Alternative hypothesis for the pre-Carboniferous evolution of Svalbard

By W. B. HARLAND and N. J. R. WRIGHT

Contents

Abstract

The stratigraphy of pre-Carboniferous Svalbard is reviewed in four major provinces. It is argued that at least three of these provinces exposed in Spitsbergen (Eastern, Central, and Western) have distinctive sequences whether their biostratigraphic or lithotectonic characters be compared. On this basis alternative palaeogeological models are compared.

One, a palaeofixistic model assumes for the time in question that the areas of Svalbard were in approximately their present relationship (having restored them to a position prior to late Phanerozoic continental drift).

The other, a palaeomobilistic model, separates these three provinces by late Devonian sinistral transcurrent faulting. The differences within Svalbard are then explained because the rocks were formed when far apart, and indeed when the constituent parts were nearer either East Greenland, or North Greenland and the Queen Elizabeth Islands. This hypothesis, suggested some years ago, is developed with more evidence than has previously been available.

I. Introduction

The Svalbard Archipelago contains critical evidence for the tectonic history of a very much larger part of the Earth's crust extending in the present Arctic to all the surrounding continental areas. There is an exceptionally rich record of events in late Precambrian and Phanerozoic strata. This record now makes it possible to reconstruct the pre-Carboniferous history of Svalbard, and a hypothesis with major horizontal displacements is argued.

1. OLDER ROCK COMPLEXES

The pre-Carboniferous rocks of Svalbard have traditionally been divided into the Devonian "Old Red Sandstone" and the pre-Devonian "Hecla Hoek" on the assumption that sequences throughout Svalbard can be best described and correlated in this way. HARLAND et al (1974) pointed out that this approach may be invalid because, if the possibility of large scale horizontal displacements along the Billefjorden Fault Zone be considered, there is no basis for assuming that the pre-Devonian sequences to the west should match the Hecla Hoek sequence of Ny Friesland.

We propose to make no such assumptions regarding pan-Svalbardian correlation here. Whether or not we interpret correctly, it is better at the outset of an investigation to distinguish diverse elements in a hypothesis, which can subsequently be equated should that be justified, rather than to assume a unity which, if not justified, could confuse the investigation.

The pre-Carboniferous rocks have been described in the literature as the result of surveys of geographical areas within which a unified stratigraphy can be discerned. We identify about twelve such areas, and use the term "complex" for the major rock bodies exposed. The term complex, larger than supergroup, implies that the sequence may not be fully understood, nor continuous, and it allows for the presence of extraneous elements.

2. PALAEOGEOLOGICAL PROVINCES

We suggest here that the twelve different complexes can be grouped in three or more provinces which correspond to major areas of present day Svalbard. The provinces are shown in Table 1 and each has distinct stratigraphic and

Table 1.
Provinces and complexes

Eastern Province (EP)

Ny Friesland (NF)
Nordaustlandet, western and central parts (NE)
More distant Nordaustlandet, Storøya and Kvitøya (EX)

Central Province (CP)

North Central with Andrée Land and related areas (NC)
South Central with Eastern Wedel Jarlsberg and Sørkapp Lands (SC)
North Western Spitsbergen from Raudfjorden to Kongsfjorden (NW)

Western Province (WP)

Brøggerhalvøya (WB)
Remainder of Oscar II Land (WO)
Prins Karls Forland (WK)
Western Nordenskiöld and Nathorst Land (WN)
Western Wedel Jarlsberg Land (WS)

Southern Province (SP)

Bjørnøya (BI)
Related part of South Barents Shelf (BS)

structural characteristics. Correlation between the complexes of one province is possible to a greater or lesser extent. We suggest, however, that detailed correlation between provinces may not be feasible, except by the long distance time-correlation characters reviewed in Chapter VI, and that this is because of the distant separation of the provinces at the time of formation of the rocks.

This division into three or more provinces (HARLAND 1972a) has recently become more plausible because of a growing understanding of the stratigraphic sequence in western Spitsbergen. Our group and others have now worked in this area for several years and, although many problems remain, the time is ripe to correlate the several complexes of the Western Province. The pre-Carboniferous sequence of this province contrasts strongly with the Central and Eastern Provinces both in facies and age, and the name Holtedahl Geosyncline has been proposed for these distinctive rocks (HARLAND, HORSFIELD, MANBY, and MORRIS, this volume).

3. PROVINCIAL BOUNDARIES AS FAULTS

Elsewhere (HARLAND et al. 1974) reasons have been given for supposing that substantial sinistral strike-slip motion took place along the Billefjorden Fault Zone (BFZ) during the Svalbardian (late Devonian) movements. Total movement of not less than 200 km and possibly 1000 km was suggested. That this major lineament separates regions of contrasting pre-Carboniferous strata has been assumed by others (e.g. KRASIL'SHCHIKOV 1973) and we take the BFZ to separate the Eastern and Central Provinces.

We also propose an analogous, but entirely speculative, fault or fault zone separating the Central and Western Provinces, with sinistral strike-slip motion

