this area. Bowing aside of the country rock is also suggested by occasional anomal north plunges of fold axes north of the granite, and a general increase in the dip of the migmatites as the contact with the granite is approached from the west.

Structure

In general the structure is dominated by the main northwest anticlinorium of NNW–SSE trend. This main open structure is apparently superimposed on most other structures, and therefore considered to be of relatively late origin, and related to migmatite upwelling and the emplacement of the Hornemantoppen granite.

The simplest structures appear in the areas of relatively well preserved metasedimentary rocks, particularly those east and west of Krossfjorden, Lilliehöökfjorden and Möllerfjorden. Three main phases of deformation are distinguished here: F0 early, weak folding of north-south trend, with a corresponding schistosity, S0 parallel to the original compositional banding of the metasediments. S0 is folded by small isoclinal folds, F1, which themselves are refolded by ubiquitous minor isoclinal folds, F2, with a common wavelength and amplitude of c. 1 dm to c. 5 m. In suitable lithologies, as pelitic rocks, this folding causes development of a pronounced axial plane schistosity, S2. These minor folds are closely related to large open synforms and antiforms with wavelengths up to a few kilometres, and with axial trend paralleling those of the smaller folds.

In general the F1 and F2 folds and corresponding lineations are homoaxial, with a shallow S to SSE plunge (Fig. 4), but local plunge culminations occur in the Krossfjorden area, around Ebeltofthamna and Fjortende Julibukta, which might indicate a later, F3 deformation of possible NW–SE trend. The relatively simple pattern of homoaxial F1 and F2 folds are more or less persistent throughout the areas of metasediments, in the coastal area northwards to Sjettebreen, in the east as far north as to Liefdefjorden.

With increasing mobilization the patterns become more complex:

(1) Layered gneiss forms in close connection with development of the F2 axial plane schistosity and gneissosity of tight minor isoclinal folds with subhorizontal axes. The F2 trend is, at least northwards from Sjettebreen, around NNE–SSW. As in the southwest, the F2 folds are here both of large open and minor tight type. A well exposed large open F2 synform appears in Knatten, at the northern entrance to Magdalenefjorden. In the western Nissenfjella a comparison of limb lengths indicates that the minor F2 folds are related to a major antiform closing up westwards.
The F1 and F2 folds are largely confined to the metasediments and their corresponding inclusions in the migmatites, however, adjacent to prominent masses of inclusions, also the mobile phase of the migmatite may show a foliation paralleling the lithological banding and/or the S2 of the metasedimentary inclusions.

(2) Migmatite and late tectonic granitic rocks develop in connection with a late, open folding, trending NW–SE to W–E with relatively steep plunges of axes, which deforms the S2 schistosities and gneissosities. Whereas the granitic layers in the layered gneiss preferably develop as concordant seams at the crests of small F2 folds, the migmatites and late tectonic granitic rocks are frequently contained in the cores of F3 open antiforms and dome-like structures. A foliation or plastic flow structure may exist in these rocks, independent of the structure of the xenoliths and therefore clearly induced during and after the F2 folding, which is preserved in the xenoliths. Thus the migmatization occurred after the F2 folding of the metasediments.

Most of the fault lines have a NNW–SSE trend, less pronounced are directions around WNW–ESE and WSW–ENE. A major fault with downthrow to the east occurs along Monacobreen and the eastern shore of Raudfjorden, separating the metamorphic rocks from the eastern lower Devonian beds. Further south small occurrences of lower Devonian rocks have also been found at Lovénøyane (GJELSVIK 1974), and in Løvlandfjellet, north of Blomstrandbreen, in all localities preserved due to faults of NNW trend. Devonian strata are not found west of Krossfjorden-Lilliehöökfjorden, however, a red weathered soil which occurs in the upper part of Mitra may suggest a pre-Devonian erosional surface here.

