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Caledonian basement in NW Wedel Jarlsberg Land south of Bellsund, Spitsbergen

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ABSTRACT: The area of NW Wedel Jarlsberg Land south of Bellsund (Spitsbergen), between Dunderbukta in the west and the Berzeliustinden mountain group in the east, consists of five fault-bounded blocks: (1) the Renardbreen Block (Middle–Late Proterozoic basement rocks), (2) the Chamberlindalen Block (Late Proterozoic basement rocks), (3) the Martinfjella Block (Late Proterozoic through Early Ordovician basement rocks), (4) the Berzeliustinden Block (Late Proterozoic and Early Ordovician basement rocks covered by Late Palaeozoic–Tertiary platform deposits), (5) the Reinodden Block (Late Palaeozoic and Mesozoic rocks). The paper presents an outline of lithostratigraphy (Middle/Upper Proterozoic–Lower Ordovician: Hecla Hoek Succession) and architecture of the Caledonian basement in which several thrust-sheets and thrust-folds have been recognized. It also discusses some aspects of Tertiary overthrusting, faulting and rotation with affected the basement rocks and remodelled its Caledonian architecture.

Key words: Arctic, Spitsbergen, Middle/Upper Proterozoic, Cambrian, Ordovician, Caledonian basement, lithostratigraphy, tectonics.

Introduction

Geological visits to Chamberlindalen, Martinfjella and the Berzeliustinden mountain group south of Bellsund, Spitsbergen (Figs 1, 2), during summer of 2002, have allowed the present author (Birkenmajer 2002b) to revise lithostratigraphy and ages of metasediments previously attributed to the Magnethøgda unit *vel* sequence *vel* Group (Middle Proterozoic), and to the Recherchefjorden sequence (Upper Proterozoic) – see Harland (1978b, 1985, 1997); Craddock *et al.* (1985); Bjørnerud (1990); Bjørnerud *et al.* (1990, 1991); Dallmann *et al.* (1990); Harland and Butterfield (1997); Harland *et al. (*1997). In the present author's opinion (Birkenmajer 2002b), these metasedimentary rocks represent a complete sequence of the Upper Proterozoic Sofiebogen Group (the Slyngfjellet-, the Höfer-

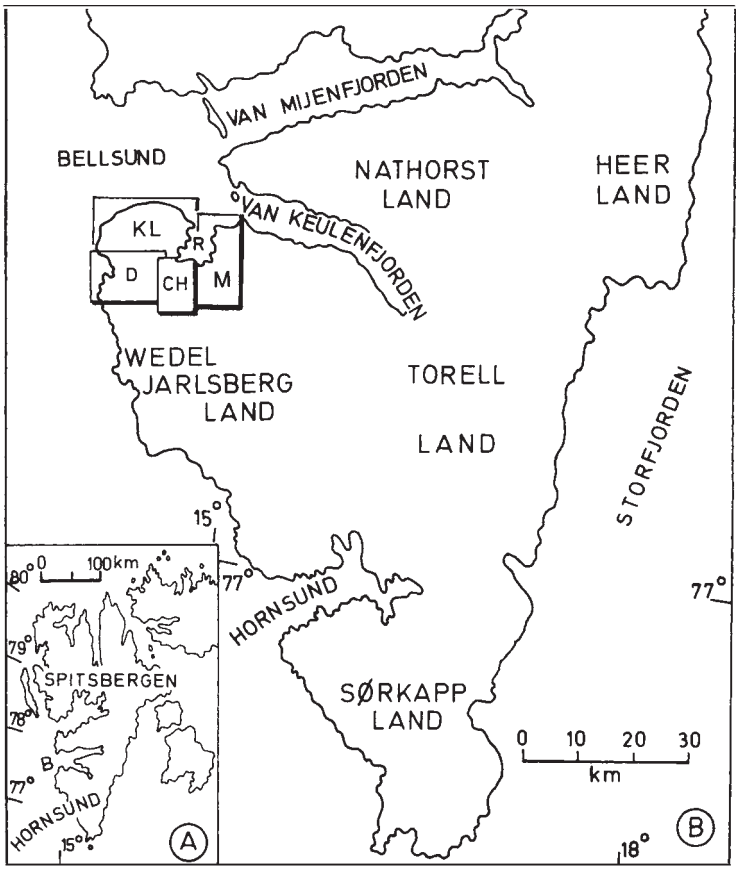


Fig. 1. Spitsbergen, location maps (**A**, **B**). B – Bellsund; CH – Chamberlindalen area, D – Dunderdalen area, KL – Kapp Lyell-Renardbreen area, M – Martinfjella-Berzeliustinden area, R – Recherchefjorden.

pynten-, and the Gåshamna formations), a very incomplete sequence of the Cambrian Sofiekammen Group (the Gnålberget Formation), and a continuous sequence corresponding to lower part of the Early Ordovician Sørkapp Land Group (the Wiederfjellet-, the Jarnbekken-, and the Luciapynten formations). This has helped to decipher Caledonian architecture of NW Wedel Jarlsberg Land south of Bellsund.

The Sofiebogen Group (between Chamberlindalen and Berzeliustinden)

In Chamberlindalen, predominantly metasedimentary rocks previously distinguished as the Upper Proterozoic Recherchefjorden sequence (*e.g.* Bjørnerud

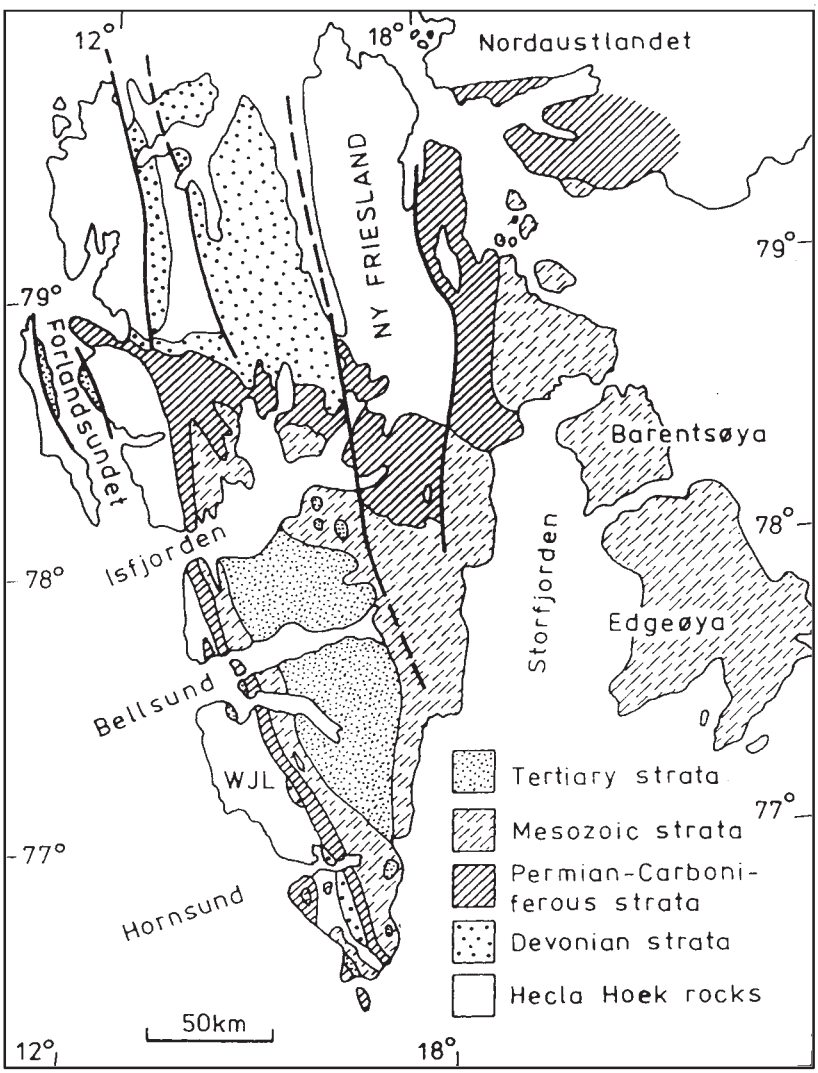


Fig. 2. Simplified geological map of Svalbard (compiled from various sources). WJL – Wedel Jarlsberg Land.

1990; Dallmann *et al.* 1990), have been correlated by the present author (Birkenmajer 2002b) with the Upper Proterozoic Sofiebogen Group of south Spitsbergen (*cf.* Birkenmajer 1958, 1972, 1975, 1981, 1990, 1991, 1992). Similarly as in the type area of the group at Hornsund, it is represented in Chamberlindalen by three major lithostratigraphic units: (1) the Slyngfjellet Formation (oldest), (2) the Höferpynten Formation, and (3) the Gåshamna Formation (Table 1).

The Slyngfjellet Formation. — This formation, consisting of metaconglomerates, crops out in middle part of a steep rocky wall rising above Recherchebreen, be-

Table 1

Correlation of lithologic units as distinguished in the Van Keulenfjorden geological map sheet 1:100,000 (Dallmann *et al.* 1990) – Dunderdalen and Chamberlindalen areas, with the Late Proterozoic standard of south Spitsbergen.

