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A Reconsideration of Late Precambrian Stratigraphy of Southern Spitsbergen*

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Abstract: Observations in Hornsund and Bellsund, especially in 1977 and 1978, challenged in some respects previously established Late Precambrian sequences and correlation. This paper makes alternative postulates using informal nomenclature. In particular the Slyngfjellet Conglomerate may have referred both to a Vendian (Varangian) tilloid unit (Fannypynten and Hansbreen) and to a much earlier conglomerate at Konglomeratfjellet. The tilloid appears to be younger and not older than the Höferpynten Formation. Tentative correlation with the Bellsund sequence is suggested. The latter has, for example, a greater volcanic content.

If these revisions are substantially correct the stratigraphic breaks used as evidence for the Torellian and the Jarlsbergian Deformation Phases may not be demonstrable. The Hornsund sequence occupies a central position with respect to contrasting sequences to the east in Ny Friesland and Nordaustlandet, and to the west in outer Bellsund and further north.

Zusammenfassung: Beobachtungen im Hornsund und Bellsund, die besonders in den Jahren 1977 und 1978 durchgeführt wurden, lassen in manchen Beziehungen früher aufgestellte spätpräkambrische Abfolgen und Korrelationen zweifelhaft erscheinen. Diese Arbeit zeigt alternative Bedingungen unter Verwendung einer abweichenden Nomenklatur. Im einzelnen könnte das Slyngfjellet-Konglomerat sowohl zur Vendian (Varangian)-Tilloid-Einheit (Fannypynten und Hansbreen) als auch zu einem viel älteren Konglomerat am Konglomeratfjellet gestellt werden. Der Tilloid scheint jünger und nicht älter als die Höferpynten-Formation zu sein. Eine vorläufige Korrelation mit der Bellsund-Folge, die z. B. einen stärkeren Vulkanismus zeigt, wird vorgeschlagen. Falls diese Revision im wesentlichen richtig ist, wären die stratigraphischen Lücken, die als Belege für die Torell- und die Jarlsberg-Deformationsphase gelten, nicht mehr beweisbar. Die Hornsund-Folge nimmt eine zentrale Position ein hinsichtlich der vergleichbaren Folgen sowohl der weiter östlich in Ny Friesland und Nordaustlandet als auch der westlich und weiter nördlich des äußeren Bellsunds gelegenen Serien.

1. INTRODUCTION

In the course of a study of strata of approximately Vendian age throughout Svalbard, opportunities were taken during voyages to Hornsund in 1977 and 1978 to compare the relevant parts of the sequences as already described (e. g. MAJOR & WINSNES, 1955; BIRKENMAJER, 1958 et seq.) at Kapp Lyell and Recherchefjorden and also with the sequences north of Bellsund as described by HJELLE (1962, 1969) and as observed by me in 1974 and 1975. In each case our Cambridge Spitsbergen Expedition boats were also servicing other investigations; moreover, in 1977 and 1978 sea ice restricted access to land so that the observations made are still at a reconnaissance level; many necessary observations were attempted but not achieved. The reason, however, for reporting these findings at this preliminary stage is that some of the observations were quite unexpected and led me to doubt the published account of Precambrian stratigraphy in South Spitsbergen which had come to be regarded as a corner-stone in correlation and interpretation by myself as much as by others.

It is premature to recommend an alternative scheme. To do so would require much work and would at best be achieved by a co-operative international effort, especially between those already involved. My group can also bring to this work the outlines of a stratigraphic sequence worked out in Prins Karls Forland and Oscar II Land and presented for the symposium in Oslo in 1975 (HARLAND, HORSFIELD, MANBY & MORRIS, in press).

This western sequence is relevant for comparison because there has been a tendency to formulate stratigraphic sequences in the west and south by extension of the better

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known sequences of Ny Friesland and Nordaustlandet. By contrast with the sequences in Ny Friesland (summarized e.g. by HARLAND, WALLIS & GAYER, 1966) and in Nordaustlandet (summarized and extended by FLOOD, GEE, HJELLE, SIGGERUD & WINSNES, 1969) the western and southern sequences are more difficult to interpret. This is because the area has suffered both mid-Palaeozoic and mid-Cenozoic deformation in different senses and in each case with significant effects that are difficult to disentangle. In these circumstances it was natural at first to look to the east where mid-Palaeozoic tectogenesis has not been confused by later deformation. Subsequently, after more than ten years work in the West, my conclusion is that not only is the West Spitsbergen Orogen different in structure but also in Precambrian sequence and facies so it is better at first to reconstruct the sequences quite independently without allowing the eastern sequences to influence too much interpretation of the west.

Therefore an attempt is made to set out the succession in each area as observed without using names that imply correlation. It is not the intention in this paper to define formally any new units. The procedure adopted is firstly to name (for the purposes of this paper only) additional units as convenient and to refer to them by place in the usual way but with unit and division. In due course some of these units may prove useful in a new stratigraphic scheme when they will need to be defined with appropriate formation, member etc.. It will be convenient however, to retain the familiar group names from BIRKENMAJER's (1960 et seq.) unified scheme on the basis that group names may be expected to refer to a wide area and include a variety of units.

Names from established formations are retained here but often restricted so that they refer to the named locality even though the formation may be better known from elsewhere. For example to avoid confusion the name Slyngfjellet Conglomerate is restricted to the locality of Slyngfjellet because it is not clear to me how to correlate with it the various conglomerates elsewhere that have been referred to by this name. This procedure may appear unnecessarily elaborate for the task in hand. On the other hand the alternative method of lumping under fewer names was premature so that miscorrelations have probably been made.

NORDAUSTLANDET (KULLING, 1934)		NY FRIESLAND (HARLAND & WILSON, 1956)		SOUTH OF HORNSUND (MAJOR & WINSNES, 1955)	BJØRNØYA (HORN & ORVIN, 1928)
KAP SPARRE Fm	U 'Early-€	Limestones "'later-€"	OSLOBREEN	etc GRÅKALLEN ' Canadian	*Tetradium* lst 'Black River Younger Dol. 'Canadian
	L dolostones quartzite	dolostones 'Early-€		SLAKLI ' (Georgian)	
	shale	sst shale		GÅSHAMNA phyllite	
	SVEANOR Fm tillites	tillites	POLARISBREEN	? tillite	slate and quartzite
MURCHISON BAY Fm	shale RYSSØ	shale		? ? ? ? ? ? ? ? ? ?	
	dolostones with stromatolites and pisolites	AKADEMIKERBREEN		HØFERPYNTEN	Older dolomite
	etc	etc			

Tab. 1: Correlation of Vendian rocks in 1956 (HARLAND & WILSON).