The majority of the faults on the north side of Kongsfjorden are not directly related to the local folding, but parallel the main anticlinorium axis, with a general downthrow to the west, suggesting a relationship to this regional structure. In the Generalfjella synform the upper marble beds are in tectonic contact with pelites of lower stratigraphic position, the thrust plane having a 30^{g} easterly dip near Krossfjorden.

West of Krossfjorden, Lilliehöökbreen, and the Hornemantoppen granite, thrust faults with easterly dip prevail, which are themselves often horizontally

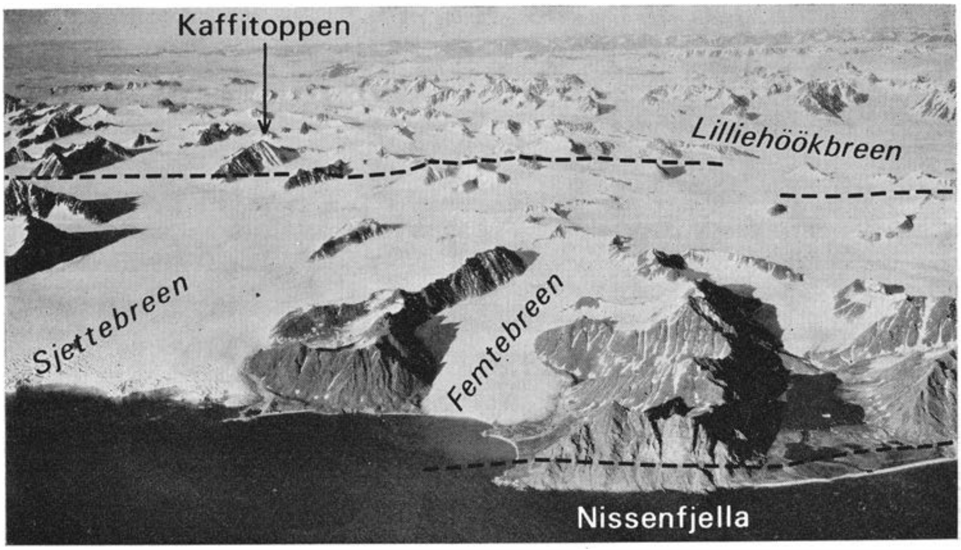

Fig. 7. *From the coastal area south of Sjettebreen, looking towards the ENE. Major thrust lines are indicated.*

displaced by faults of SW to NW trend. These have often also caused dislocations of the granite and the post lower Devonian faults.

From Lilliehöökbreen to Smeerenburgfjorden an important reverse fault zone passes NNW–SSE through the migmatites (Fig. 7). It contains mylonitic as well as brecciated material. The occurrence of skarn masses and pink aplitic veins in this zone east of Magdalenefjorden, indicates a correlation to the emplacement of the postorogenic granite in the east.

In Mitrahalvøya many faults are apparently directly related to folding, mainly F2, and folds overturned to the west are often thrusted along the axial planes, both in mesoscopic and megascopic scale.

It is concluded that three main groups of faults may be distinguished in northwest Spitsbergen:

(1) Related to folding, mainly F2, early Palaeozoic? Mainly NNW strike.

(2a) Related to anticlinorium development, late Palaeozoic? Mainly NNW strike.

(2b) Related to the Hornemantoppen granite emplacement, late Silurian. Mainly NNW strike.

(3a) Occurred after the granite emplacement, post late Silurian, mainly strike NW to NE.

(3b) Post early Devonian (reactivated older faults), strikes around NNW.

In the western areas (A4W, A5W, and A6W) well defined maxima of joints have developed around W–E, with steep northerly dip of joint planes. The pronounced directions about normal to the F1 and F2 trends suggest cross joints, the general northerly dip of joint planes being due to the regional southerly plunge of the fold axes.

In the eastern areas (A4E, A5E, and A6E) the most distinct joint maxima occur around N to NNW This direction parallels the main anticlinorium and the main fault lines, including the post lower Devonian faults near Kongsfjorden. These longitudinal joints are considered to be tension joints developed along the main anticlinal structure.