Age	Group	Formation	Dominant Lithology	Van Keulen-fjorden Sheet No
PROTEROZOIC LATE	Sofiebogen	Gåshamna	phyllite, green to black	35
			phyllite, calcareous	33
			quartzite inter-calations	32
		Höferpynten	carbonates undifferentiated	36
			oolitic dolostone (= Dunøyane Mbr)	(36)
			massive dolostone (= Wurmbrandegga Mbr)	(36)
			phyllitic limestone (= Fannytoppen Member)	37
		Slyngfjellet	metaconglo-merate/diamic-tite	38
				27
			green (upper unit)	29
			brown-yellow (lower unit)	30
				31
MIDDLE	Deilegga		phyllite	35 (part)
				28

tween Solhøgda (663 m) and Gaimardtoppen (595 m) – see Figs 8, 10, 11. The metaconglomerates form core of an anticline recumbent to the east, its flanks being

built of dolostone attributed to the Höferpynten Formation (see below) – see Fig. 12. Thickness of the Slyngfjellet Formation probably exceeds 300 m.

Outside the study area, to the south of Gaimardtoppen, this metaconglomerate (No *38* in Dallmann *et al.* 1990) reappears at Steinegga (695 m), Foldnutane (660 and 700 m), Konglomeratfjellet (800 m – type location of the "Konglomeratfjellet conglomerate" – Dallmann *et al.* 1990), Brenibba (692 m), Varderyggen (peaks 565, 625, 703, 604 and 540 m), Pilten (518 m), in eastern part of Haraldhaugen (477 m), and at several nunataks (nordre Nunatak, søre Nunatak, Haugknatten) in head part of Recherchebreen.

The same metaconglomerate (Konglomeratfjellet Formation – Bjørnerud 1990) reappears along the southern margin of the Dunderdalen Monocline (between Saksbreen in the east, and Fløyodden in the west) as part of the "Dunderbukta and Recherchefjorden sequences (Upper Proterozoic)" (Dallmann *et al.* 1990). Bjørnerud *et al.* (1991) correctly correlated it with the Slyngfjellet (Conglomerate) Formation of south Spitsbergen, similarly dividing it into the lower *brown* (diamictite and quartzite, >400 m thick) and the upper *green* (diamictite and quartzite >300 m thick) subunits.

The Höferpynten Formation. — Steep mountain ridge which borders the Recherchebreen glacier from the west, between Rubypynten-Observatoriefjellet (565 m) in the north and Palanderfjellet (725 m) – Ramondbreen in the south, consists mainly of dolostones of the Höferpynten Formation (Figs 8–12). It forms upper and lower flanks of the Chamberlindalen Fold recumbent to the east, the core of which consists of metaconglomerates of the Slyngfjellet Formation (see above and Fig. 12). Thickness of the Höferpynten Formation amounts to about 400–500 m.

At the northern slope of Observatoriefjellet, above Rubypynten, we see grey to bluish banded dolostone with thin intercalations of dolostone-pellet sedimentary breccias. Cross-lamination and streaks of silicified oolites have been observed in the upper part of the formation close to its contact with phyllites of the Gåshamna Formation (Birkenmajer 2002b). Lithological character of the dolostone allows to compare it with the Wumbrandegga and the Dunøyane members of the Hornsund area (see Birkenmajer 1970, 1990, 1992; Radwański and Birkenmajer 1977).

These members have also been distinguished in exposures of the Höferpynten Formation between Raudfjellet and Klockmannfjellet, inclusively, half-way from Hornsund to Recherchefjorden (Birkenmajer 1994). Their reapearance in the Chamberlindalen-Recherchebreen area is, therefore, not surprising.

In Martinfjella, to the Höferpynten Formation has been included a yellow-weathered dolostone maximum about 300 m thick which crops out at south-western slope of Maria-Theresiatoppen (Birkenmajer 2002b).

Outside the study area, the Höferpynten Formation continues from Observatoriefjellet along eastern slopes of Solhøgda, and from Palanderfjellet to Gaimardtoppen, reaching Foldnutane, Konglomeratfjellet and Haraldhaugen in the south. Its western prolongation lies in the mountain ridge Trinutryggen-Fløykalven (= Nos *36* and *37* in Dallmann *et al.* 1990: geological map; Slettfjelldalen Formation 50–300 m thick of Bjørnerud 1990).

The dolostone unit attributed in this paper to the Höferpynten Formation has been distinguished as "carbonate rocks (undifferentiated)", No *36*, of the "Dunderbukta and Recherchefjorden sequences (Upper Proterozoic)" by Dallmann *et al.* (1990). This unit continues along the

Dunderbukta Monocline between Saksbreen in the south-east and Gaulodden in the north-west (see Dallmann *et al.* 1990: geological map).

To the north of the study area, the Höferpynten Formation (>600 m thick) has recently been recognized at Midterhuken (Birkenmajer 2002a).

The Gåshamna Formation (type development). — In Chamberlindalen, at Observatoriefjellet, Solhøgda and Palanderfjellet, the Höferpynten Formation is directly overlain by a predominantly phyllitic complex up to 4000 m thick (see Fig. 12: cross-section A–B) which correlates well with the Gåshamna Formation of Sørkapp Land and south-eastern and central Wedel Jarlsberg Land (*cf.* Birkenmajer 1990, 1991, 1992, 1994). The following lithologies have been recognized in the Gåshamna Formation (Birkenmajer 2002b):

- *Phyllites and slates*. These are predominantly green to dark-green, locally also blue-grey and black, sometimes purple pelitic metasediments (Fig. 3), which crop out widely in Chamberlindalen between the Cramerbreane Fault and the mountain ridge Observatoriefjellet-Palanderfjellet. Here belong lithologies distinguished in the Van Keulenfjorden geological map sheet, 1:100,000 (Dallmann *et al.* 1990): No *35* (phyllite), and No *33* (calcareous green phyllite) – see Table 1. It seems that a considerable part of green chloritic schists designated as "greenstone" by Dallmann *et al.* (1990: No *34*) does also belong here;

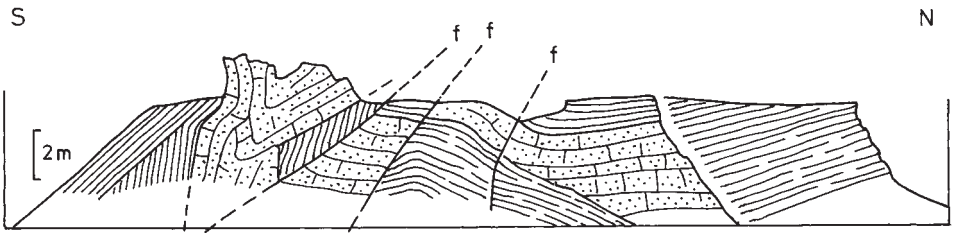


Fig. 3. Exposure of the Gåshamna Formation in coastal cliff at Vestervågen, SW Recherchefjorden (Chamberlindalen Block). Ruled – phyllites; stippled – quartzites; f – faults.

- *Quartzites*. These rocks form intercalations and horizons 2–10 m thick within the phyllites. They are often traceable over hundreds of metres. Their colour is black, brownish, greenish or whitish. The quartzites form beds usually 0.5–0.7 m in thickness (see Fig. 3). They occur at base (*e.g.* at Observatoriefjellet – Birkenmajer 2002b) and, mainly, in an upper part of the Gåshamna Formation (*e.g.* between Tomtodden and southern part of Chamberlindalen, close to the Cramerbreane Fault – Figs 10, 12). In the Van Keulenfjorden geological map sheet 1:100,000 (Dallmann *et al.* 1990), here belong quartzites distinguished under No *32*;
- *Limestones*. The limestones are platy or schistous, recrystallized (marbles) with thin interlayers of shale/schist (Fig. 4). The limestones occur as 20–30-m thick

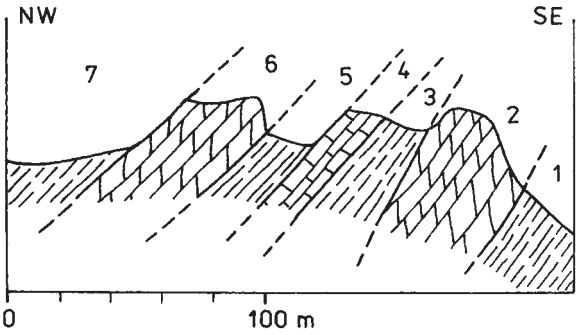


Fig. 4. Schematic geological cross-section of the Gåshamna Formation at Vestliknausane, Chamberlindalen (Chamberlindalen Block). 1, 5, 7 – phyllites; 2, 6 – dolostone intercalations, 4 – limestone (marble) intercalation.

bands within phyllites at Vestliknausane (Birkenmajer 2002b) – Figs 10, 12. In the Van Keulenfjorden geological map sheet, 1:100,000 (Dallmann *et al.* 1990), here belongs a part of "carbonate rocks, undifferentiated" (No *36*);

- *Dolostones*. The dolostones are massive, bluish if fresh, yellow-weathered. They form two separate horizons 20–40 m thick within the phyllitic complex at Vestliknausane (Figs 4, 10, 12). Thin bands of dolostone-pellet conglomerate and of silicified ooids occur in upper part of some dolostone layers.
- *Stratabound greenstones*. Stratabound rocks called the "greenstones" (No *34* in Dallmann *et al.* 1990: geological map) have been distinguished at numerous sites between Vestervågen and Steinegga, both within the phyllite complex (*op. cit.*, Nos *35* and *33*), and within the "carbonate rocks, undifferentiated" (No *36*). In the present author's opinion, many of these outcrops should rather be mapped as chlorite schists. Pillow-lava structures recognized in some greenstones (see Dallmann *et al.* 1990) may be an evidence for coeval basic volcanic effusive activity in the NW part of the Gåshamna Formation marine basin;
- *Hypabyssal mafic rocks*. Intrusive rocks determined as metagabbro, greenstone and serpentinite (Nos *56* and *57* in Dallmann *et al.* 1990: geological map), and associated asbestos veins, occur in the area occupied mainly by the Gåshamna Formation. Their age is unknown so far. Some of these mafic rocks resemble Mesozoic dolerites (see Birkenmajer 2002b).