Tab. 1: Korrelation von Vendian-Gesteinen im Jahre 1956 (HARLAND & WILSON).

2. THE PUBLISHED SEQUENCES

The stratigraphic successions as published are summarized in tabular and graphic form. Table 1 shows the correlation of late Precambrian strata as proposed in 1956 (HARLAND & WILSON), that related the newly described sequence in Ny Friesland with that first described in South Spitsbergen by MAJOR & WINSNES (1955).

Table 2 shows the unified scheme for Hornsund proposed by BIRKENMAJER in 1959 and 1960 and confirmed in 1975, while Fig. 1 shows his 1960 map of the same units. This scheme combined WINSNES' (1955) sequence south of Hornsund with the newly observed strata north of Hornsund in 1958 and has generally been adopted for the south of Spitsbergen (e.g. FLOOD et al., 1971), so acquiring official status.

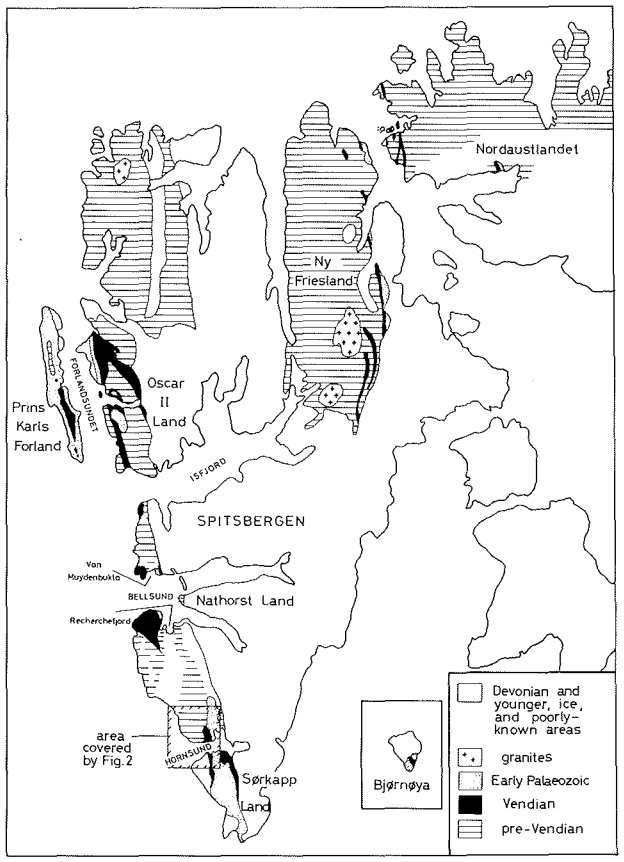


Fig. 1: Geological sketch map showing locations of Vendian exposures, place names, and area of Fig. 2.

Abb. 1: Geologische Kartenskizze mit der Verbreitung von Vendian-Aufschlüssen, Ortsnamen und dem Umriß des Gebietes der Abb. 2.

Throughout there were attempts to correlate with the Ny Friesland sequence (later revised by HARLAND, WALLIS & GAYER, 1966), for example by HJELLE (1969) for Bellsund (Table 3). A useful contemporary synthesis was made by BIRKENMAJER in 1975 (Fig. 3).

Table 4 is summarized from HARLAND et al. (in press) in which the succession on both sides of Forlandsundet (further north) is described. HARLAND & WRIGHT (in

Supergroup	Group	Formation	Diastrophism	Age
Hornsund	Sørkapp Land 1.4 km	several formations (0)	[HORNSUNDIAN]	mainly Early Ordovician
	Sofiekammen 0.5 to 1.0 km	Nordstetinden (N) Gnålberget Marbles (G) Slakli (S) Blåstertoppen Dolomite (B)	[JARLSBERGIAN]	M. & L. Cambrian? M. Cambrian? E. Cambrian E. Cambrian?
	Sofiebogen 1.6 to 3.7 km	Gåshamna Phyllite (Gå) Höferpynten Dolomite (H) Slyngfjellet Conglomerate (Sy)	[TORELLIAN]	Vendian and Late Riphean (Carolinidian)
Torellbreen	Deilegga 3.5 km +	U Bergskardet (Du) M Bergnova (Dm) L Tonedalen (Dl)	[WERENSKIOLDIAN]	
	Eimfjellet 0.6 to 3.5 km	SE: Skålfjellet Subgroup (Sk); NW: Vimsodden Subgroup (V) Gulliksenfjellet (Gu)		
	Isbjörnhamna 1.7 to 3.0 km	Revdalen (R) Ariekammen (A) Skoddefjellet (Sd)		

Tab. 2: Hornsund sequence according to BIRKENMAJER (1959 to 1975). Symbols in parentheses refer to his 1960 map (Fig. 2 here).

Tab. 2: Hornsund-Folge nach BIRKENMAJER (1959—1975). Symbole in Parenthese beziehen sich auf dessen Karte von 1960 (Fig. 2 in dieser Arbeit).

press) showed that these western sequences differed very considerably from the eastern sequences and the alternative (western) standard for correlation undermined the monopoly of Ny Friesland and Nordaustlandet as the models for interpreting stratigraphy in south Spitsbergen.

S. of Bellsund	N. of Bellsund	Correlated by HJELLE (1969) with Hornsund [& Ny Friesland]
Bellsund-Dunderdalen tillite	Lågneset tillite	Upper Gåshamna
mainly dolomitic		[Polarisbreen]
Konglomeratfjellet shale and quartzite beds Konglomeratfjellet volcanic beds	Lågneset-Kapp Martin grey and green shales	
Konglomeratfjellet calcareous beds	Lågnesrabbane calcareous beds	
mainly limestone and dolomite beds, partly with oolite and silicified horizons		Höferpynten
	Subordinate dark shales	[Backlundtoppen Fm of Upper Akademikerbreen Gp]
Konglomeratfjellet conglomerate beds	Kapp Martin conglomerate beds	
quartzite conglomerate with subordinate dolomite and with marly horizons		Slyngfjellet
		[Draken Conglomerate of Lower Akadmikerbreen Gp]

Tab. 3: Bellsund sequences from HJELLE (1962, 1969).

Tab. 3: Bellsund-Folgen nach HJELLE (1962, 1969).