The major longitudinal and oblique fault directions can easily be recognized in the geomorphology of northwest Spitsbergen; coastal lines, fjords, glaciers, and mountain ridges frequently run in the NNW, WSW or WNW directions.

Metamorphism, absolute ages

When approaching the axial part of the main anticlinorium, increasingly deeper tectonic sections are exposed. The regional southerly plunge of fold axes has a similar effect towards the north. The result is a relatively narrow belt of gneissic and granitic rocks in the southern extension of the anticlinorium, widening towards the north. In general the metamorphic grade appears to correlate with tectonic depth and the lowest grade rocks occur at the southwestern flanks of the anticlinorium, in the ctual area particularly in the synclines east and west of Krossfjorden. The metamorphic grade there increases from the chlorite zone in the beds above the upper marble unit to the garnet zone below the marble. The garnet crystallized here during the F1 deformation phase. This was later overprinted during and after the F2 formation under conditions stable to biotite and with decomposition of garnet. Chloritoid-bearing schists which occur locally in Mitrahalvøya in areas of thrusting and faulting, appear to be related to the immediate tectonic setting rather than being of regional metamorphic significance.

In the gneiss areas, cordierite-garnet-biotite paragenesis is common and sillimanite develops very often. Of the thin sections of gneiss and migmatite rocks examined from Danskøya and Amsterdamøya, about $\frac{1}{3}$ contain cordierite and sillimanite together, indicating a relatively low pressure amphibolite facies. Assuming $P_{H_2O} = 5$ Kb and a Ab/An ratio of 2.9, a value frequently met with in the biotite gneisses, the composition of a common migmatite mobilisate falls close to the cotectic line in the Ab-Or-Q diagram, suggesting that initial anatexis could have taken place at $P_{H_2O} = 5$ Kb and a temperature of 650–700°. Also the occurrence of wollastonite indicates that the metamorphism took place at a temperature where at least partial melting of pelitic and psammitic rocks would be expected.

In the Kennedybreen area, east of Smeerenburgfjorden, mesoperthite mantled with oligoclase were found in biotite gneiss containing diopside-wollastonite skarn. The perthite is supposed to be formed through replacement of sericitized calcic plagioclase by potash feldspar in the upper amphibolite facies, under extremely wet conditions.

Kyanite is only found in two rocks from Danskøya; the mineral shows inversion to muscovite from grain margins, and may indicate local pockets of high pressure or small relics of older deepseated (Archean?) basement rocks. Special parageneses are corundum-spinel-cordierite-biotite in clots in