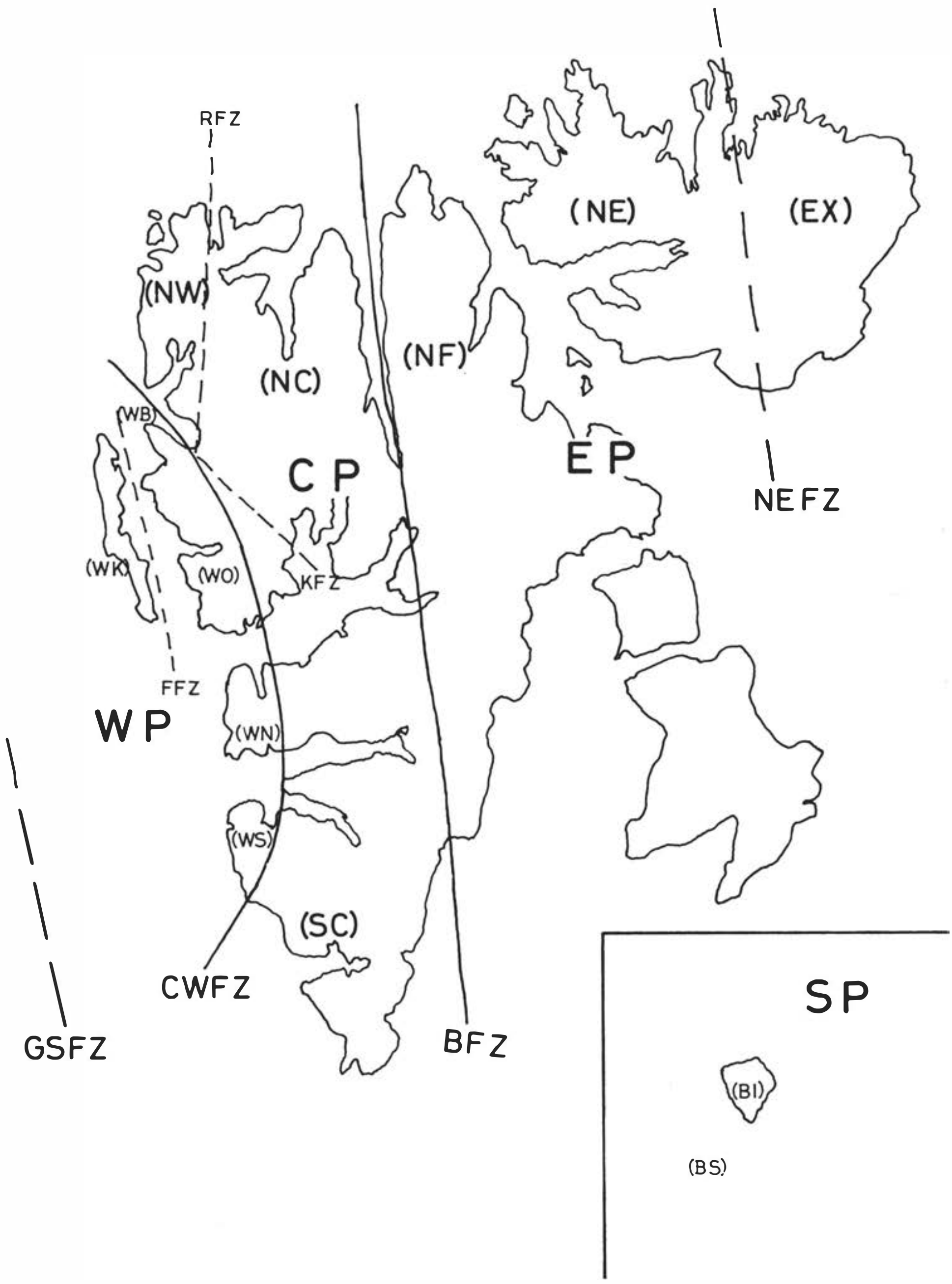

Fig. 1. *Map of Svalbard showing location of pre-Carboniferous complexes, the suggested provinces and the boundary fault zones. Abbreviations of complexes and provinces are shown in Table 1 (in brackets).*

CWFZ – Central–West Fault Zone
GSFZ – Greenland-Svalbard Fault Zone
FFZ – Forlandsundet Fault Zone
RFZ – Raudfjorden Fault Zone
KFZ – Kongsvegen Fault Zone
BFZ – Billefjorden Fault Zone
NEFZ – North–East Fault Zone

of the same phase as the BFZ. We name this the Central West Fault Zone (CWFZ, see Fig. 1). We suggest that the fault zone is concealed beneath the front of the West Spitsbergen Orogen (it may even have provided some control over the location of the orogen) and thus no continuous surface expression of the fault zone is preserved. During sinistral transcurrence in late Devonian time the CWFZ would have been straight; its present postulated curved shape would be the result of dextral transpression and overthrusting during the mid-Cenozoic West Spitsbergen Orogeny (LOWELL 1972; HARLAND and HORSFIELD 1974).

The CWFZ passes within Torellbreen, dividing the north-west from the rest of Wedel–Jarlsberg Land, and to the east of the older rock outcrops up the west coast to Kongsfjorden. While Kongsfjorden seems to be the most probable route, a splay of the fault might run directly to the north, determining the line of the Raudfjorden Fault Zone.

The Kongsfjorden–Kongsvegen line (KFZ) may be considered in two parts. The north-western part is equated to the northern extension of the CWFZ, while a possible extension to the south-east (as for example in KRASIL'SHCHIKOV's map 1973) may be another splay.

The major tectono-stratigraphic provinces proposed here, along with their constituent complexes and the major fault boundaries suggested, are shown in Figure 1.

4. APPROACH TO THIS STUDY

The four provinces indicated above will be outlined, in terms of their constituent complexes, in Chapters II to V. In Chapter VI we consider those characters that make long-distance international time-correlation possible. We then compare the provinces by reference to those other characters of more regional or local significance, in order to assess alternative hypotheses of palaeopositions. Two such hypotheses are compared in the last chapter.

II. Eastern Province

1. NY FRIESLAND AND WESTERN NORDAUSTLANDET COMPLEX

The Eastern Province comprises the most completely elucidated pre-Silurian (Hecla Hoek) sequence in Svalbard, whose type development is in North Ny Friesland at Heclahuken and whose earliest investigators worked also in western Nordaustlandet. Lithofacial correlation across Hinlopenstretet is sufficiently detailed to justify including rocks on both sides of the strait in the same province. An apparently continuous sequence has been published and most formations have been divided into two or more members, many of which can be correlated, but only the formations and groups are correlated in Table 2. Convenient sources (taking only recent references in each case) are KULLING 1934; HARLAND and WILSON 1956; HARLAND, WALLIS, and GAYER 1966; FLOOD et al. 1969; KRASIL'SHCHIKOV 1973; FORTEY and BRUTON 1973; WINSNES 1965.

Table 2.

NY FRIESLAND

HINLOPENSTRETET SUPERGROUP

<u>Oslobreen Group</u> (1.2km)

Valhallfonna Fm (limestones)
Kirtonryggen Fm (limestones and dolomites)
Tokammane Fm (dolomites and sandstones)

<u>Polarisbreen Group</u> (0.8km)

Drakoisen Fm (shales)
Wilsonbreen Fm (tillites)
Elbobreen Fm (shales)

LOMFJORDEN SUPERGROUP

<u>Akadamikerbreen Group</u> (2km)

Backlundtoppen Fm (dolomites and shales)
Draken Conglomerate Fm
Svanbergfjellet Fm (limestones and dolomites)
Grusdievbreen Fm (limestones)

<u>Veteranen Group</u> (3.8km)

Oxfordbreen Fm (shales)
Glasgowbreen Fm (greywackes and quartzites)
Kingbreen Fm (quartzites and shales with greywackes and carbonates)
Kortbreen Fm (quartzites and limestones)

STUBENDORFFBREEN SUPERGROUP

MOSSEL PHASE

<u>Planetfjella Group</u> (4.8km)

Vildadalen Fm (semipelites, psammites and quartzites)
Flåen Fm (semipelites, psammites and quartzites with acid pyroclastics)

ATOMFJELLA PHASE

<u>Harkerbreen Group</u> (4.1km)

Sørbreen Fm (quartzites and psammites)
Vassfaret Fm (semipelites, psammites and amphibolites)
Bangenhuk Fm (feldspathites, psammites and amphibolites)
Rittervatnet Fm (psammites, semipelites and amphibolites)
Polhem Fm (quartzites and amphibolites)

<u>Finnlandveggen Group</u> (2.7km)

Smutsbreen Fm (semipelites and marbles)
Eskolabreen Fm (feldspathites, semipelites and amphibolites)