In Martinfjella, the Gåshamna Formation (in its type development) is only 150–200 m thick (Birkenmajer 2002b). There, it consists of black phyllites with quartzite intercalations (No *55* in Dallmann *et al.* 1990).

Outside the study area, the Gåshamna Formation is widely distibuted to the south of Recherchebreen and Chamberlindalen (lithologies Nos *53, 54, 55* in Dallmann *et al.* 1990: geological map): at both sides of Skarvpasset and Tverrbreen (Tverrbrenuten, Dolomittfjellet E, Skarven); at Kvartsittkammen, at Gothankammen and east of it, at Pukkelryggen and Pukkelen; at Kiselnutane. Contacts of this formation with Cambrian and Ordovician lithostratigraphic

units are mainly tectonic, as is also often the case in the type area at Hornsund (cf. Birkenmajer 1990, 1992).

At Dunderdalen, to the Gåshamna Formation (= Dunderdalen Formation, 1000–2000 m thick, of Bjørnerud 1990) should be included rock units Nos *32*, *35* and *36* of the Van Keulenfjorden 100,000 geological map sheet (Dallmann *et al.* 1990).

To the north of the study area, the Gåshamna Formation (about 300 m thick) has recently been recognized at Midterhuken (Birkenmajer 2002a).

Aldegondaberget Member (new unit). — This is a new lithostratigraphic unit distinguished within the Gåshamna Formation, previously described (Birkenmajer 2002b) as the *migmatite-bearing Gåshamna Formation*. The unit is widely distributed in Martinfjella and in the Berzeliustinden mountain group: at Aldegondaberget, Berzeliuseggene and Berzeliustinden (Figs 5–8), where it forms a separate Caledonian thrust-sheet up to about 1500 m thick (Fig. 12). The name of the member is derived from Aldegondaberget (590 m), the western part of which has been chosen as the stratotype section of the unit (Fig. 5).

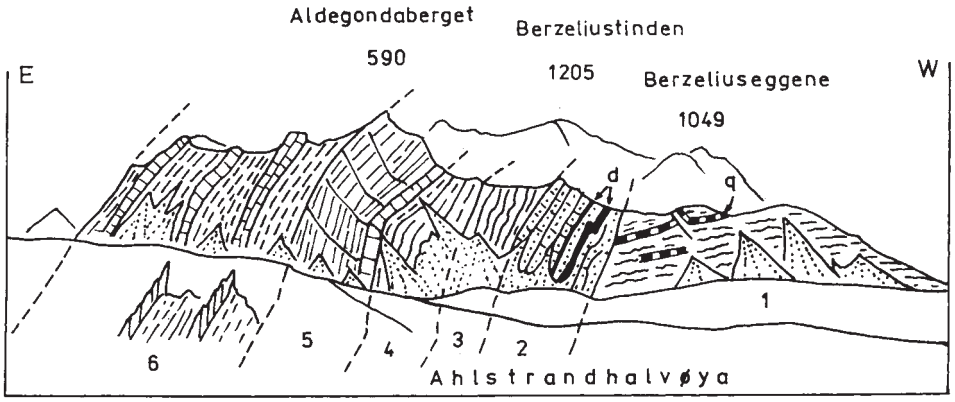


Fig. 5. Geological panorama of Aldegondaberget (type location of the Aldegondaberget Member), as seen from Ahlstrandodden (after Birkenmajer 2002b, explanatioons slightly modified). Berzeliustinden Block. 1 – Gåshamna Fm., Aldegondaberget Mbr (= migmatite-bearing Gåshamna Fm. *in* Birkenmajer 2002b; g – K-feldspar gneiss bands), 2 – Hyrnefjellet-Reinodden fms (Middle–Upper Carboniferous, d – Mesozoic dolerite sills), 3 – Gipshuken Fm. (Lower Permian), 4 – Kapp Starostin Fm. (Upper Permian), 5 – Vardebukta Fm. (Lower Triassic), 6 – Middle–Upper Triassic strata.

Principal rocks of the Aldegondaberget Member are represented by epimetamorphic black to dark-green phyllites and chlorite schists interbedded with single or multiple bands of white to black quartzite/metaarkose. Such lithologies are typical of the Gåshamna Formation. However, in contast to the latter, in the Aldegondaberget Member the schists locally pass to massive gneisses, particularly in the vicinity of pink to red migmatite interbeds. The latter rocks (called augengneiss and feldspathic quartzite, No *49* in Dallmann *et al.* 1990: geological map) occur as:

(1) bands up to a decimetre or so thick consisting of alternating laminae (*lit-par-lit*) 1–2 mm thick each of pink K-feldspar/microcline and green chlorite schist, parallel with phyllite schistosity or with banding of quartzite interlayers;

(2) pink to red K-feldspar veins 2–3 cm thick, which are concordant with phyllite schistosity or with banding of quartzite interlayers;

(3) isolated, red K-feldspar nests of various size, up to several metres long and up to several decimetres thick;

(4) pinching and swelling bands and zones of pink to red feldspathic gneiss (augen-gneiss) up to several metres thick and up to about 2 km long (*e.g.* at Aldegondaberget and Berzeliuseggene – Birkenmajer 2002b) – Figs 5, 8, 12.

These feldspar-rich gneissic rocks (migmatites) are often associated with micaschists which contain large muscovite flakes (Birkenmajer 2002b). White and pink pegmatite veins have locally been found (Dallmann *et al.* 1990).

A younger (second) generation of pink feldspar veins often cuts the older (first) one transversally to the prevailing schistosity (Birkenmajer 2002a).

Outside the study area, to the south of Martinfjella, the Aldegondaberget Member probably crops out in western part of Gothankammen (see Dallmann *et al.* 1990: geological map, No *49*) where it seems to be thrust over a phyllite complex attributable to the typical Gåshamna Formation, and over a marble comparable with the Gnålberget Formation.

The Sofiekammen Group (in Martinfjella)

The Sofiekammen Group (Cambrian) is represented in the area of Bellsund by a single lithostratigraphic unit – the Gnålberget Formation (Birkenmajer 2002a, b). Other formations of this group, both older and younger than the Gnålberget Formation, which are well known form the Hornsund area, south Spitsbergen (see Birkenmajer 1978a, 1990), are missing from Bellsund (Table 2) probably as a result of Caledonian thrusting.

The Gnålberget Formation. — Bluish to whitish, grey-yellow weathered, usually strongly foliated limestone/marble, up to about 500 m thick, which occurs in the Martinfjella mountain range, correlates with the Cambrian Gnålberget Formation of the Hornsund area (see Birkenmajer 1978a, 1990). It crops out at the top, at north-western and north-eastern slopes of Maria-Theresiatoppen, moreover at the foot and western slopes of Jarnfjellet and Magnethøgda (Birkenmajer 2002b) – Figs 6–8, 12. This unit has been included by Dallmann *et al.* (1990: geological map, No *51*) to the "Magnethøgda sequence (Middle Proterozoic)".

Outside the study area, the Gnålberget Formation (= No *51* in Dallmann *et al.* 1990: geological map) seems to occur also at: Kiselnutane, S Helhornet, middle and western parts of Gothankammen; eastern and northern parts of Kvartsittkammen, and at E Bleikskollen. Its contact with the Gåshamna Formation (= Nos *53, 54, 55* in Dallmann *et al.* 1990: geological map) everywhere seems to be tectonic.

Table 2

Correlation of lithological units as distinguished in the Van Keulenfjorden geological map sheet 1:100,000 (Dallmann *et al.* 1990), with the Late Proterozoic through Early Ordovician standard of south Spitsbergen (after Birkenmajer 2002b, explanations slightly modified). B – Berzeliustinden Block, Ch – Chamberlindalen Block, M – Martinfjella Block. For No *49* (microcline gneiss, augengneiss) – read: the Aldegondaberget Member, (np) – not present.