Prins Karls Forland	Oscar II Land
Grampian Gp 3.6 km (turbidites, pelites, conglomerates and quartzites)	Bullbreen Gp 0.7 km (pelites, conglomerates, limestones, with M. & L. Silurian fauna)
Scotia Gp 1.0 km (shales, pelites and limestones)	[tectonic break]
Peachflya Gp 1.3 km (pelite, sandstones and volcanics)	Sarsøyra Fm 0.5 km (marbles, conglomerates, pelites and vulcanites with ? Silurian coral)
Ferrier Gp 0.73 km (tilloids, greywackes, pelites, psammites and psephites)	[tectonic break]
[tectonic break]	Comfortlessbreen Gp 2—4 km (tilloid, quartzite, volcanics, limestone and dolostone)
Pinkie Fm 0.2 km (metavolcanics)	St Jonsfjorden Gp 3.8 km (limestone, quartzite, volcanics, dolostones)
	[tectonic break]
	Kongsvegen Gp 3.1 km (pelites, marbles, psammite)
	[tectonic break]
	Vestgötabreen Fm (blue schist meta-volcanics)

Tab. 4: Forlandsundet sequences from HARLAND, HORSFIELD, MANBY & MORRIS (in press).

Tab. 4: Forlandsundet-Folgen nach HARLAND, HORSFIELD, MANBY & MORRIS (im Druck).

3. POSSIBLE MISCORRELATION OF SLYNGFJELLET AND HÖFERPYNTEN FORMATIONS

In 1977 visits to both sides of Hornsund led me to doubt the correlation of the Slyngfjellet Conglomerate and the Höferpynten Formation as published by BIRKENMAJER in 1959 et seq. (Tables 2 and 3, Figs. 2 and 3). BIRKENMAJER (1958) described the Sofiebogen Formation as below the Slakli Series with the Gåshamna Series above the Höferpynten Series, which in turn rested on the Slyngfjellet Conglomerates. He wrote (1958: 146) "above the Deilegga Formation lies a vast (c. 500 m) complex of metamorphosed green conglomerates which rest without distinct unconformity and without transition on slates. The complex may be considered a tillite." He did in effect make a scheme that incorporated WINSNES' (1955) observations south of Hornsund with his own to the north with a unified nomenclature. In attempting to correlate this apparently single sequence elsewhere (i. e. using the WINSNES, 1955 and HARLAND & WILSON, 1956 correlations as in Table 1) he faced the alternatives of whether to correlate his Höferpynten Series with the Akademikerbreen rocks of Ny Friesland (in which case the Slyngfjellet Conglomerates would be older than the Sveanor-Polarisbreen tillites) or whether to correlate the Slyngfjellet Conglomerate (as glacial) with the Sveanor-Polarisbreen tillites to the north-east, in which case the Höferpynten would not be correlated with the Akademikerbreen rocks.

In his 1959 paper this dilemma was resolved without further discussion; he opted to make the Slyngfjellet Conglomerate older than the Akademikerbreen rocks and a glacial origin was not again seriously considered.

In 1960, the International Geological Congress Party, of which I was a member, did not have time to look at all the exposures planned but was taken to the slopes of Fannytoppen. Here a conglomerate was shown which certainly looked like an aqueous conglomerate rather than a tillite. The unified scheme for the whole stratigraphy of Spitsbergen published for that Congress (BIRKENMAJER, 1960a, b) then became the established sequence to which further work added detail or confirmation; for example

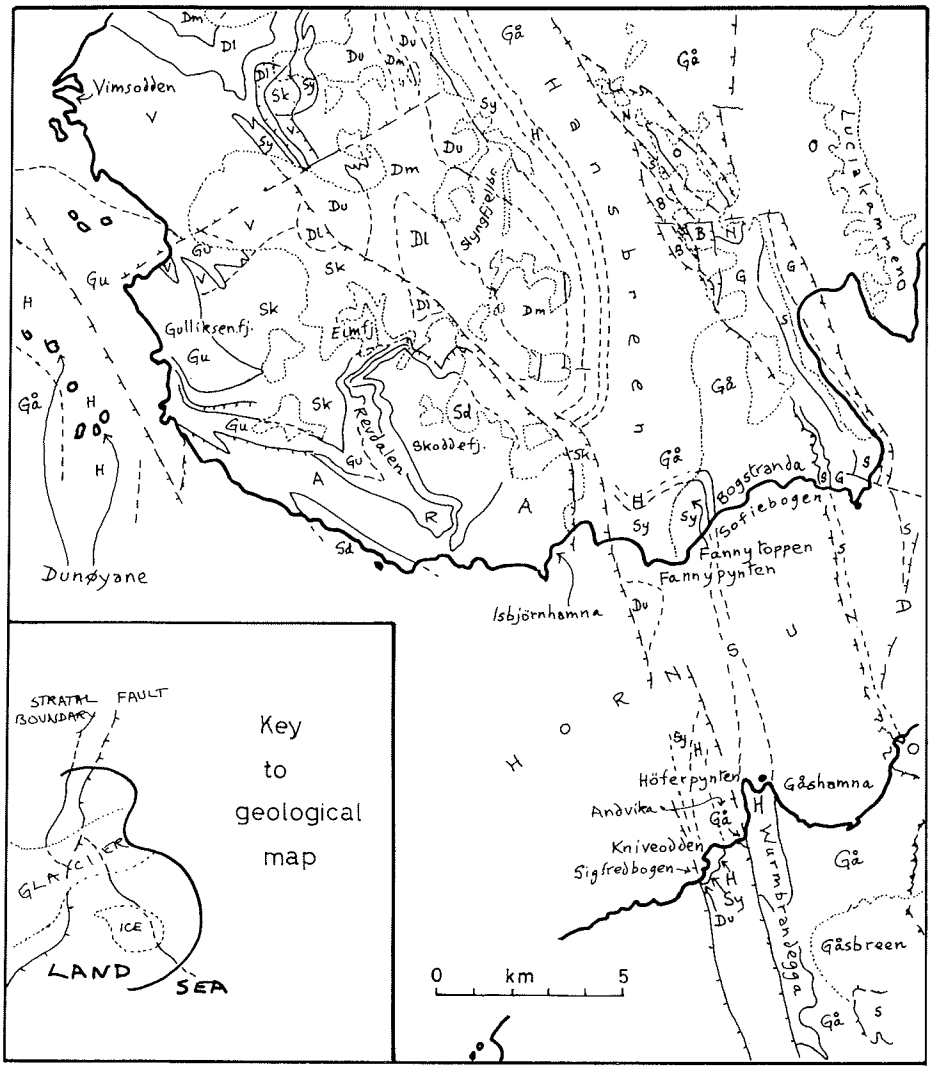


Fig. 2: Geological map of outer Hornsund from BIRKENMAJER, 1960. The stratigraphic abbreviations used here are given in brackets in Tab. 2.