NORDAUSTLANDET

MURCHISONFJORDEN SUPERGROUP

Kap Sparre Fm (limestones)

<u>Gotia Group</u> (0.6km)

Klackberget Fm (shales with sandstones and marls)
Sveanor Fm (tillites)
Backaberget Fm (shales with sandstones and marls)

<u>Raoldtoppen Group</u> (1.3km)

Ryssö Fm (dolomites with limestones, cherts and shales)
Hunnberg Fm (limestones)

<u>Celsiusbreen Group</u> (2.1km)

Raudstup-Sälodd Fm (dolomites and sandstones)
Norvik Fm (sandstones with shales)
Flora Fm (sandstones)

<u>Franklinsundet Group</u> (1.8km)

Kapp Lord Fm (mudstones with sandstones and limestones)
Westmanbukta Fm (mudstones and siltstones)
Persberget Fm (quartzites and shales)

— — — — — — — — — UNCONFORMITY

<u>Botniahalvøya Group</u> (>6km)

Kapp Platen Fm (quartzites and shales)
Austfonna Fm (quartzites and limestones)
Brennevinsfjorden Fm (quartzites, siltstones and shales)
Kap Hansteen Fm (acid volcanics)

In summary, this Ny Friesland Geosyncline totals at least 18 km in thickness. The two lower groups (Finnlandveggen and Harkerbreen), which are combined as the Atomfjella phase of development by KRASIL'SHCHIKOV (1973), are characterized by acid and basic volcanics but by only a few conglomerates and one tilloid sequence in the Rittervatnet Formation. The Planetfjella and equivalent Botniahalvøya Group (KRASIL'SHCHIKOV'S Mossel phase) are characterized by mainly acid volcanics. Thereafter almost no igneous activity is evident and the sequence assumes miogeosynclinal characteristics by degrees, through greywackes to platform-type limestones and dolomites of late Riphean through Llanvirnian age, interrupted only by the clastic sequence correlated with the Varangian ice age. No significant break in this sequence has been established and there is very little evidence of tectonic mobility except for volcanic components becoming increasingly coarse to the east. The highest rocks in the sequence contain one of the richest known mid-Ordovician faunas.

2. EASTERNMOST COMPLEX (EX)

This comprises the most distant area of eastern Nordaustlandet and the islands further east such as Storøya and Kvitøya. The strata are entirely metamorphosed. The only radiometric ages are Caledonian (GAYER et al. 1966) and these are associated with extensive migmatites. The sequences could be coeval with the "Lower Hecla Hoek" but, as no precise correlation has been attempted, the possibility of an independent province should be considered. It was once proposed that this area was one of Archaean basement rocks and it seems that Krasil'shchikov separates this province on that account. If there was an ancient craton then parts of it have been remobilized. We keep an open mind on this question.

If a different easternmost province be considered then a zone of one or more faults may be implied, and we suggest the name North East Fault Zone (NEFZ) for this possibility. It may be useful not only as a key to the structures of Nordaustlandet but also for interpreting the structure of the Barents Shelf to the south.

III. Central Province

The province comprises three different terrains. The North Central area is occupied by Old Red Sandstone rocks, resting unconformably on a metamorphic complex that may be continuous with the north-west coast of Spitsbergen. There are faults dividing these older rocks and so, until correlation is secure throughout the region, a North West Complex is distinguished. Both these areas are separated from the South Central (Hornsund) Complex by outcrops of younger rocks of the Platform Sequence. We see no reason why all three complexes should not be combined into a single province.

1. NORTH CENTRAL COMPLEX (NC)

The Old Red Sandstone sequence began with the recently discovered Siktefjellet Group (GEE and MOODY-STUART 1966), of unknown (possibly late Silurian) age, that rests unconformably on metamorphic rocks with late

Table 3.
Old Red Sandstone sequences of Central Province.

North Central Province		South Central Province
Andrée Land Group (5 km)		*Marietoppen Group* (1 km)
Wijde Bay Fm	Mimer Valley Fm	Upper
Grey Hoek Fm		Middle
Wood Bay Fm	Wood Bay Fm	Lower
Red Bay Group (2 km)		
Ben Nevis Fm		
Frænkelryggen Fm		
Andréebreen Sandstone		
Red Bay Conglomerate		
UNCONFORMITY		
Siktefjellet Group (<2 km)		
Siktefjellet Sandstone		
Lilljeborgfjellet Conglomerate		

Caledonian radiometric ages. Then followed folding, faulting and possible thrusting (the Haakonian movements of GEE 1972), and a new unconformity developed. The clastic Red Bay Conglomerates are basal to the remainder of the relatively fine-grained, mostly continental, Old Red Sandstone sequence that persisted there without break or widespread conglomerates until Eifelian time (e.g. FRIEND and MOODY-STUART 1972).

The break which followed, before latest Devonian or earliest Carboniferous time, accommodated the Svalbardian movements with significant strike slip movement at least along the Billefjorden Fault Zone (HARLAND et al. 1974) and by analogy probably along other faults, e.g. CWFZ.

2. NORTH WESTERN COMPLEX (NW)

This large area comprises not only the mainland of northwestern Spitsbergen but also the off-lying islands (e.g. Amsterdamøya etc.), and extends from Raudfjorden to Kongsfjorden. It is a unified terrain with a coherent stratigraphy over large areas, with metasedimentary rocks of limited type passing downwards into migmatites, and cut by a late tectonic granite pluton.

The range of rock types led to correlation of these with the Lower Hecla Hoek Stubendorffbreen Supergroup of Ny Friesland (HARLAND 1960), and when the sequence was established with three formations (Table 4) GEE and HJELLE (1966) correlated them in detail (on the basis of marbles) with Ny Friesland. These arguments are good only insofar as the rocks might have formed at something like their present separation.

Most radiometric dates indicate that the main metamorphism and granite formations were Caledonian, but there remains the possibility of residual late Precambrian ages (GAYER et al. 1966). If late Precambrian diastrophism occurred this would distinguish the sequence from that in Ny Friesland where there is no such break, and this possibility was used to suggest closer proximity of the NW complex to NE Greenland where the Carolinidian Orogen (HALLER

Table 4.

Sequence of older rocks of North West Complex.

Generalfjella Formation (2 km)
Marbles and interbanded marbles, pelites and quartzites in the lower part

Signehamna Formation (2–2.5 km)
Pelites with psammites and subordinate quartzites

Nissenfjella Formation (3 km)
Pelites with subordinate amphibolites and psammites. Feldspathic gneisses. Passes down into migmatites.

Migmatite

1971) appears similarly to contrast with the sequence in Central East Greenland (HARLAND 1969a).