Age		Group	Formation	Dominant Lithology	Van Keulenfjorden Sheet No	Area
EARLY ORDOVICIAN		Sørkapp Land	Luciapynten	dolostone (phyllite)	50 53 (part)	M B
			Jarnbekken	Fe-ore-bearing dolostone	(in 49 part and 50)	M
			Wiederfjellet	quartzite (dolomitic)	49 (part)	M
CAMBRIAN	?L.	Sofiekammen	Nørdstetinden	(np)	(np)	
	?M.		Gnålberget	limestone (phyllitic)	51	M
	EARLY		Slaklidalen	(np)	(np)	
			Vardepiggen			
			Blåstertoppen			
PROTEROZOIC	LATE	Sofiebogen	Gåshamna	phyllite	53 (part)	M B
				quartzite, phyllite	48, 54	
				microcline gneiss (augen-gneiss)	49	
				phyllite	35	Ch
				dolostone, limestone	36 (part)	
				quartzite	32	
			Höferpynten	dolostone (loc. oolitic)	36 (part)	M Ch
			Slyngfjellet	metaconglomerate/diamictite	38	Ch
	MIDDLE	Deilegga	(np)			

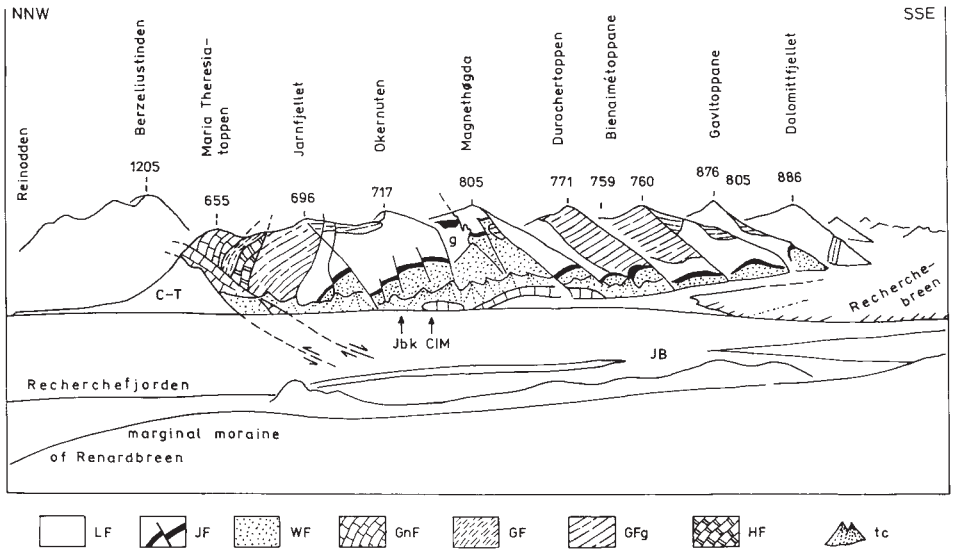


Fig. 6. Geological panorama of Martinfjella, as seen from left marginal moraine of Renardbreen (after Birkenmajer 2002b, explanations slightly modified). Martinfjella Block (*cf.* Table 2). LF – Luciapynten Fm., JF – Jarnbekken Fm., WF – Wiederfjellet Fm., GnF – Gnålberget Fm., GF – Gåshamna Fm., GFg – Gåshamna Fm., Aldegondaberget Mbr (= migmatite-bearing Gåshamna Fm. in Birkenmajer 2002b); HF – Höferpynten Fm., tc – talus cones, C-T – Carboniferous through Triassic strata, Jbk – Jarnbekken (type locality of the Jarnbekken Fm.), CIM – "Camp Iron Mountain" (see Dallmann *et al.* 1990), JB – Josephbukta, main Tertiary strike-slip faults marked (*cf.* Fig. 8).

To the north of the study area, the formation occurs at Midterhuken where it is probably more than 300 m thick (Birkenmajer 2002a).

The Sørkapp Land Group (in Martinfjella and mountain range east of Antoniabreen)

Three formations attributable to the Lower Ordovician Sørkapp Land Group have recently been distinguished in mountain ranges west and east of Antoniabreen, within the "Magnethøgda sequence" *sensu* Dallmann *et al.* (1990): (1) the Wiederfjellet Formation, (2) the Jarnbekken Formation, and (3) the Luciakammen Formation (Birkenmajer 2002b). Two of these formations (*1* and *3*) have long been known from the Hornsund area (see Birkenmajer 1978b, 1990).

The Wiederfjellet Formation. — This unit consists of dolomitic quartzite, bluish-grey to whitish if fresh, yellowish weathered, about 200 m thick. It forms strongly tectonized (phyllitic) bands 1–2 m thick. The formation crops out along western slopes of Martinfjella between Jarnfjellet in the north and Gavltoppen in the south (Figs 6, 8, 12). In the Van Keulenfjorden geological map sheet (Dall-

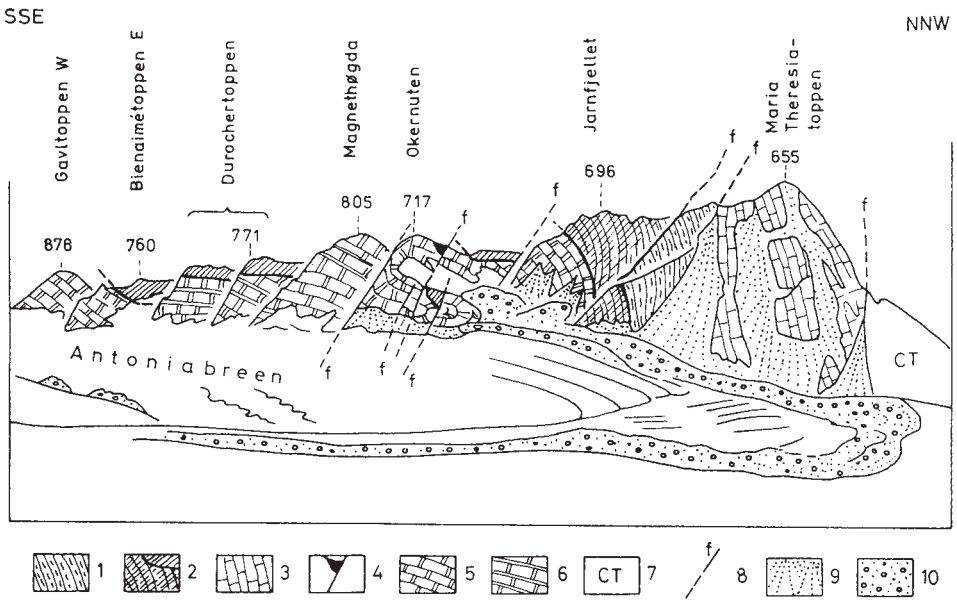


Fig. 7. Geological panorama of Martinfjella, as seen from frontal moraine of Blümckebreane (after Birkenmajer 2002b, explanations slightly modified). Martinfjella Block (*cf.* Table 2). 1, 2 – Gåshamna Fm. (2 – Aldegondaberget Mbr = migmatite-bearing Gåshamna Formation *in* Birkenmajer 2002b); 3 – Gnålberget Fm., 4 – Jarnbekken Fm., 5, 6 – Luciapynten Fm. (5 – bedded dolostones, 6 – dolostones with shale/phyllite bands), 7 – Carboniferous–Triassic strata, 8 – faults, 9 – talus cones; 10 – marginal and terminal moraines.

mann *et al.* 1990), rocks of the Wiederfjellet Formation are included to "augengneiss and feldspathic quartzite", No *49*.

The Jarnbekken Formation. — This newly distinguished lithostratigraphic unit of the Sørkapp Land Group (Birkenmajer 2002b) is exposed mainly on western slopes of Martinfjella between Jarnbekken/Jarnfjellet in the north, and Gavltoppane in the south (Figs 6, 8, 12). It consists of ore-bearing dolostone 20–30 m thick which forms bands 0.1–1 m thick, bluish if fresh, intensely red to yellow-red weathered. The ore consists principally of haematite and limonite, subordinately of magnetite, forming laminae up to 1 cm thick. This is a stratabound sedimentary iron-ore deposit. It was subject to short-lasting prospecting at the beginning of the past century (Dallmann *et al.* 1990: p. 47).

The Luciapynten Formation. —This unit is represented by a massive grey to bluish dolostone, from 600 to >700 (?1500) m thick, which builds up most of the Martinfjella mountain range (Figs 6–8, 12). The dolostone displays alternating lighter and darker laminae, it also shows the presence of streaks and intercalations 1–2 cm thick of medium-grained quartz sand and dolostone-pellet sedimentary