Abb. 2: Geologische Karte des äußeren Hornsundes nach BIRKENMAJER 1960. Die hier verwendeten stratigraphischen Abkürzungen sind in Tab. 2 in Klammern verzeichnet.

in 1972 and 1977. In 1972 BIRKENMAJER described observations of the succession to the south first described by WINSNES. He gave more detail of the Höferpynten Formation, showing evidence of stromatolites near the top that confirmed the way-up of the strata. This put out of doubt the assumption by WINSNES to the south and BIRKENMAJER to the north that both sequences, which dip to the west, are inverted. In a 1977 paper by RADWANSKI & BIRKENMAJER, the first author investigated oolite and pisolite petrology from the Fannytoppen unit to the north and Dunøyane unit to the south, both units being regarded by BIRKENMAJER as members of the Höferpynten Formation.

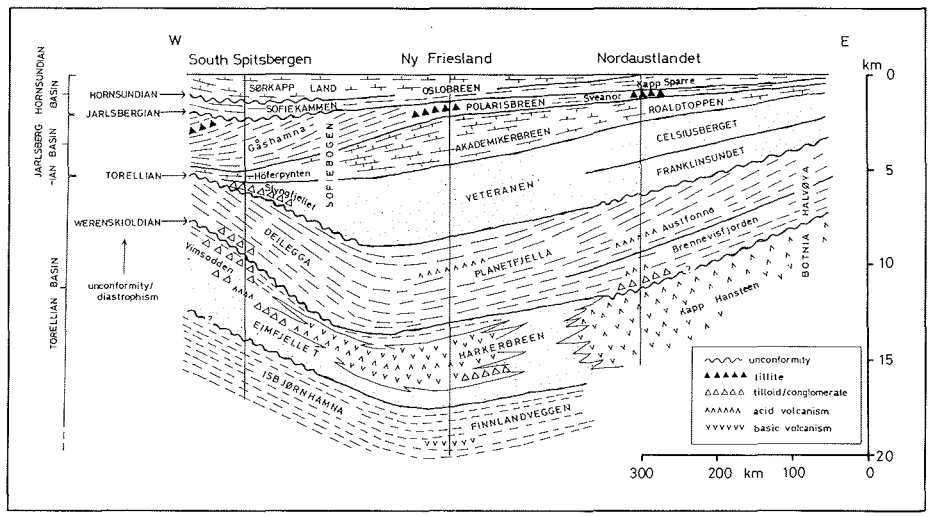


Fig. 3: Correlation, with interpretation, of pre-Devonian strata of Svalbard. Redrawn from BIRKENMAJER (1975: Fig. 3) by C. A. G. Pickton. The western part of this diagram needs radical revision according to the interpretations of this paper (see Tabs. 6 & 7).

Abb. 3: Korrelation mit Interpretation der prädevonischen Schichten von Svalbard. Neu gezeichnet von C. A. G. Pickton nach BIRKENMAJER (1975: Fig. 3). Der westliche Anteil dieses Diagramms bedarf einer radikalen Revision entsprechend den Darstellungen dieser Arbeit (vgl. Tabs. 6 & 7).

The Gåshamna Formation was thus taken to be the equivalent of the tillite-bearing Polarisbreen Group in Ny Friesland and it was of interest whether that sequence contained tillites corresponding to tillites elsewhere, and if not, why not, if there had been a widespread glacial episode. In reviewing this question WILSON & HARLAND (1964: 216) mentioned the report of a tillite-like specimen collected at Gåshamna by HOEL & ROVIG (FØYN, 1937: 144). But generally the absence of publicised tillites was regarded as an embarassment (SCHERMERHORN, 1974) for the Varangian ice age theory of, for example, KULLING (1934) and HARLAND (1964).

Observations in 1977 and 1978 suggested to me that the Höferpynten Formation as originally described south of Hornsund and the unit so correlated and named north of Hornsund (BIRKENMAJER, 1958 et seq.) were not the same.

Similarly I thought that the Slyngfjellet Conglomerate as originally described north of Hornsund and the small outcrop mapped as this formation south of Hornsund (BIRKENMAJER, 1960, see Fig. 1) had little in common.

It was on the assumption of the identity of these two formations on each side of Hornsund that the sequence of the Sofiebogen Group (i. e. Gåshamna — Höferpynten — Slyngfjellet) became established. If the assumptions are thrown into doubt then that sequence is also in doubt. In that case the alternative (originally assumed by WINSNES in 1958 and considered by BIRKENMAJER in 1958 but rejected by him in 1959) should now be reconsidered (i. e. Gåshamna — Slyngfjellet — Höferpynten). This possibility has many implications.

My own observations supported the view of WINSNES (1955) that there was a tectonic break above the Höferpynten Formation south of Hornsund and that this would be the position of the probable tillite formation.

Table 5 shows the correlation table of the Höferpynten Formation as shown by BIRKENMAJER (1972). I doubt the identity of his Höferpynten Formation at Fannytoppen and of his Slyngfjellet Conglomerate at Dunøyane and (west of) Höferpynten.

4. REVISED OUTLINE OF SOUTH SPITSBERGEN SEQUENCES

In order to reconsider the late Precambrian stratigraphy of south Spitsbergen and avoid the confusion that would result from existing nomenclature that equates distant rock units under one name, I redescribe here in outline the sequences in the principal areas (not using the same formational name for more than one principal area). This will facilitate discussion of correlation between areas without prejudice. However, because the work is still in an exploratory stage no new formational names are proposed. Informal names (unit and division) are used for discussion in this paper only. Further investigations may or may not justify them.

Each sequence is outlined from top to bottom.

4.1 South of Hornsund

The evidence given by BIRKENMAJER (1972) of overturned stromatolites is clear. The figured specimens can be seen exposed through the scree slopes west of Gåshamna. This confirms that although the strata to the west dip vertically the Höferpynten Formation, at least, youngs to the east. I also accept that the whole succession youngs to the east on general grounds though accepting WINSNES' observation of a tectonic break between the Gåshamna phyllites and the quartzites at the top of the Höferpynten Formation (confirmed by HAMBREY and WADDAMS in 1977). The stromatolite evidence does not directly establish the way-up of the Gåshamna Formation nor its stratigraphic relation to the Höferpynten Formation.