Correlation of rocks north and south of Kongsfjorden is not at all obvious, and so in this paper we separate them by the CWFZ. Even if the rocks are not equivalent the NW complex could possibly underlie the western sequence stratigraphically or tectonically. Correlation with the South Central Complex is not obvious but the oldest rocks that might be of equivalent age are few and might not be coeval, so there is no contradiction in combining them into one province.

3. SOUTH CENTRAL COMPLEX (SC)

This comprises the older rocks outcropping in south Spitsbergen, and includes both pre-Devonian strata and the Devonian Marietoppen Group of Old Red Sandstone facies. These have been investigated from Hornsund, first to the south by Norsk Polarinstitutt expeditions in Sørkapp Land (MAJOR and WINSNES 1955) and then to the north, in southern Wedel Jarlsberg Land, by Polish expeditions (e.g. BIRKENMAJER 1958). The Devonian strata have been correlated with the Old Red Sandstone sequence to the north, and are shown in Table 3. Correlation of the pre-Devonian strata north and south of Hornsund was effected in some detail (e.g. BIRKENMAJER 1960), so these are not distinguished in Table 5.

Seeking a provincial boundary to fulfil the function of the CWFZ proposed above, a hypothetical Birgebukta fault was proposed (HARLAND 1972a), but closer study shows that a N-S fault so far east would not fit the evidence. Therefore the CWFZ is now postulated to be west of the whole sequence shown in Table 5.

Correlation has been readily assumed between SC and NE sequences (e.g. HARLAND 1960 and BIRKENMAJER 1958) but a close connection between these areas is now called into question.

IV. Western Province (WP)

This province comprises the area from Kongsfjorden to Bellsund-Recherchefjorden. The constituent complexes outcrop in the following geographical areas: 1. Prins Karls Forland; 2. Brøggerhalvøya; 3. Oscar II Land (less

Table 5.

Sequence of older rocks of South Central Complex.

Sørkapp Land Group (1.7 km)

h Arkfjellet Fm (slates and dolomites)
g Sjdanovfjellet Fm (limestones and dolomites)
f Tsjebysovfjellet Limestone
e Rasstupet Limestone
d Nigerbreen Limestone
c Dusken Limestone
b Luciapynten Dolomite
a Wiederfjellet Quartzite

UNCONFORMITY

Sofiekammen Group (0.8 km)

b Slaki Fm b2 Slaki Limestone
b1 Olenellus Shale
a Blåstertoppen Dolomite

Sofiebogen Group (2.5 km)

c Gåshamna Fm (phyllites with quartzites and limestones)
b Höferpynten Fm (limestones, dolomites and chert)
a Slyngfjellet Conglomerate

UNCONFORMITY

Deilegga Group (3.5 km)

c Upper Fm (slates and phyllites with quartzites)
b Middle Fm (slates and phyllites with dolomites)
a Lower Fm (dolomites and conglomerate)

Eimfjellet Group (1.5 km)

b2 Vimsodden Fm (slates and phyllites with amphibolites, limestones and schists)
b1 Skålfjellet Fm (amphibolites, schists and quartzites)
a Gulliksenfjellet Fm (quartzites)

Isbjørnhamna Group (1.5 km)

c Revdalen Fm (garnetiferous mica schists)
b Ariekammen Fm (garnetiferous mica schists and marbles)
a Skoddefjellet Fm (garnetiferous mica schists)

(After BIRKENMAJER 1960, with his "series" raised to the status of Formation etc.)

Brøggerhalvøya); 4. Western Nordenskiöld Land; 5. Western Nathorst Land (a very small outcrop); 6. Northern Wedel Jarlsberg Land. The northern boundary is a clear tectonic line. The boundary in the south may not be geologically obvious though a major fault line has been shown here by KRASIL'SHCHIKOV (1973 p. 103).

The northern part of the province, north of Isfjorden (areas 1 to 3), is the subject of another paper in this symposium (HARLAND, HORSFIELD, MANBY, and MORRIS) from which the details (in Table 6, columns 1 and 2) are entirely derived. Western Nordenskiöld Land and northern Wedel Jarlsberg Land are shown in column 3 and depend on work by HJELLE (1962 and 1969).

Table 6.

PRINS KARLS FORLAND	OSCAR II LAND	"BELLSUND"	
		NORDENSKIÖLD LAND	NORTH WEDEL JARLSBERG LAND
<u>Grampian Group</u> (3.6 km)			
Geddesflya Fm (turbidites)			
Fugelhuk Fm (quartzites,slates)	<u>Bullbreen Group</u> (0.7 km)		
Barents Fm (turbidites)	Holmesletfjella Fm (calc slates,conglomerates)		
Conqueror Fm (quartzites)	Motalafjella Fm (limestones)		
Utnes Fm (slates,quartzites)			
<u>Scotia Group</u> (1.0 km)			
Roysha Fm (siltstones,slates)			
Kaggen Fm (slates)	Sarsøyra Fm (0.5 km)(marbles,argillites)		
Baklia Fm (siltstones,slates,limestones)			
<u>Peachflya Group</u> (1.3 km)			
Knivodden Fm (phyllites)			
Hornnes Fm (phyllites,sandstones)			
Alasdairhornet Fm (volcanics)			
Fisherlaguna Fm (phyllites)			
<u>Geikie Group</u> (0.77 km)			
Rossbukta Fm (sandstones)			
Gordon Fm (limestones)			
<u>Ferrier Group</u> (0.73 km)	<u>Comfortlessbreen Group</u> (2-4 km)	<u>Kapp Linné Group</u> (1.3 km)**	
Neukpiggen Fm (tillites)	Engelskbukta Fm (tillites)	(NORDENSKIÖLD LAND)	(NORTH WEDEL JARLSBERG LAND)
Peterbukta Fm (greywackes)	Annabreen Fm (quartzites)	Laagneset Fm (tillites)	Kapp Lyell Fm (tillites, conglomerates)
Hardiefjellet Fm (tillites)	Haaken Fm (tillites)	Kapp Martin Fm (shales)	
Isachsen Fm (tillites,schists,volcanics)	<u>St Jonsfjorden Group</u> (3.8 km)	<u>Bellsund Group</u> (1.4 km)**	
	Alkhorn Fm (limestones)	Laagnesflya Fm (dolomites,limestones)	Konglomeratfjellet Fm (quartzites,dolomites, limestones,conglomerates)
	Lovliebreen Fm (quartzites,volcanics)		
	Moefjellet Fm (dolomites)		
	Trondheimfjellet Fm (varied lithologies)		
? Pinkie Fm (0.2 km)(metavolcanics)	<u>Kongsvegen Group</u> (3.1 km)		
	Nielsenfjellet Fm (Mullerneset Fm)(pelites,quartzites)		
	Steenfjellet Fm (slates)		
	Bogegg Fm (schistose pelites)		
? Pinkie Fm (0.2 km)(metavolcanics)	? Vestgötabreen Fm (blue schist metavolcanics)		[** Hjelle (1962 and 1969)]

Visits by WBH to these areas south of Isfjorden have strengthened the view that correlation throughout the Western Province is feasible and correlation with Ny Friesland, for example, is not so obvious. Characteristic of the Western Province are thick flyschoid and conglomeratic sequences with volcanic horizons below, within, and above the tillite horizons. Also, the very rich sequence of turbiditic conglomerates associated with the Kapp Lyell tillite has no analogue a short distance away in the Southern Province; we satisfied ourselves from the literature that the Slyngfjellet conglomerate is not coeval.