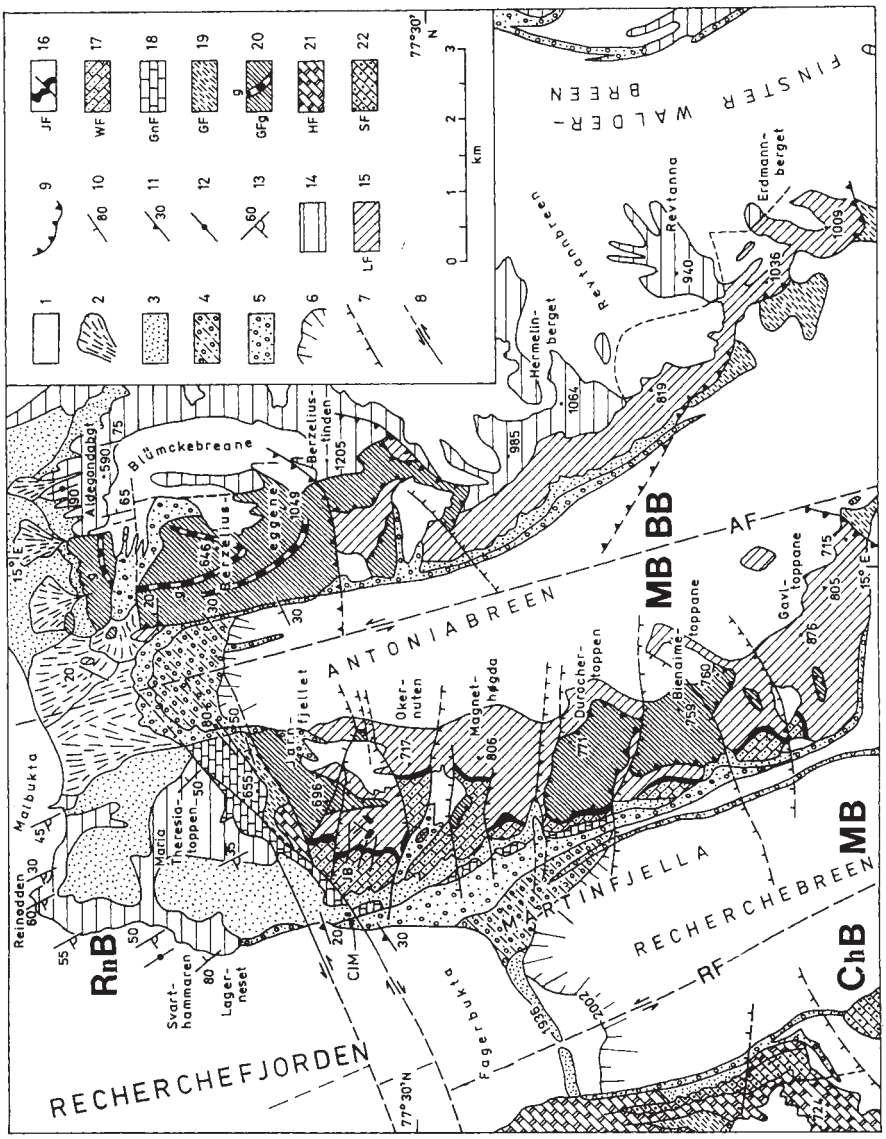


Fig. 8. Geological sketch-map of Martinfjella and its vicinity (after Birkenmajer 2002b, explanations slightly modified), based on the present author's field survey of 2002, and on reinterpretation of geological maps 1:50,000 by Różycki (1959) and 1:100,000 by Dallmann *et al.* (1990). The **Martinfjella** and **Berzeliustinden blocks**. 1 – ice and sea; 2 – alluvial/outwash cones; 3 – beach, talus, talus cones and raised marine beaches; 4 – ground moraine; 5 – marginal and terminal moraines; 6 – glacier front; 7 – dip-slip faults (barbed on downthrown side); 8 – strike-slip faults; 9 – overthrust; 10 – strike and dip of strata; 11 – strike and dip of foliation; 12 – vertical strata; 13 – tectonically overturned strata; 14 – Carboniferous–Mesozoic strata; 15 – Luciapynten Fm.; 16 – Jarnbekken Fm.; 17 – Wiederfjellet Fm.; 18 – Gnålberget Fm.; 19, 20 – Gåshamna Fm. (20 – Aldegondaberget Mbr = migmatite-bearing Gåshamna Fm. in Birkenmajer 2002b; g – K-feldspar gneiss bands); 21 – Höferpynten Fm.; 22 – Slyngfjellet Fm. **Symbols**: AF – Antoniabreen Fault; BB – Berzeliustinden Block; ChB – Chamberlindalen Block; MB – Martinfjella Block; RF – Recherchebreen Fault; RnB – Reinodden Block.

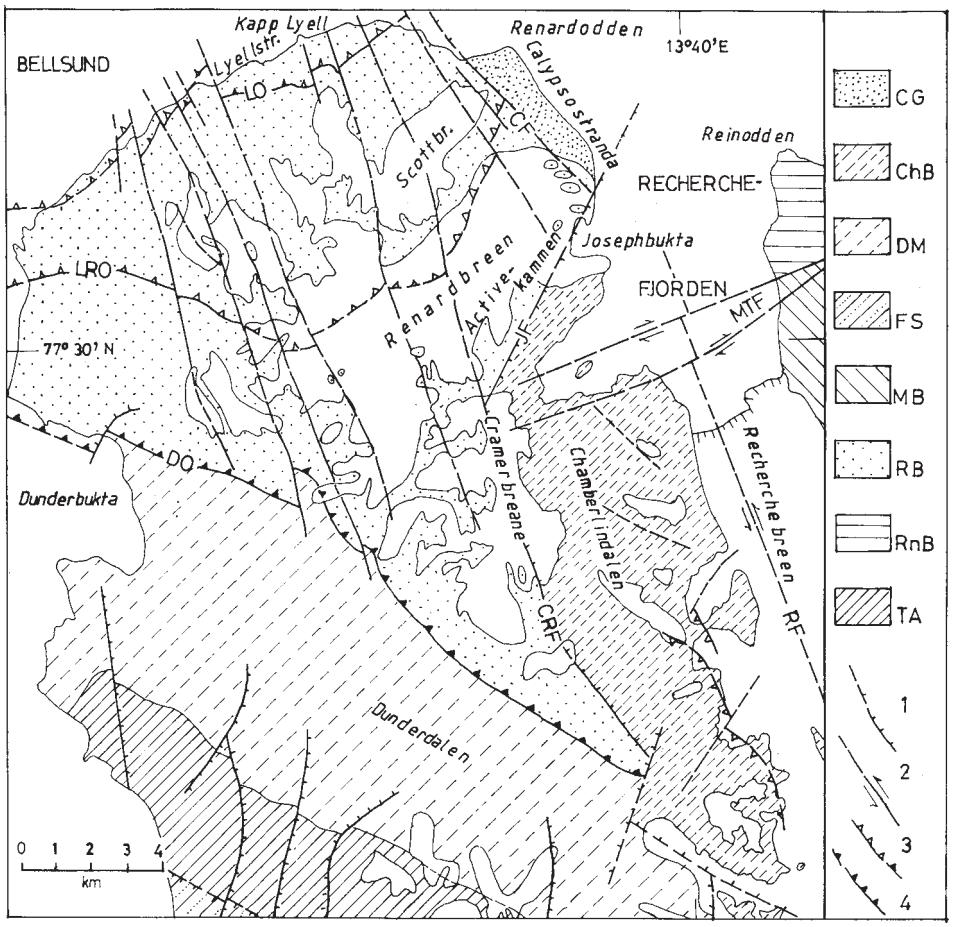


Fig. 9. Major tectonic elements in NW Wedel Jarlsberg Land. Reinterpreted from geological map 1:100,000 sheet Van Keulenfjorden (Dallmann *et al.* 1990) and supplemented by the present author. **Major tectonic elements:** ChB – Chamberlindalen Block (mainly Late Proterozoic rocks), CG – Calypsostranda Graben (Tertiary coal-bearing deposits), DM – Dunderdalen Monocline (Late Proterozoic metasediments), FS – Fløysletta Synclinorium (?Middle–?Early Proterozoic metasediments), MB – Martinfjella Block (Late Proterozoic–Early Ordovician metasediments), RB – Renardbreen Block (Middle–Late Proterozoic metasediments), RnB – Reinodden Block (Late Palaeozoic–Mesozoic deposits), TA – Thiisfjellet Anticlinorium (Middle Proterozoic rocks). **Overthrusts** (Caledonian) and **faults** (mainly Tertiary): DO – Dunderfjellet Overthrust, LO – Lyellstranda Overthrust, LRO – Lognedalen-Renardbreen Overthrust, CF – Calypsostranda Fault, CrF – Cramerbreane Fault; MTF – Maria-Theresiatoppen Faults, 1 – dip-slip faults (barbs on downthrown side), 2 – strike-slip faults (arrows indicate relative movement directions), 3 – faults (probably mainly strike-slip), 4 – overthrusts.

breccia. In the Van Keulenfjorden geological map (Dallmann *et al.* 1990), to the Luciapynten Formation belongs most of the "massive dolomite" No *50*.

The formation continues eastwards across Antoniabreen, reappearing in the Berzeliustinden mountain range. It has been recognized: at an isolated stack in

outwash fan west of Aldegondaberget; in a small outcrop at right margin of the Antoniabreen glacier (at foot of northwest slope of Berzeliuseggene); and at western slopes of the Berzeliustinden-Erdmannberget mountain range (Birkenmajer 2002b) – Figs 8, 12.

Outside the study area, the Luciapynten Formation (= No *50 in* Dallmann *et al.* 1990: geological map) probably occurs also at: Pukkelryggen, Supanberget, Helhornet, Kvartsittkammen, and Gothankammen. Its contacts with the Gåshamna Formation (Nos *53, 54, 55*) are there obviously tectonic.

Tectonic framework

In the area of NW Wedel Jarlsberg Land, several major Tertiary faults have been recognized (see Dallmann *et al.* 1990, Birkenmajer 2002b): the Cramerbreane and Josephbukta faults (dip-slip); the Recherchebreen Fault (strike-slip); the Maria-Theresiatoppen faults (strike-slip); and the Antoniabreen Fault (strike-slip) – Figs 8–12.

These faults divide the northwest Wedel Jarlsberg Land into five tectonic blocks: the Renardbreen Block (west of the Cramerbreane-Josephbukta faults); the Chamberlindalen Block (between the Cramerbreane-Josephbukta- and the Recherchebreen faults); the Martinfjella Block (between the Recherchebreen-, the Maria-Theresiatoppen-, and the Antoniabreen faults); the Berzeliustinden Block (western limb of the Central Spitsbergen Depression: east of the Antoniabreen Fault); the Reindodden Block (north of the Maria-Theresiatoppen faults) – Figs 8–11.