	Unified scheme of nomenclature	W ← 20 km → E DUNØYANE	N ← 6 km → S FANNYTOPPEN	HÖFERPYNTEN KNIVODDEN
SOFIEBOGEN GROUP	GÅSHAMNA FM	150 m +	Phyllites 2500 m	Phyllites Quartzites 1500 m
	HÖFERPYNTEN FM Dunøyane Mbr	750 m	24 m (oolitic) dolostones	40 m oolitic and stromatolitic dolostones
	Wurmbrand-eggen Mbr	1150 m 400 m grey dolostones	118 m 14 m	710 m 350 m grey dolostones
	Andvika Mbr	?0	0 m	300 m cherty dolostones
	Fannytoppen Mbr	?0	80 m	20 m
	SLYNGFJELLET CONGLOM. FM	?0	500 m +	10 m
DEILEGGA GROUP		500 m +		?

Tab. 5: Variation of the Höferpynten Formation from BIRKENMAJER (1962).

Tab. 5: Schwankungen der Höferpynten-Formation nach BIRKENMAJER (1962).

The following summarizes the sequence as seen along the coast from east to west:

Lower Palaeozoic unit (from MAJOR & WINSNES, 1955: 9—10)

Tsjebysjovfjellet limestone and

Rasstupet limestone (400 m)

Nigerbreen silicified limestone (120 m)

Hornstullodden dolostones and limestones (80 m)

The above may correspond in part to the Gråkallen rocks to the south which have Early Ordovician fossils.

Phyllitic limestone (5 m) with Early Cambrian fossils probably equivalent of Slakli rocks to south.

Gåshamna phyllite unit

Described by WINSNES (1955) as mostly green phyllite and possibly 1.5 km thick; exposed mostly to the south of the shore. The middle part is south of Gåsbreen. The eastern (uppermost) subdivision, as exposed at or near the shore, is about 500 m of predominantly black shales and phyllites. The western (lowermost) subdivision is variable, with green and grey slates and phyllites. The contact to the west (in Wurmbrandegga)is certainly tectonic, so with both its top and bottom truncated the full extent of this unit cannot be seen here.

Gåshamna tilloid unit

Probably this occurs as a thin tectonic slice between the Gåshamna phyllite unit and the Höferpynten unit. A specimen of tillite was collected by HOEL and RØVIG in 1917 and referred to by FØYN (WILSON & HARLAND, 1964: 216). In 1977 I observed a narrow talus train of distinctive tilloid facies (not tectonized) coming from the position of the thrust as though from an obscured thrust slice. The 1917 specimen was probably collected here.

Höferpynten unit

WINSNES (1955) described this unit in three zones from east to west (i. e. top to bottom):

3. Quartzite
2. Limestone with oolites
1. Dolomite with cherts

BIRKENMAJER (1972) described the formation in more detail and in four members (see Table 5).

I now list six divisions of the Höferpynten unit to take account of what has been published.

6. Höferpynten quartzite division

As described by WINSNES these rocks clearly connect with the Höferpynten rather than the overlying Gåshamna unit with which they were classified by BIRKENMAJER when he described these rocks. I estimated a thickness of at least 300 m, with at least three prominent ribs of quartzite. The softer beds between these ribs are not exposed near the shore. The quartzites interdigitate with phyllites which grade into the underlying division.

5. Höferpynten oolitic limestone division

This was redescribed by BIRKENMAJER as the Dunøyane Member. It contains the conspicuous stromatolite bed near the top and is stratigraphically just beneath the lowest quartzite bed. The bulk of this division (40 m) is of grey limestone with oolites (WINSNES, 1955) but contains pale weathering dolomitic oolites and pisolites (BIRKENMAJER 1972, 1977).

4. Wurmbrandegga dolomite division

This is the upper part of WINSNES' dolomites. It was distinguished by BIRKENMAJER by lack of cherts and named the Wurmbrandegga Member with a thickness of 350 m. It is a massive grey dolostone with occasional current bedding.

3. Andvika dolomite division

This is the lower part with cherts and so named as one of BIRKENMAJER's four members, 300 m thick. It is a grey dolomite with chert layers that are more continuous in the upper part.

2. Knivodden division — upper part

This part of the sequence was distinguished by BIRKENMAJER as the Fannytoppen Member with a thickness of 20 m. It is a complex of grey-greenish and yellowish dolostones.

1. Knivodden division — lower part

This appears to be what BIRKENMAJER mapped as the Slyngfjellet Conglomerate with a thickness of 10 m in this section. It bears little resemblance to the rocks north of Hornsund (tilloid unit; c. 1.5 km) with which he correlated it. It is not a polymict conglomerate. Deformed lenticular yellow or reddish quartzitic pebbles and boulders 2 to 20 cm in diameter with a matrix of equally deformed quartz phyllite were observed. It is interpreted provisionally as a silicified intraformational conglomerate that may have been dolomitized before it was silicified. It appears to be conformable with, and is here grouped with, the other carbonate units of the Höferpynten unit.

Sigfredbogen unit

The next oldest rocks are described by BIRKENMAJER (e. g. 1972) as more than 300 m of slates and phyllites of the upper division (Bergskardet Member) of the Deilegga Group. I do not question this correlation but for discussion only in this paper I differentiate it with another name. BIRKENMAJER claimed conformity and I do not see any evidence of a stratigraphic or tectonic break. At this point the Höferpynten and Sigfredbogen units might well be conformable, thus in one locality not providing support for the Torellian diastrophism.

4.2 North of Hornsund

Sofiekammen Group (from BIRKENMAJER, 1959)

Nørdstetinden strata
Gnålberget marbles
Grey limestone with *Protolenus*
Shales with *Olenellus*
Blåstertoppen dolomite

The rocks that are described below are clearly older (i. e. in part or wholly Precambrian). Although the contact is tectonic where seen at the coast, BIRKENMAJER reports a stratigraphic transition.

Sofiebogen Group

This group name as used by BIRKENMAJER in this area is retained but the constituent units are listed again and renamed for discussion of correlation from youngest to oldest (i. e. east to west and top to bottom).