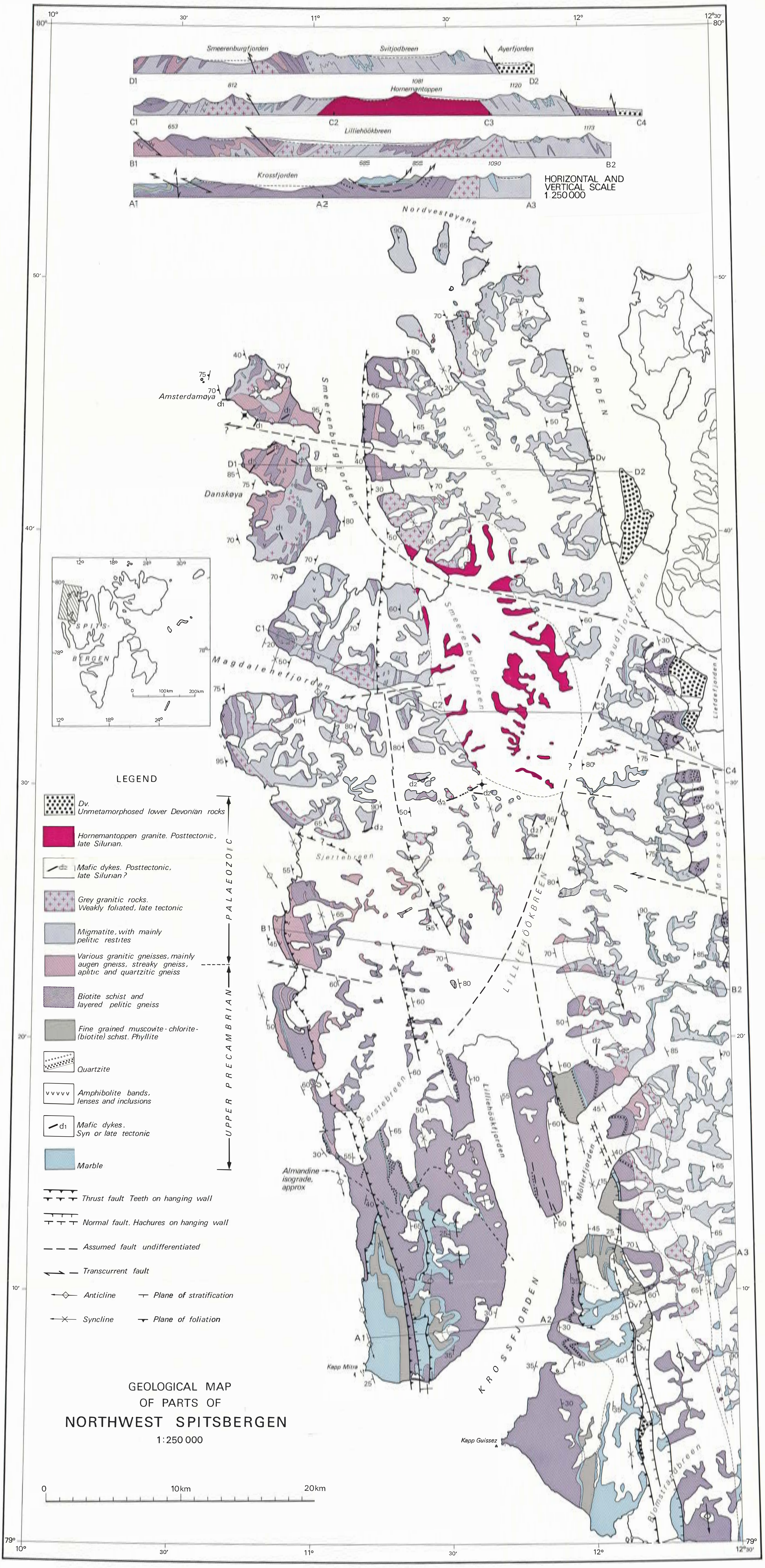

Fig. 9. *Geological map of northwest Spitsbergen. Scale 1 : 250 000.*

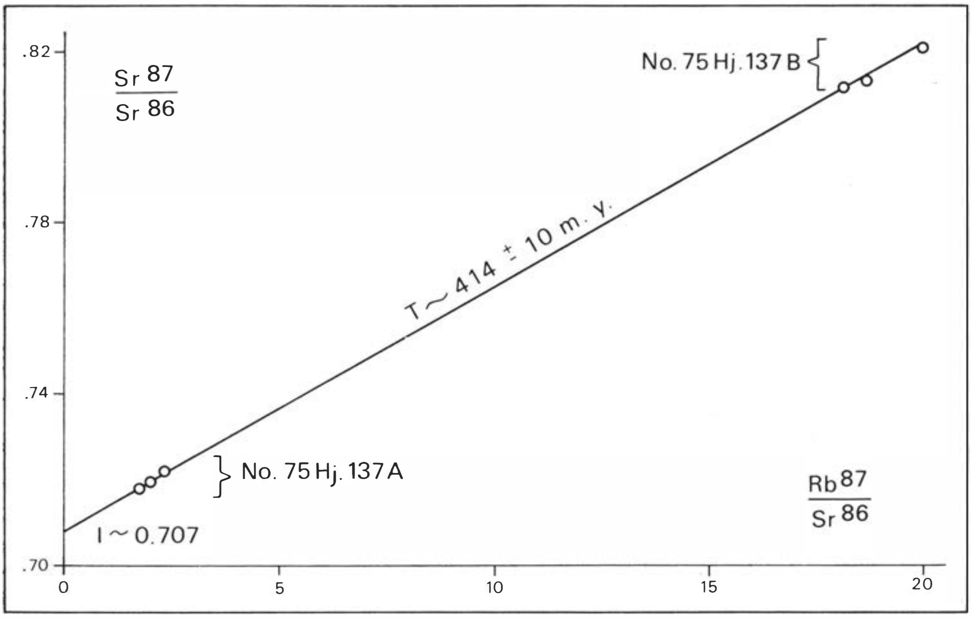

Fig. 8. *Preliminary Rb/Sr isochron for the Hornemantoppen granite. No. 137 A: Coarse grained main granite. 137 B: Aplitic granite. Location: Nunatak 1 km south of Hornemantoppen (79°32.4′N–11° 46.0′E). Analyst:* A. RÅHEIM, *Geological Museum, University of Oslo.*

some pelitic rocks on the eastern side of Smeerenburgfjorden and spinel-fayalite-clinohumite-phlogopite and wollastonite-diposide-scapolite in the Fuglefjorden area. In Danskøya and Amsterdamøya a diopside-wollastonite-vesuvianite-hematite paragenesis is common in skarn rocks. In the Magdalenefjorden area diopside and garnet are common skarn minerals; vesuvianite and wollastonite are observed in some relatively thick skarn layers, and antophyllite was found at one locality. East of Magdalenefjorden, skarn lenses with hedenbergite, grossularite, epidote, pyrite, chalcopyrite and magnetite occur in a relatively late (F4) shear zone associated with the intrusion of the post-tectonic Hornemantoppen granite. Shear zones elsewhere around the granite, commonly show chloritization.

The post-tectonic granitic dyke activity in northwest Spitsbergen is closely related to the formation of the migmatites, and granitic dykes are scarcely found outside the gneiss-migmatite areas. This suggests that migmatization has occurred slightly before the intrusion of the dykes. The apparent K/Ar ages of granitic dykes, which centres around 400 m.y. (GAYER et al. 1966), thus may give an indication of the age of the migmatitization.