The Renardbreen Block. — The Renardbreen Block (Figs 9, 10) consists entirely of Proterozoic rocks which are represented by: (1) the Bergskardet Formation (youngest formation of the Middle Proterozoic Deilegga Group), a minimum 200 m thick; (2) the Kapp Lyell diamictite unit/formation (probable age equivalent to the Slyngfjellet Formation of the Upper Proterozoic Sofiebogen Group), further subdivided into: (2.1) the *yellow diamictite* (older unit), 720 to >1325 m thick; and (2.2) the *green diamictite* (younger unit) up to >960 m thick (Birkenmajer 2003a, b).

Along its whole southern/southwestern margin (see Dallmann *et al.* 1990: geological map), the Renardbreen Block is delimited from the Gåshamna Formation metasediments (type development = Dunderdalen Formation of Bjørnerud 1990) by the Dunderfjellet Overthrust. The latter formation plunges under the yellow diamictite unit of the Renardbreen Block.

At its northeastern margin, the Renardbreen Block is delimited from Tertiary strata of the Calypsostranda Graben by the dip-slip Calypsostranda Fault (NW-SE). Further south, the dip-slip Josefbukta Fault (NE-SW), and the Cramerbreane Fault (NNW-SSE) juxtapose the Renardbreen Block against the Chamberlindalen Block.

Three large-scale tectonic units thrust one over another from NW to SE, have been recognized within the Renardbreen Block (Fig. 10):

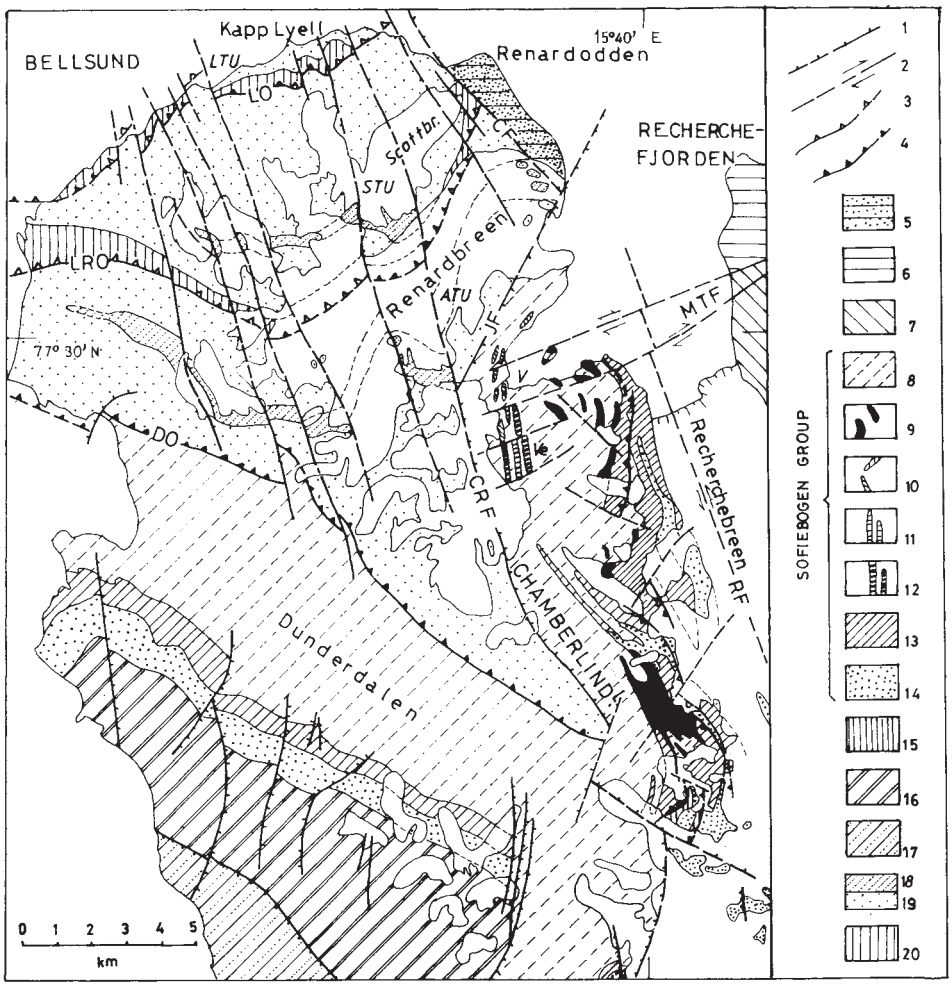


Fig. 10. Selected tectonic/structural elements in the Renardbreen and Chamberlindalen blocks. Based on reinterpretation of geological map 1:100,000, sheet Van Keulenfjorden (Dallmann *et al.* 1990), supplemented by the present author. 1 – Tertiary dip-slip faults (barbs on downthrown side), 2 – Tertiary strike-slip faults, 3 – minor Caledonian overthrusts (barbs towards upper unit), 4 – major Caledonian overthrusts (barbs towards upper unit), 5 – Tertiary deposits (Calypsostranda Graben), 6 – Reinodden Block (Carboniferous–Mesozoic platform cover), 7 – Martinfjella Block (Late Proterozoic–Early Ordovician rocks), 8, 10–14 – Sofiebogen Group (Upper Proterozoic): 8 – Gåshamna Fm. (phyllites and chlorite schists), 9 – selected stratabound mafic rocks (and ?Mesozoic dolerites) within the Gåshamna Fm., 10–12 – intercalations within the Gåshamna Fm. (10 – quartzite, 11 – limestone, 12 – dolostone), 13 – Höferpynten Fm.; 14 – Slyngfjellet Fm., 15 – ?Bergskardet Fm. (Deilegga Gp, Middle Proterozoic), 16 – rocks of the Thiisfjellet anticlinorium (Middle Proterozoic), 17 – rocks of the Fløysletta synclinorium (?Middle–?Early Proterozoic), 18, 19 – Kapp Lyell diamictite (18 – upper: *green*, 19 – lower: *yellow*), 20 – Bergskardet Fm. (Deilegga Gp, Middle Proterozoic), V – Vestervågen, Ve – Vestliknausane. For symbols of faults, overthrusts and tectonic units – see Fig. 9.

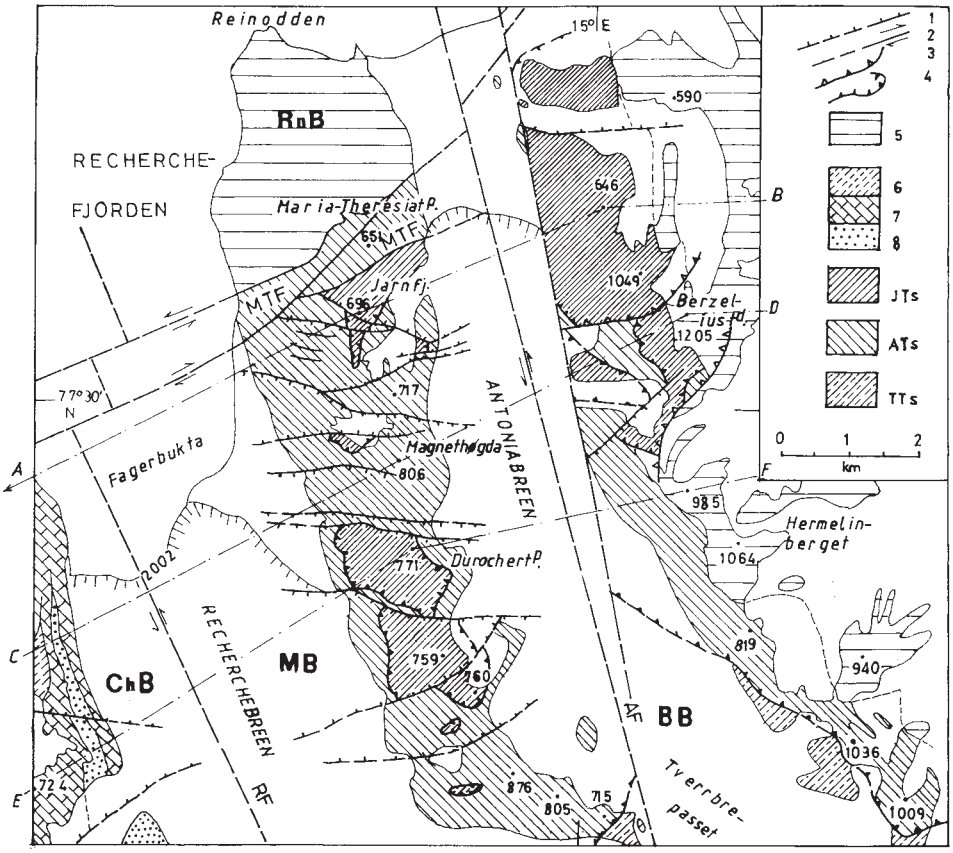
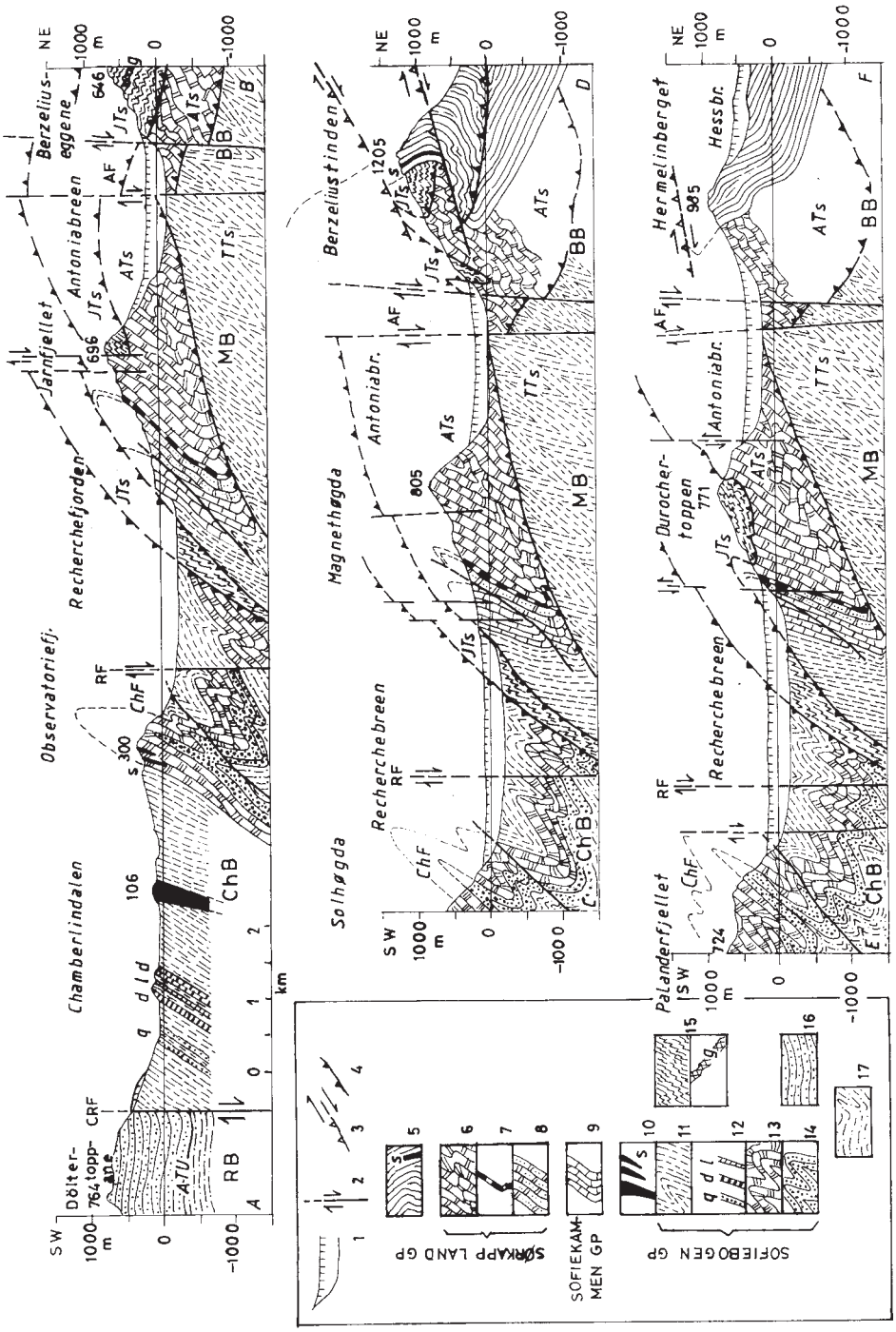