Bogstranda unit (c. 2.5 km)

This is without doubt the equivalent of the Gåshamna phyllite unit as originally described by WINSNES to the south. It is more continuously exposed here, altogether thicker (i. e. about 2.5 km) and appears to pass stratigraphically down into the next unit. It is dominantly a phyllite lithology with the upper part more calcareous and the lower part pelitic. The lowest beds are purple and green slates passing down into brown-weathering silty shales.

Basal quartzite division (c. 5 m)

A thin bed (few metres at most) of tectonized black quartzite with white irregular quartz veins is noted because it is distinguished in a sequence on the north-east slope of Fannytoppen and also on the shore where the younger Bogstranda strata are observed.

Fannytoppen unit

A dearth of place names has led me to use this name even though it has already been used by BIRKENMAJER (e. g. 1972, 1977) to describe the lowest part of the unit as described here.

Pisolitic division (0—24 m)

A pale-weathering pisolitic dolostone shows dramatic oncolitic structures and has been described in detail by RADWANSKI & BIRKENMAJER (1977) as the Dunøyane Member of the Höferpynten Formation. On the basis of pisolitic texture alone this is an obvious correlation, but the related rocks throw doubt on this. It occurs as a conspicuous cliff on the north-east spur of Fannytoppen, but is not evident round to the north of that mountain where it would be expected; nor does it occur in the shore exposures, so it appears to wedge out.

Dolostone division (14 m)

The next 14 m were described by BIRKENMAJER (1972, 1977) as the Wurmbrandegga Member, which is 350 m thick across the fjord to the south and with which this division has few features in common. It weathers to a pale brown colour rather than dark grey and is tectonically laminated, appearing to be altogether less competent.

Limestone division (80 m)

This division was described by BIRKENMAJER (1972) as the Fannytoppen Member of the Höferpynten Formation and appropriately it is the largest part of my Fannytoppen unit. It is made of "phyllites and laminated limestone" here, whereas the rock described south of Hornsund and referred to as the Fannytoppen Member by BIRKENMAJER comprises 20 m of dolostone.

Tilloid unit

Fannypynten tilloid division

This tilloid facies is characterized by a great range in size and composition of dispersed clasts. About half the stones are quartzite, a fifth feldspathite and the remainder of dolostone, limestone and schist in approximately equal proportions. The rock has been tectonically much elongated and sedimentary structures have been destroyed; never-

theless the impression is of a typical tillite. From the presence of feldspathites (granite and granitic gneisses) it would appear to be similar to other late, as distinct from early, Varangian tillites.

Middle division
A stratigraphic thickness of about 500 m appears not to be exposed. It would lie beneath the shingle beach of the tombolo extending out from Fannypynten.

Hansbreen tilloid division
Occupying the rocky promontory at the western end of the tombolo is an outcrop of tilloid of greyish overall colour in which dolostone, limestone and quartzite dispersed stones dominate and no feldspathites were observed. BIRKENMAJER (1959) noted a colour contrast between the lower and upper divisions.

4.3 South of Bellsund

We may now look forward to a definitive study of this area by Dr. C. Craddock and his co-workers which will have taken into account the tectonic complications of the area. In the meantime it may be useful to tabulate the general succession as it emerges from studies made during short visits in 1974, 1975, 1977 and 1978 (in the course of other work).
Five large units (or groups) are distinguished, whose mutual relationships are not clear, but while tectonic contacts are commonly observed it is probable that they can be arranged in stratigraphic order and are listed below from the top (western, youngest) down to the bottom (eastern, oldest).

Kapp Lyell unit

This unit is characterized by conglomerates of one kind or another. From the Kapp Lyell coastline GARWOOD & GREGORY (1898) first described a conglomerate with very large exotic granite boulders from the shore at "Fox Point" as a glacial moraine of probable Precambrian age. Spitsbergen is now known to be rich in Varangian (Vendian) tillites. However, recent investigation suggests that the rock described might occur as blocks of tillite slumped in Palaeogene time not so recognised until our investigation of the Tertiary sequence in 1975. This appears to lie at the base of Tertiary graben deposits and is located one or two kilometres west of Renardodden in the innermost part of Skilvika.

Lyellstranda division
The top is not seen, the rocks dipping into the sea along Lyellstranda. The unit is largely composed of massively bedded quartzitic sandstone and conglomerate, often with graded bedding in units commonly one metre (and up to 5 m) thick. The coarsest basal units have stones up to 10 cm in diameter, suggesting formation as turbidites from a source where stones of quartzite, dolostone and limestone were abundant. This division passes down through softer black shales and slates into the

Renardbreen division (1 to 2 km)
This unit is dominantly of tilloid lithology. A greater variety of stones is evident in this tilloid, which outcrops both in the east (at Renardbreen), in the west (at Dundrabreen and Tunodden), and up Dunderdalen — this being one outcrop area of HJELLE's (1969) Bellsund-Dunderdalen tillite. The name Renardbreen is preferred as it is placed within the sequence that runs, possibly continuously, eastward and downward from the youngest Lyellstranda division. The facies is of tilloidal pelite deformed by chevron and gleit-bretter-style folding, forming resistant dark cliffs on both sides of Renardbreen as well

as in the west. The stones are mostly pale dolostone and dark limestone, exceptionally with granite. Several stones up to half a metre in diameter were observed.

Slate and quartzite division
This is less competent, less exposed and certainly faulted. It is thus difficult to survey along the coastal area.

Chamberlindalen unit

This unit overall is less competent than the overlying and underlying units which form hilly regions. The valley exposes a complex of ridges, some isolated, in which there is a general sequence with much variety of lithology.

Upper division
This consists principally of carbonates, both limestone and dolomitic marbles, with grey oolitic limestones in the upper part and amygdaloidal basalt just beneath. These more competent strata appear to be interbedded with phyllites that are not so well exposed.

Lower division
Asbestos has been excavated in the Asbestodden basic rocks, both on the coast and up the valley where pyroclastic lavas and small intrusions occur. Pelites and carbonates are interbedded with volcanics.

Solhögda unit

This is a dominantly carbonate unit, occupying much of the mountain ridge from the coastal cliffs in the north and seen in cliffs along the west of Recherchebreen further south. Three divisions can be distinguished by colour.

Upper division
Bedded grey limestone and dolostones predominate.

Middle division
Yellow-weathering, dolomitic and black bituminous limestone marbles are found.

Lower division
This consists of pale yellow-weathering, dolomitic marbles with dark volcanics.