One preliminary Rb/Sr age determination has been carried out on Hornemantoppen granite material. Two types of granite from the same locality were analyzed, aplite granite and coarse grained granite with interfingering and transitional contacts (Fig 8).

The published absolute ages from northwest Spitsbergen give no evident support for an early Precambrian complex in this part of Svalbard. Although rapid changes might occur in metamorphism and structure in the Kongsfjorden area, no basal conglomerate or undisputable depositional unconformities have yet been established between the Precambrian metasedimentary strata and the highly metamorphic rocks. Thus, information up to now suggests that all metamorphic rocks in northwest Spitsbergen took part in the Palaeozoic metamorphism and deformation.

The main phases of the tectonic development and metamorphism in northwest Spitsbergen are summarized below:

F0 Geosynclinal deposition, weak regional recrystallization. Greenschist facies. Late Precambrian.

F1 Regional metamorphism, tight isoclinal folding, development of cleavage. Upper amphibolite facies. Late Proterozoic or early Palaeozoic. (Early Caledonian phase).

F2 Main recrystallization, tight isoclinal folding, development of layering and gneissosity. Upper to lower amphibolite facies. (Mid ?-) Silurian ?

F3 Migmatization, emplacement of syntectonic grey granitic rocks. Weak open folding, initiation of main anticlinorium. Lower amphibolite facies. (Local development of lowermost granulite facies east of Smeerenburgfjorden). Probably Silurian.

F4 Intrusion of post-tectonic Hornemantoppen granite. Block movements, mylonitization. Lower amphibolite to greenschist facies. Late Silurian. Dislocation lines were reactivated in Devonian.

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