Fig. 11. The Martinfjella and Berzeliustinden blocks, tectonic map (*cf.* Fig. 8). 1 – dip-slip faults, mainly Tertiary (barbs on downthrown side), 2 – Tertiary strike-slip faults, 3 – Tertiary overthrusts, 4 – Caledonian overthrusts, 5 – Carboniferous–Mesozoic platform cover deposits, 6–8 – Caledonian Chamberlindalen Fold, Sofiebogen Gp (6 – Gåshamna Fm.; 7 – Höferpynten Fm., 8 – Slyngfjellet Fm). **Caledonian thrust-sheets**: ATs – Antoniabreen, JTs – Jarnfjellet; TTs – Tverrbrepasset. For symbols of faults and tectonic blocks – see Fig. 9.

- The *Activekammen Tectonic Unit, ATU* (= lower tectonic mega-unit of Birkenmajer 2003a) is a syncline recumbent to the southeast. It occurs to the south of the Renardbreen-Lognedalen Overthrust. Its core is made up of green diamictite, while the flanks – of yellow diamictite;
- The *Scottbreen Tectonic Unit*, *STU* (= middle tectonic mega-unit, *op. cit.*) is also a syncline recumbent to the southeast. It occurs to the north of the Renardbreen-Lognedalen Overthrust. Its core is made up of green diamictite, while the flanks – of yellow diamictite. In bottom flank of the syncline, the yellow diamictite passes downward into the Bergskardet Formation which is thrust directly over yellow diamictite of the ATU;



- The *Lyellstranda Tectonic Unit*, *LTU* (= upper tectonic mega-unit, *op. cit.*) occurs farthest north, between Klokkestranda and Rochesterpynten, where it is thrust over the STU. At Kapp Lyell and vicinity, its basal Bergskardet Formation passes upward into the yellow diamictite unit.

These three tectonic units might summarily represent a large Caledonian thrust-sheet superposed in its southern part over the Gåshamna Formation metasediments of the Dunderdalen Monocline. Eastern margins of this thrust-sheet have been strongly modified by vertical (dip-slip) Tertiary faults (see Figs 9–11).

The Chamberlindalen Block. — This tectonic block is bounded in the west and east by two submeridional (NNW-SSE) faults: the Cramerbreane Fault (dip-slip), and the Recherchebreen Fault (strike-slip, left lateral), respectively (Figs 9–12). In the north, the Chamberlindalen Block is bounded by the NE-SW-trending Josefbukta Fault (dip-slip) against the Renardbreen Block (Proterozoic metasediments) and the Calypsostranda Graben (Tertiary deposits).

In the present interpretation (see above, and Birkenmajer 2002b), all metasediments which occur in the Chamberlindalen Block belong to the Late Proterozoic Sofiebogen Group: (1) the Slyngfjellet Formation (oldest), (2) the Höferpynten Formation (middle), and (3) the Gåshamna Formation (youngest). Summarily, they represent an anticline recumbent to the east – the *Chamberlindalen Fold*, the core of which consists of the Slyngfjellet Formation (metaconglomerates), and the flanks – of the Höferpynten Formation (dolostones) – Fig. 12. The Gåshamna Formation in its type development (mainly phyllites and slates, with quartzite, dolostone and limestone intercalations/horizons, with some mafic rock interlayers – see above, and Birkenmajer 2002b), overlie the Höferpynten Formation in upper flank of the Chamberlindalen Fold.

The Chamberlindalen Fold is a Caledonian structure, probably somewhat remodelled during Tertiary thrust-faulting. Scale of this thust-faulting is a matter of debate: in the present author's opinion it was smaller than that suggested by Dallmann *et al.* (1990, 1993). In their geological maps and cross-sections, nearly all contacts between different lithologies, belonging in fact to the same Sofiebogen Group, have been marked as overthrusts, that is not necessary the case.

← Fig. 12. Geological cross-sections (A–B, C–D, E–F) of the area between the Berzeliustinden (BB) and the Chamberlindalen (ChB)/Renardbreen (RB) blocks (area between Berzeliustinden in the north and Hermelinberget in the south adapted from Różycki 1959 and Dallmann *et al.* 1990, 1993). 1 – glacier, 2 – Tertiary fault, 3 – Tertiary overthrust, 4 – Caledonian overthrust, 5 – Carboniferous–Mesozoic platform cover deposits (s – Mesozoic dolerite sill), 6 – Luciapynten Fm., 7 – Jarnbekken Fm., 8 – Wiederfjellet Fm., 9 – Gnålberget Fm., 10 – stratabound mafic intrusions (in the Gåshamna Fm.) and dolerite sills (s: Mesozoic ?), 11 – Gåshamna Fm. (phyllites, chlorite schists), 12 – intercalations in the Gåshamna Fm. (q – quartzite, d – dolostone, l – limestone), 13 – Höferpynten Fm., 14 – Slyngfjellet Fm., 15 – Aldegondaberget Mbr (= migmatite-bearing Gåshamna Fm. *in* Birkenmajer 2002b, g – K-feldspar gneiss band), 16 – Kapp Lyell diamictite (lower member: *yellow diamictite)*, 17 – Bergskardet Fm. (Deilegga Gp). ChF – Chamberlidalen Fold; for symbols of tectonic blocks, faults and overthrusts – see Figs 9 and 11.

A conspicuous change in strikes of quartzite bodies within the Gåshamna Formation in NW corner of the Chamberlindalen Block (Vestervågen area – see Fig. 10), well shown in the Van Keulenfjorden geological map (Dallmann *et al.* 1990), could be a result of Tertiary clockwise rotation (of the order of some 45 degrees) of Proterozoic rock-units at the junction of the Tertiary Cramerbreane/Josefbukta faults (see Figs 9, 10).

The Martinfjella Block. — The Martinfjella Block is longitudinally delimited by two submeridional strike-slip left-lateral faults: the Recherchebreen Fault in the west, and the Antoniabreen Fault in the east (Figs 8–12). Three Caledonian thrust-sheets have been distinguished in the block (Figs 11, 12): (1) the Tverrbrepasset Thrust-sheet, TTs (lower), (2) the Antoniabreen Thrust-sheet, ATs (middle), and (3) the Jarnfjellet Thrust-sheet, JTs (upper).