Konglomeratfjellet unit

This unit is dominantly of quartzose composition and varies in grain size from conglomerate to siltstone, all highly tectonized. It outcrops in dark mountain cliffs with scree along the west of the upper part of Recherchebreen. The name is taken from HJELLE's (1969) account oft this seqquence which is confirmed. However, as we have not been over the whole ground we are not sure whether there is one main conglomerate facies or more than one, so the sequence described here is what was observed up Recherchebreen and related to observations on Konglomeratfjellet from Chamberlinpasset.

Gaimardtoppen division (? 500 m)
A dark psammitic, semi-pelitic facies.

Foldnutane conglomerate division (? 500 m +)
This could be the same as HJELLES's Konglomeratfjellet Conglomerate. His description fits. It is made of well-rounded boulders mainly of grey quartzite deformed in lensoid

shapes in a quartzitic schistose matrix (similar to the body of the Gaimardtoppen facies). The downward continuation of the sequence up the glacier was not observed, but from a study of moraines no other major rock facies outcrops on the west side of Recherchebreen.

Magnethögda unit (? 1 km +)

This unit occupies the mountain ridge east of Recherchefjorden and Recherchebreen. We have only briefly visited it, but it appears to have some distinctive characteristics — in particular the occurrence of acid feldspathites as well as amphibolites within a sequence of psammites and marbles. It is different from, and probably older than, the units described above, being separated by a least 2 km of ice or water which could be the locus of a major tectonic lineament.

4.4 Mid-Bellsund (Western Nathorst Land)

The low ground and cliffs at the western promontory extending from Midterhuken expose a small area of older rocks cropping out beneath the Lower Carboniferous basal conglomerate.

Midterhuken unit

A sequence of more than 1 km of well-bedded marbles of variable calcareous and dolomitic facies passing (to the SW) into calc-phyllites. No dispersed stone, nor pisolitic textures were seen. Nor was any way-up evidence seen.

4.5 North of Bellsund

The sequence north of Bellsund was published in outline by HJELLE (1962, 1969). I had seen it briefly on three occasions, but the following summaries are taken from a few days work in 1978. The sequence is clearly folded and repeated by faulting. Moreover, there are large gaps obscured by Quaternary and Recent deposits and we did not have time to work out a full sequence; so it is presented here in two parts.

4.5.1 *Sequence west of Van Muydenbukta*

This summary is from an account kindly offered by Mr. P. WADDAMS and Dr. M. HAMBREY. There is a general dip to the west. Structural complexity accounts for the widely-ranging figures for thickness. The names of the units follow HJELLE (1969).

Lågnesbukta unit

The whole sequence in the west is of carbonates and phyllites with dispersed stones and some volcanics appearing in a variety of facies.

Diabaspynten division (c. 100 m)
Along the west coast amphibolites form three promontories and comprise both tuffaceous metasediments and some lavas. These volcanic facies are closely associated with, and interbedded with, the upper part of the Lågneset tilloid division in which this division might well be included. Its top is not seen where the strata dip into the sea.

Lågneset tilloid division (250 m +)
This consists of an orange-grey weathering, sandy phyllite with dispersed clasts

consisting dominantly of white quartzite with subordinate limestone and dolomite fragments. This division may either be relatively thin (150 to 250 m), being repeated by faulting, or with two tillite beds it may achieve a thickness of up to 1 km.

Lågnesrabbane calcareous division (1—2 km)
This division is of softer facies and forms the embayment of Lågnesbukta, consisting largely of laminated grey limestone, grey to green calcareous phyllite and subordinate massive white limestone beds. Limestone and distinctive orange-weathering dispersed dolomite stones occur that are matched in other tilloid units north and south of Bellsund.

Kapp Martin dolomite division (c. 600 m)
Well-bedded light grey dolostone with beds of green calcareous schist form the rocky headland to the west of Kapp Martin.

Kapp Martin conglomerate division (c. 800 m)
Beds of various facies with recurring conglomerate are present. The stones are of dolostone (50%), quartzite (35%), limestone (10%) and schist (5%). They are sometimes graded and sometimes interbedded with black pisolitic limestone and black phyllites. Some pisolitic limestones contain dispersed stones up to 10 cm across and some beds are well graded. The lowest strata seen are calcareous schists.

4.5.2 *Sequence east of Van Muydenbukta*

The strata dip westwards from beneath the Lower Carboniferous basal conglomerates at Millarodden. The way-up has not been confirmed, but on general grounds it seems possible that the strata are overturned and young eastwards.

Millarodden tilloid unit (up to 0.5 km)

Eastern (? upper) division (c. 200 m)
This is a tilloid rich in dispersed stones. These are mainly dolostones, but quartzites and limestones are also present.

Western (? lower) division (c. 200 m)
There are large dolostone clasts (up to 80 cm) at the western end, while the remainder of the division is of fissile limestones with very occasional dolostone clasts.

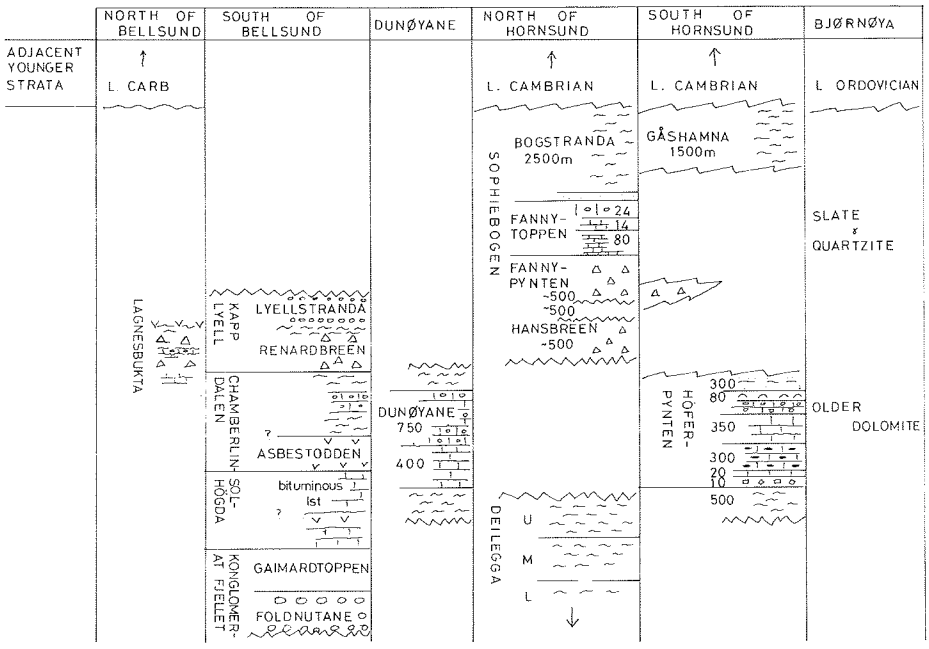
Vårsolbukta limestone unit
No exotic stones were seen in this unit.