HARLAND et al. (this symposium) postulate for the northern part of this Western Province a geosyncline of 18 to 20 km thick, of distinct facies, a substantial part of it consisting of Palaeozoic rocks up to Wenlock or Ludlow age. The sequence shows similarities with that of North Greenland or the Queen Elizabeth Islands and leaves place for orogeny of Ellesmerian rather than Ny Friesland–Caledonian affinity.

V. Southern Province (SP)

Bjørnøya is a distinct and isolated entity that completes the land areas in Svalbard exposing pre-Carboniferous rocks. KRASIL'SHCHIKOV and LIVSHITS (1974) recognised two pre-Devonian structural complexes, of late Precambrian and Ordovician age, and their sequence is related to the original descriptions of HOLTEDAHL (1920) and HORN and ORVIN (1928) in Table 7.

Table 7.
Sequence of older rocks in Bjørnøya.

KRASIL'SHCHIKOV and LIVSHITS 1974				HORN and ORVIØ 1928
Devonian		Rødvika Formation		Ursa Sandstone
Ordovician	L	Ymerdalen Fm.	Upper Member	Tetradium Limestone 240 m
	M-L		Middle Member	Younger Dolomite 400 m
			Lower Member	
Vendian		Sørhamna Formation		Slate-Quartzite 175 m
Late Riphean		Russehamna Formation		Older Dolomite 400 m

The Caledonian structures of Bjørnøya contrast strongly with the rest of Svalbard. A hiatus occurred during Cambrian time with a phase of minor folding (as has been suggested for south Spitsbergen) but the overlying Ordovician rocks are almost flat-bedded and show few signs of major tectonic activity.

VI. Time-correlation of sequences

Characters in the sequences of the three provinces that have value in international time correlation are tabulated, with the object of distinguishing those with long range correlation potential from those which would only be useful over a short distance. Conclusions from the following are set out in Fig. 2. Age determinations are treated according to the nature of the characters used: 1 biostratigraphic; 2 palaeoclimatic; 3 radiometric; 4 lithotectonic.

1. BIOSTRATIGRAPHIC SEQUENCE

A. *Devonian*

The coal-bearing continental sandstones and shales of the Røedvika Formation in Bjørnøya are dated as Famennian to Tournaisian on the basis of macro- and microfloral assemblages (SCHWEITZER 1969; KAISER 1970, 1971). However, they are both lithologically and structurally part of the post-Svalbardian Billefjorden Group.

Middle and Lower Devonian fish of Spitsbergen are among the richest Old Red Sandstone faunas anywhere and compare closely with British continental faunas which, in southern England, interdigitate with the type marine sequence of Europe.

A relatively limited fauna is found in the Mimer Valley Formation, comprising several fish groups (especially Psammosteids and the Antiarch *Asterolepis*) which have long been recognised as being of late Middle Devonian age (Givetian) (for fuller list of Devonian faunas see FRIEND 1961). The formation also contains plant remains (and a cannel coal), and VIGRAN (1964) described two microfloral assemblages from near the top and near the base of the formation. These may be dated with some confidence as Frasnian and Late Givetian respectively.

The Wijde Bay Formation contains an assemblage of Heterostraci, Arthrodira, Antiarchi, Crossopterygii, molluscs and plants. FØYN and HEINTZ (1943) regarded the assemblage as Givetian.

The underlying Grey Hoek Formation contains Osteostraci, ?Heterostraci, Arthrodira, Petalichthyida, Crossopterygii, bivalves, gastropods, ostracods, charophytes and land plants. The fish genera *Lunaspis*, *Homostius*, *Heterostius* and *Porolepis* are significant, and together with the molluscs suggest an Emsian to early Eifelian age.

The Wood Bay Formation has yielded a very rich vertebrate fauna and has been subdivided into three faunal divisions (FØYN and HEINTZ 1943; FRIEND, HEINTZ and MOODY-STUART 1966), of which the lower two are used for international correlation. The "Lykta" fauna consists of Osteostraci, Heterostraci, Arthrodira, Crossopterygii and Charophyta; the significant genera are *Doryaspis*, *Arctolepis*, *Homostius*, *Actinolepis* and *Porolepis*, and suggest a mid-Siegenian to Emsian age (Breconian) (DINELEY 1960). The lowest faunal division is similar, but the Cephalaspids *Giganthaspis* and *Arctaspis* are present and suggest a Siegenian age.

The two higher formations of the Red Bay Group are fossiliferous, containing Osteostraci, Heterostraci, Acanthodii, Arthrodira, ostracods, bivalves, worms, Merostomata and plants, and, largely on the basis of close comparison of the Heterostracan and Cephalaspid genera with those of the Anglo-Welsh area, the assemblages have been dated as Dittonian (Ben Nevis Formation) and