- The *Tverrbrepasset Thrust-sheet (TTs)* crops out in the head (southern) part of Antoniabreen, starting from Tverrbrepasset. In the present interpretation, it consists mainly of the Gåshamna Formation in its type development (phyllites with quartzite horizons). Between Hermelinberget and Erdmannberget (eastern side of Antoniabreen), and in south-eastern part of the Martinfjella mountain range, phyllites attributed here to the TTs emerge from below the ATs overthrust.
- The *Antoniabreen Thrust-sheet* (*ATs*) consists of: the Höferpynten and Gåshamna formations (Sofiebogen Group); the Gnålberget Formation (Sofiekammen Group); the Wiederfjellet, Jarnbekken and Luciapyntan formations (Sørkapp Land Group). This tectonic unit is well exposed on both sides of Martinfjella, above the Recherchebreen and Antoniabreen glaciers, respectively (see Birkenmajer 2002b: figs 2, 3, 5). Continuation of this tectonic unit is easily traceable in the Berzeliustinden Block, along eastern margin of Antoniabreen between west slopes of Aldegondaberget, and western slopes of the Berzeliustinden-Erdmannberget range.
- The *Jarnfjellet Thrust-sheet* (*JTs*) consists solely of the Aldegondaberget Member (= migmatite-bearing Gåshamna Formation of Birkenmajer 2002b). In Martinfjella, base of the thrust sheet truncates rock-units of the Sofiekammen (Cambrian) and the Sørkapp Land (Lower Ordovician) groups which belong to the underlying Antoniabreen Thrust-sheet (ATs). At western slopes of Berzeliustinden, the JTs basal surface truncates the Luciapynten Formation (Lower Ordovician) of the underlying ATs.

In the north, two Tertiary ENE-WSW-trending strike-slip Maria-Theresiatoppen faults (northern and southern) juxtapose Caledonian basement rocks of the Martinfjella Block against steeply folded Upper Palaeozoic and Mesozoic deposits of the **Reindodden Block** (see Różycki 1959, Dallmann *et al.* 1990) – Figs 8–11. Numerous vertical to subvertical dip-slip faults (E-W; NE-SW; NW-SE) cutting the Caledonian thrust-sheets are distinguishable along Martinfjella (see Dallmann *et al.* 1990: geological map, Birkenmajer 2002b: fig. 5) – Figs 6–8, 11.

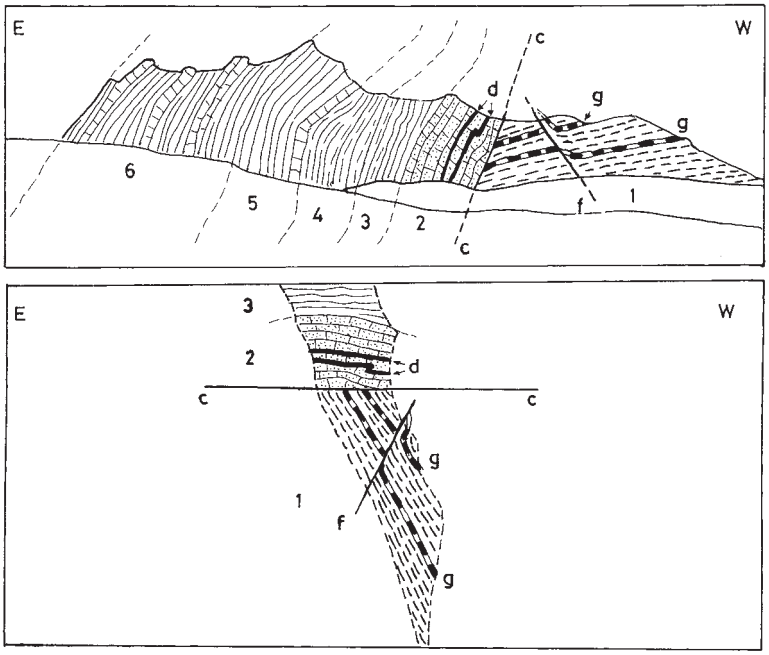


Fig. 13. Aldegondaberget. **Upper fig.** – present geological structure: the Carboniferous/Proterozoic unconformity (c-c) and the overlying strata (2–6) steeply dip due east, the Aldegondaberget Mbr (1) gently dips due east (see Fig. 5). **Lower fig.** – the Carboniferous–Proterozoic unconformity (c-c) and the overlying strata (2–6) restored to horizontal position, the Aldegondaberget Mbr (1) steeply dips due west. d – Mesozoic dolerite sills, f – fault, g – K-feldspar gneiss bands), 2–6 – see Fig. 5.

The Berzeliustinden Block. — The Berzeliustinden Block, consisting of Caledonian basement rocks, is delimited in the west by the Antoniabreen Fault. The basement rocks plunge eastwards under a thick pile of post-Caledonian platform-cover deposits (Carboniferous–Tertiary) and, together with the latter, take part in architecture of the Tertiary fold-and-thrust belt of the Main Range (see Różycki 1959, Dallmann *et al.* 1990).

Three Caledonian thrust-sheets (TTs; ATS; JTs), analogous to those of Martinfjella, are distinguishable in the Main Range between Erdmannberget-Hermelinberget in the south, and Berzeliustinden-Aldegondaberget in the north (Figs 11, 12):

- The *Tverrbrepasset Thrust-sheet (TTs)* emerges from below dolostones of the Luciapynten Formation (belonging to the ATS), along eastern margin of Antoniabreen – south of Hermelinberget, and at Erdmannberget;
- The *Antoniabreen Thrust-sheet (ATs)*, consisting of a dolostone slab (Luciapynten Formation), crops out between Erdmannberget and Berzeliustinden. It is unconformably covered by Upper Palaeozoic platform deposits (Różycki 1959, Dallmann *et al.* 1990: geological map). At western slope of Berzeliustinden, the ATs unit is overthrust by the JTs one.

- The *Jarnfjellet Thrust-sheet (JTs)*, consisting of the Aldegondaberget Member (= migmatite-bearing Gåshamna Formation of Birkenmajer 2002b) grows in thickness in the northern direction, from Berzeliustinden to Aldegondaberget.

At Aldegondaberget, we see a well exposed contact (stratigraphic unconformity) of the JTs with the overlying Carboniferous–Triassic strata, steeply dipping east (Fig. 5; Birkenmajer 2002b: fig. 4). Restoration of this unconformity surface to horizontal position (Fig. 13), as at the time of Carboniferous deposition, makes the Proterozoic strata (JTs) to steeply (70–80 degrees) dip west, instead of the present low-angle (20–30 degrees) eastern dip. This shows a degree of tectonic deformation to which the Caledonian architecture was subject during the Tertiary folding and thrusting.

Conclusions

(1) Several Caledonian tectonic units have been recognized in the area between Renardbreen Block in the west, and the Berzeliustinden mountain group in the east: (i) three isoclinal SE-recumbent tectonic units (two of these recognized as recumbent synclines) in the Renardbreen Block, (ii) one E-recumbent fold (anticline) in the Chamberlindalen Block, (iii) three thrust-sheets in the Martinfjella and Berzeliustinden blocks.

(2) In the Renardbreen Block, the Caledonian tectonic units are recumbent to the south/southeast. It remains to be found whether this is an original thrust-direction of Caledonian age, or an effect of Tertiary rotation of the whole block with respect to the Chamberlindalen Block.

(3) In the Chamberlindalen Block, rock-succession in its Caledonian Chamberlindalen Fold (E-recumbent anticline) is correlatable well with that of the Dunderdalen Monocline further west. Though contacts between different lithologies in the Gåshamna Formation rocks in Chamberlindalen are often tectonized, the scale of thrusting in that area seems to be smaller than that shown in the Van Keulenfjorden geological map, 1:100,000 (see Dallmann *et al.* 1990).

(4) A considerable difference in rock-succession and architecture of the Chamberlindalen and the Martinfjella blocks, which are divided by the strike-slip left-lateral Recherchebreen Fault, might suggest a significant post-Caledonian displacement along it. There is an open question whether this fault delimits some fundamental Early Palaeozoic Arctic plates – *sensu* Harland (1978a), or plays only a much restricted role (see Bjørnerud 1990: p. 138).

(5) Metasomatic changes (K-feldspar migmatitization) in the Aldegondaberget Member of the Gåshamna Formation are a characteristic feature for the highest Caledonian thrust-sheet (Jarnfjellet Thrust-sheet, JTs) in the Martinfjella and the Berzeliustinden blocks. They might indicate that at the onset of Caledonian orogeny a part of the Gåshamna Formation sedimentary sequence had been subject

to metasomatic alteration, probably in a subductional regime, subsequently obducted and thrust eastward over the two lower tectonic units (TTs and ATs) as a separate thrust-sheet (JTs).

(6) Continuity of the Caledonian thrust-sheets between the Martinfjella (western) and the Berzeliustinden (eastern) blocks might indicate that the Tertiary left-lateral strike-slip displacement along the Antoniabreen Fault was probably a minor one compared with that along the Recherchebreen Fault.

(7) The Caledonian architecture of the area had been remodelled by the Tertiary east-vergent thrusting, moreover by associated rotation of individual tectonic blocks, and of rock-complexes within the blocks. The degree of Tertiary tectonic remodelling increases eastwards, in the direction of the main Tertiary fold-and-thrust belt of western Spitsbergen.

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