Eastern (? upper) division (c. 0.5 km)
This is mainly black massive limestone with white veins, interbedded occasionally with black fissile limestones and green and grey phyllites.

Western (? lower) division (c. 1 km)
Massive black limestone that forms the headland and islands at the western end of Vårsolbukta and the eastern shore of Van Muydenbukta. Exposure near the shore then ceases.

5. TENTATIVE CORRELATION OF REVISED SEQUENCES AND OUTSTANDING QUESTIONS

To stimulate further work rather than to present a conclusion, I tabulate my present thinking about correlation in Southern Svalbard in Table 6 and put these speculations



Tab. 6: Southern Svalbard sequences suggested by this paper.

Tab. 6: Abfolgen in Süd-Svalbard, wie sie in dieser Arbeit vorgeschlagen werden.

into place in Svalbard as a whole in Table 7. While I prefer these interpretations, insufficient work has been done to establish them. Indeed it is very unlikely that the whole of this scheme would survive.

Oolites and pisolites appear to have been the key lithologies in BIRKENMAJER's correlation, and indeed this paper suggests that these facies as seen at Höferpynten and in Fannytoppen are not of the same age. This may appear premature for one who has not seen the facies in Dunøyane — the eponymous locality of BIRKENMAJER's pisolitic member. However, we have evidence of pisolite amongst tilloid facies in the Kapp Martin conglomerate division north of Hornsund. It would indeed seem that terms such as pisolite, conglomerate etc. have been used as critical elements in correlation from the literature.

Not having seen Slyngfjellet I have avoided this name because it seems to me that conglomerates of two quite different ages have been so labelled.

(1) One group of conglomerates includes the extensive tilloids that I have little doubt correlate with the Vendian/Varangian tillite units elsewhere in Svalbard. In the mobile depositional environments of western and southern Spitsbergen these strata may well achieve 5 km or more in thickness. It seems to be unnecessary to distinguish any part of the sequence to the north-west of Bellsund from this tillite, tilloid, conglomerate, carbonate stratigraphic rock group (Lågnesbukta unit).

(2) The other conglomerate, that is different in facies and appears to be much older, was described by HJELLE at Konglomeratfjellet and so distinguished by him. This lower

stratigraphic position would more nearly fit BIRKENMAJER's sequence, in which all the tilloids/conglomerates are placed below the Höferpynten rocks.

Too close a parallel between lithological sequences of the different areas need not be expected if, as has been argued (e. g. HARLAND & WRIGHT, in press), the areas were far more distant at the time of deposition of the strata. On this basis a contrast would be expected between the sequences of Bellsund (except for the Magnethögda unit) and Hornsund; the former belonging to the Western Province and the latter to the Central Province. Indeed, whether initially formed far apart or not, the sequences are indeed different and so more field work must take the place of assumptions about correlation. I have already cautioned against using the name Hecla Hoek for rocks far away from Ny Friesland, such as those discussed here (e. g. HARLAND & WRIGHT, in press).

According to this scheme for Hornsund, some of the evidence for BIRKENMAJER's crustal deformations (e.g. 1977: 14) is weakened if not eliminated. Radical redrawing of the map (Fig. 2) would be necessary anyway, and from this the places where contacts between the rock groups are not tectonic would need critical investigation. On the face of it the Torellian and Jarlsbergian phases are questioned.

Acknowledgements

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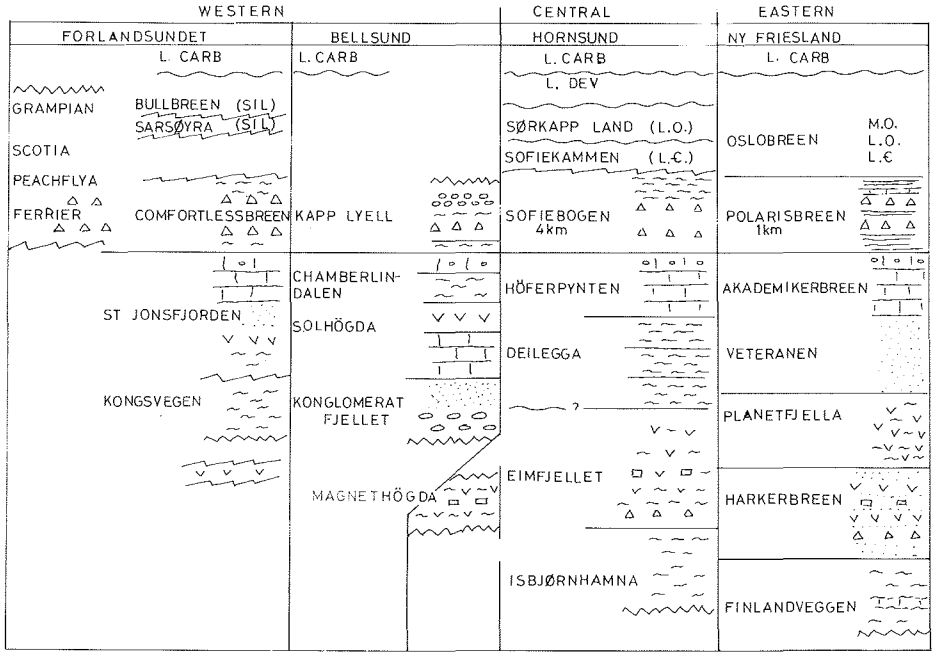

Tab. 7: Correlation of Western, Central and Eastern sequences suggested by this paper.

Tab. 7: Vergleich der Folgen im Westen, im Zentralbereich und im Osten Spitzbergens, wie sie in dieser Arbeit vorgeschlagen werden.

Wright accompanied me on several days in 1977 and the whole work was only possible because of the mobility (albeit restricted) afforded by Cambridge Spitsbergen Expedition transport (e. g. Polar Record 19 (48): 54 and earlier issues). Ms K. Fancett typed several drafts and C. A. G. Pickton helped assemble the manuscript.

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