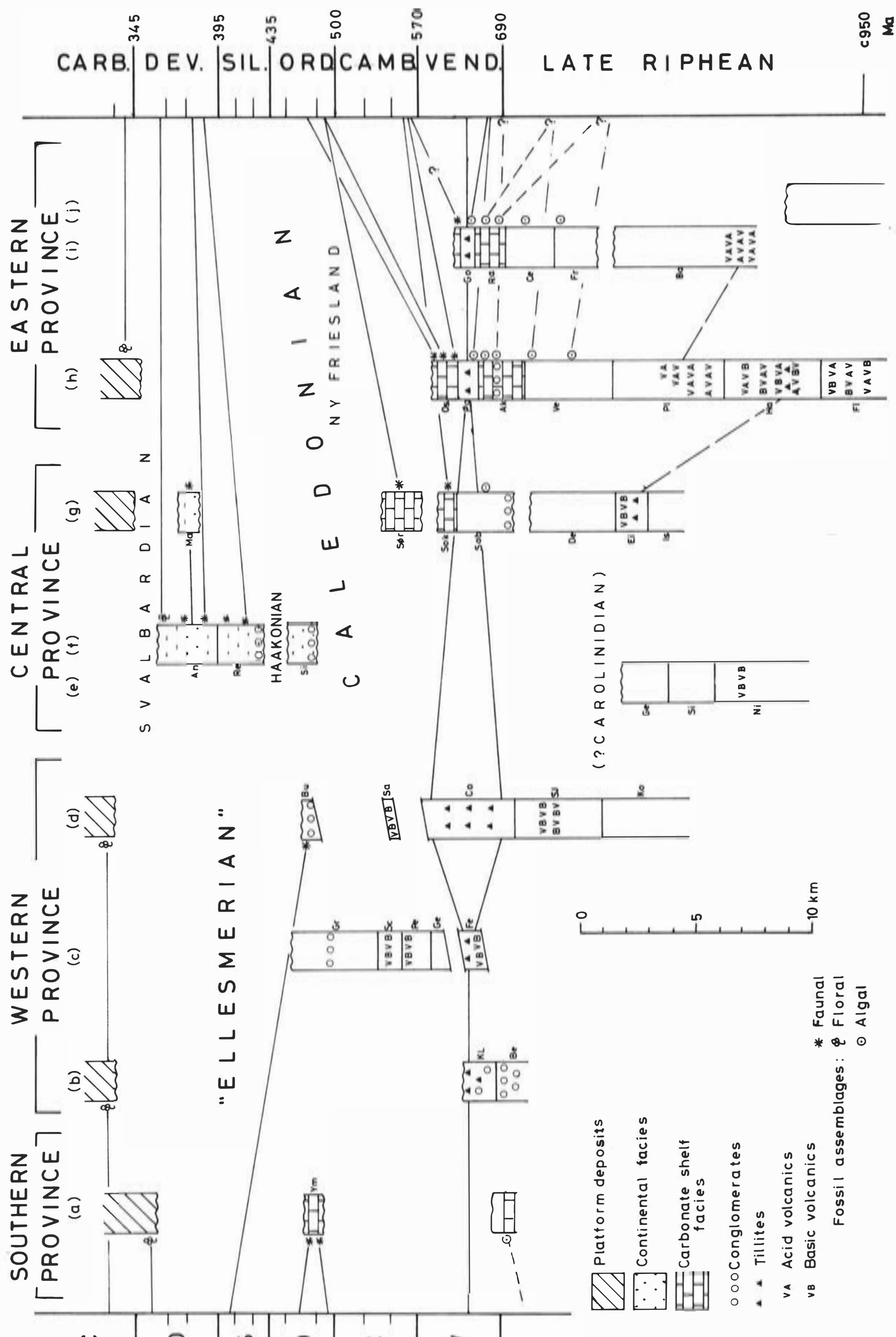
CARB. DEV. SIL. ORD CAMB VEND. LATE RIPHEAN
345
395
435
500
570
690
c950 Ma
SOUTHERN PROVINCE (a)
WESTERN PROVINCE (b) (c) (d)
CENTRAL PROVINCE (e) (f) (g)
EASTERN PROVINCE (h) (i) (j)
SVALBARDIAN
HAAKONIAN
CALEDONIAN
NY FRIESLAND
"ELLESMERIAN"
(?CAROLINIDIAN)
0 5 10 km
Platform deposits
Continental facies
Carbonate shelf facies
Conglomerates
Tillites
VA Acid volcanics
VB Basic volcanics
Fossil assemblages: Faunal Floral Algal
C
D
S
O
Є
V

Fig. 2.

Late Downtonian/Dittonian (Frænkelryggen Formation) (i.e. mid and late Gedinnian).

B. *Silurian*

The Bulltinden Member in the Bullbreen Group is a coral-bearing shelf carbonate limited to the Western Province (HARLAND et al. this Symposium). The fauna has been provisionally identified as of Wenlock or Ludlow age (SCRUTTON, HORSFIELD and HARLAND 1976).

C. *Mid-Early Ordovician faunas*

The "Tetradium Limestone" of Bjørnøya yields a fauna including *Tetradium syringoporoides* and the cephalopod genera *Gonioceras* and *Actinoceras*. HOLTEDAHL (1920) stated that the fauna indicates a Black River (Bolarian) age.

The underlying "Younger Dolomite" contains a fossiliferous horizon 250 m below the top which yields the genera *Calathium*, *Atchaeoscyphia* and *Piloceras*, indicating a Canadian age.

Better defined Canadian faunas occur in the south Central Province (Sørkapp Land Group), where gastropods, brachiopods, sponges and cephalopods occur. The fauna and facies resemble the Beekmantown Group of (eastern) North America (MAJOR and WINSNES 1955; BIRKENMAJER 1958, 1960).

The Eastern Province contains exceptionally rich trilobite and graptolite faunas in the Valhallfonna Formation. Several assemblages have been distinguished (FORTEY and BRUTON 1973); the youngest is dated as early Llanvirn, while the base of the formation contains an early Arenig graptolite fauna.

The underlying Kirtonryggen Formation contains abundant trilobites, brachiopods, nautiloids, gastropods and ostracods. Two assemblages, in the top and bottom members of the formation, are of stratigraphic importance and indicate Upper and Lower Canadian ages respectively when compared with western North America.

D. *Cambrian faunas*

No definite Middle or Late Cambrian faunas are known anywhere in the Western Arctic, although poorly preserved brachiopods (probably obolids)

←

Fig. 2. *Correlation scheme of pre-Carboniferous strata in Svalbard. Height of columns represents thickness of strata preserved. Characters used in international tim*ₑ *correlation and local correlation are shown in the key.*

The names of each group, with brief lithology of formations, are given in Tables 2 to 7. Group names are abbreviated in the figure beside each column.

(a) Bjørnøya (Table 7)
(b) Nordenskiöld Land and N.W. Wedel Jarlsberg Land (Table 6)
(c) Prins Karls Forland (Table 6)
(d) Oscar II Land (Table 6)
(e) North west Spitsbergen (Table 4)
(f) North central Spitsbergen (Table 3)
(g) South Spitsbergen (Tables 3 and 5)
(h) Ny Friesland (Table 2)
(i) Western Nordaustlandet (Table 2)
(j) Eastern Nordaustlandet

occur in the top part of the Sofiekammen Formation of Hornsund which may be Late Cambrian. COWIE (1974) has suggested a hiatus as the explanation in the Ny Friesland area; alternatively tropical shallow marine conditions could have been chemically inimical to the occurrence or preservation of faunas within the lower Kirtonryggen dolomites.

In the south of the Central Province a rich trilobite fauna was described by MAJOR and WINSNES (1955) from the Slaki Formation (Sofiekammen Group), including *Serrodiscus*, *Callodiscus* and *Olenellus* species. They correlated this fauna with the late Early Cambrian (Georgian) of North America.

In the Eastern Province *Salterella* cf. *rugosa* has been known from the Tokammane Formation of Ny Friesland (HARLAND and WILSON 1956) with hyolithids and a single *Olenellus*. The supposed equivalent of these rocks in Nordaustlandet is the Kap Sparre Formation in which Hecla Hoek fossils were first found (inarticulate brachiopods). These may not be chronostratigraphically distinctive and a superficial re-examination of the Kap Sparre section by WBH suggested that correlation of these rocks with the Ordovician part of the Kirtonryggen Formation should be examined.

E. *Vendian*

Relatively abundant Vendian and Late Riphean floras of stromatolites, microphytolites, oncolites and katagraphites exist in the late Precambrian carbonates of Nordaustlandet, Ny Friesland, Hornsund and Bjørnøya. The stratigraphic value of some of these algal forms may be dubious but they have been used by Soviet workers to distinguish several Precambrian age-assemblages on a broad scale.

Vendian assemblages have been described from the Backaberget Formation of Nordaustlandet, where dolomite bands contain the oncolite species *Osagia svalbardica* and the katagraphite *Vermiculites irregularis* (KRASIL'SHCHIKOV, GOLOVANOV and MIL'SHTEIN 1965). In the Polarisbreen Group shales of Ny Friesland, MIL'SHTEIN reported microphytolite assemblages from the *Vesicularites*, *Nuberculerites*, *Radiosus* and *Volvatella* groups, correlated with groups in the Vendian of the Urals and Timan (MIL'SHTEIN in KRASIL'SHCHIKOV 1973 and this volume).

F. *Late Riphean*

Late Riphean stromatolite assemblages have been described from the Hunnberg and Ryssö Formations of Nordaustlandet by GOLOVANOV (1967), including species of the groups *Conophyton*, *Kusiella*, *Inseria*, *Gymnosolen* and *Tungussia*, which he compared with the Upper Riphean Karatau rocks of the Southern Urals. The Hunnberg Formation also contains the katagraphite *Vesicularites flexuosus* and the oncolite species *Osagia columnata*, again indicating Late Riphean age. Further down the succession, the Norvic Formation is said to contain oncolites of the *Asterospheroides* and *Radiosus* groups, of Riphean age, while *Osagia* of a mid-Riphean type is reported from the Kapp Lord Formation (GOLOVANOV and RAABEN 1967).

In Ny Friesland, stromatolite and microphytolite assemblages occur in the Backlundtoppen, Draken and Svanbergfjellet Formations of the Akademikerbreen Group. The highest formations contain oncolites of the *Osagia* group with both Upper Riphean and Vendian affinities, and stromatolites of the *Conophyton* and *Tungussia* groups. The Draken Formation contains microphytolites (*Vesicularites* and *Radiosus* groups) of possible Vendian age (RAABEN and ZABRODIN 1969). The underlying Svanbergfjellet Formation contains Upper Riphean stromatolites of the *Inseria*, *Conophyton*, *Tungussia* and *Gymnosolen* groups and many microphytolites of the *Vesicularites* and *Osagia* groups. A late Riphean microphytolite assemblage of *Radiosus*, *Asterospheroides* and *Volvatella* types occurs in the Oxfordbreen Formation, while the Kingbreen Formation contains stromatolites of the *Inseria* and *Collenia* types as well as microphytolites of the *Rachosis* and *Osagia* groups, also indicative of late Riphean age (RAABEN and ZABRODIN 1969).

In south Spitsbergen, stromatolites occur in the upper part of the Høferpynten Formation. They were described by BIRKENMAJER (1972) who doubted their stratigraphic value but correlated the horizon with the Draken Formation of Ny Friesland. MIL'SHTEIN (this Symposium) reports a microphytolite assemblage of possible Middle-Late Riphean age, suggesting perhaps a correlation with the Veteranen Group of Ny Friesland.

The Older Dolomite (Russehamna Formation) of Bjørnøya is reported by MIL'SHTEIN to contain microphytolites of Late Riphean type.

2. PALAEOCLIMATIC CORRELATION

A. *Ordovician*

The possibility that a tilloid in the Holmesletfjella beds of Oscar II Land was a tillite had been seriously considered (HARLAND 1972b), but a further visit in 1975 to the locality showed (by associated conglomerates) that this pebbly mudstone was probably not glacial. Indeed, almost simultaneously, its Silurian age was established. No other rocks have been suggested as Ordovician tillites.

B. *Varangian*

There is still some argument about the origin of the Svalbard tilloids but even those who are sceptical of a glacial origin agree that the Arctic tilloids provide good marker horizons for correlation. However, if a glacial origin be admitted, and the evidence for this is strong (e.g. CHUMAKOV 1968), then this distinct climatic episode has a wider international correlation potential. Low latitude glaciation in this part of the Arctic has been argued (e.g. HARLAND 1964; HARLAND and HEROD 1975) and so what has been referred to as the Varangian Ice Age provides a powerful correlation character, in association with which orthoconglomerates should not be ignored.

There can be little doubt of the correlation value, both local and international, of the Varangian tillites of the Eastern Province. The Sveanor tillite is well developed between the Klackberget and Backaberget Formations; similarly, in the Polarisbreen group, the Wilsonbreen tillite lies between shales of the Drakoisen and Elbobreen Formation (see Table 2). The tillites often occur in two members as is characteristic of Varangian tillites generally.

Tillite horizons of the Western Province are different; they are more deformed and often slightly metamorphosed so that much primary evidence of sedimentation has been lost; they are in very much thicker flysch sequences so that they are associated with both slumped and turbiditic rocks and also with conglomerates. The Comfortlessbreen Group of Oscar II Land and the Ferrier Group of Prins Karls Forland are of the order of 3 to 4 km thick and each contains two tillite formations. In Nordenskiöld Land, if a similar thickness and varied facies be assumed, then most of the tilloids and conglomerates, from the Kapp Linné tillite in the north to the Kapp Martin tillite in the south, are of this age. Also in northwestern Wedel Jarlsberg Land the Kapp Lyell tillite first described by GARWOOD and GREGORY in 1898, is a remarkable, thick sequence consisting of a minority of beds that are tillitic and a great majority of coarse thick turbidite units, from 1 to 2 m, each with initial conglomerates (clasts up to 10 and 20 cm) and grading upwards to coarse or fine sandstone. The clast content has similar composition to that of the tillites.

No tillites have been recorded from the Central Province, with one possible exception (WILSON and HARLAND 1956, p. 216). From their stratigraphic position it seemed most likely to us and to Birkenmajer that the Gåshamna shales of Hornsund could be equivalent to the upper and/or lower shales of the Polarisbreen Group. The lack of obvious tillites in this sequence could be due to uplift of the Central Province at the time of lowest sea level. Conversely, the lack of conglomerates or obvious break between the pre-Varangian Høferpynten Formation and the Cambrian Sofiekammen Group would be surprising if the Kapp Lyell conglomerates and tillites were forming at anything like their present distance.

The upper and lower tillites of the type area in Varangerfjord (Norway) are separated by the Nyborg Formation which has yielded a radiometric age of 668 ± 13 Ma (PRINGLE 1973).

C. *Pre-Varangian tillites*

The only tilloids of this age reported from Svalbard are the Vimsodden tilloid of the South Central Province and the Rittervatnet tilloid of Ny Friesland. The latter occurs 12 km beneath the Varangian tillites, as does the Gnejssø tillite of East Greenland on which basis correlations have been attempted (e.g. HARLAND 1964). Similar correlation within Spitsbergen between the provinces is also feasible.

3. RADIOMETRIC AGES

Most radiometric ages obtained from the older rocks relate to the Central and Eastern Provinces and are Caledonian (*sensu stricto*), i.e. roughly 420 to 380 Ma. Nothing earlier than this would be expected in Ny Friesland where an unbroken sequence of older rocks is found, but there have been anomolous ages to the east and west that are difficult to interpret (GAYER et al. 1966).

In the Western Province not only is the earlier story overprinted by Mid-

Palaeozoic metamorphism (e.g. HORSFIELD 1972) but the region also suffered Mid-Cenozoic diastrophism.

In conclusion, little correlation can be done from present data (mostly K-Ar) but a further attempt at dating some of the old rocks is being made using Rb-Sr methods.

4. LITHOTECTONIC CORRELATION

The virtual absence of biostratigraphic, palaeoclimatic and radiometric characters in the oldest rocks of Svalbard presents a major problem for all but local time-correlation. The lithostratigraphic recognition of rock bodies and similar sequences of lithotypes is applicable only when the areas of comparison were physically close and can be shown to be part of a structurally continuous regime. If the four major provinces of Svalbard were once separated, attempts at lithological correlation between provinces (e.g. by volcanics or marbles) are suspect.

An attempt was made by HARLAND and GAYER (1972) to reach an independent estimate of the age of the Ny Friesland succession by comparing the observed thickness with known overall sedimentation rates from other Caledonian geosynclinal sequences. There is a clear distinction between the younger part of the succession (Akademikerbreen, Polarisbreen and Oslobreen Groups) which develops mainly shelf carbonate lithologies, and the older part (Finnlandveggen, Harkerbreen, Planetfjella and Veteranen Groups) in which volcanics and clastics occur. Assuming sedimentation rates of 80–200 m/Ma for the older sequence by comparison with similar geosynclines, HARLAND and GAYER concluded an age of 1055–950 Ma (Middle–Late Riphean) for the base of the observed sequence. The method may be dubious, as it relies to some extent on a circular argument, but it gave an estimate when no other seemed possible. Because such an estimate is in effect based on a net-subsidence rate it is reasonable only to apply it in averaging large thicknesses of strata.

KRASIL'SHCHIKOV (1973) presented an overall scheme of time-correlation, with five separate large-scale chronostratigraphic divisions. His Cambro-Ordovician, Vendian and Late Riphean units are all based on independent time-correlation characters, but his older divisions (Early Riphean and Early to Mid Proterozoic) are supported by no independent evidence. We think that the correlation is based only on a lithological comparison of Svalbard sections with dated successions elsewhere and on the belief that the whole post-Archaean sequence is present and exposed. Krasil'shchikov's correlation dated the oldest Ny Friesland rocks as 2600 Ma, which gives an average sedimentation for the "eugeosynclinal" sequence of 8m/Ma; this figure we consider to be too low by a factor of least 10 when compared to similar dated sequences. Moreover we do not know of other geosynclines that have subsided without interruption for 2200 Ma.

VII. Characteristics of the different provinces

The object of this section is to consider those characteristics that provide evidence for the separation of the provinces.

1. BIOLOGICAL

A. *Devonian*

Outcrops of Devonian rocks in Spitsbergen are confined to the Central Province, and therefore no provincial comparisons can be made. However, a very wide correlation of the assemblages with those of the Old Red Sandstone in Central East Greenland, NE America and Britain suggests that the late orogenic "Old Red Land" was a unified faunal province with no major ecological barriers.

B. *Silurian*

Apart from the barren (possibly late Silurian) Siktefjellet Group in the Central Province the only established Silurian fauna is in the Western Province. No such fauna is known in East Greenland but Silurian faunas are known in North Greenland and in the Canadian Arctic Islands.

C. *Ordovician*

The Ordovician fauna of Ny Friesland is exceptionally rich, and is still in the process of being described. On the basis of the trilobites, FORTEY (1974) has commented on the close similarity of the fauna with that of the Cap Weber Formation in East Greenland. The youngest Ordovician fauna was compared by WHITTINGTON (1965) with the Table Head Formation of Newfoundland.

No direct comparison can be made with the Ordovician Sørkapp Land Group because, although fairly abundant gastropods, brachiopods, cephalopods and porifera occur, no trilobites have yet been found. Time-correlation has been based on comparison of the cephalopods with North American occurrences, but no detailed assemblage comparison has been noted.

The Ordovician fauna of Bjørnøya is similarly devoid of trilobites, and rather restricted in forms. Three of the genera found can be compared with genera from Sørkapp Land (MAJOR and WINSNES 1955), but the faunas are not closely related.

Thus the three provinces which yield Ordovician faunas do not as yet reveal any close similarities. Comparison of the Ny Friesland and South Spitsbergen faunas may prove to be closer than they appear at present when the cephalopods of Ny Friesland have been described. However, such a study may alternatively bring to light a real difference.

D. *Cambrian*

Cambrian faunas occur only in the Eastern and Central Provinces. In Ny Friesland the assemblage is restricted and consists mainly of inarticulate brachiopods and burrows (GOBBETT and WILSON 1960). In contrast, the Sofiekammen Formation of South Spitsbergen yields a wide trilobite assemblage of Pacific Province type, despite the development of very similar limestone/dolomite/clastic shelf facies in both provinces. This difference of faunas was noted by COWIE who concluded: "The contrast in Cambrian faunas between Ny Friesland and south-west Vestspitsbergen implies the existence at that time of a geographical-ecological barrier" (1974, p. 129).

E. *Precambrian*

Stromatolites, oncolites, and katagraphites are widespread in the shelf carbonate facies of the Eastern and Central Provinces but cannot be easily distinguished. The Western Province has so far yielded only oncolites except in the tillite clasts.

2. LITHOGENETIC

A. *Continental facies*

Old Red Sandstone facies of Early and Middle Devonian age are limited to the Central Province. The earliest Continental Sandstones in the Eastern, Western and Southern Provinces are of latest Devonian to early Carboniferous age. The Central East Greenland Old Red Sandstone is of Middle and Upper Devonian age. Old Red Sandstone facies of Devonian age are not familiar in North Greenland.

B. *Carbonate facies*

Carbonate shelf facies with relatively clean quartzites and shallow-water carbonates are developed to a greater or lesser extent in the Late Riphean to Ordovician strata of the Eastern, Central and Southern Provinces. In contrast, the Western Province is entirely lacking such "miogeosynclinal" sequences. Such facies are typical of the Cambro–Ordovician sequence of Central East Greenland but not so in Peary Land.

C. *Flyschoid facies*

Calcareous flyschoid turbidites are characteristic of much of the Western Province, especially during Varangian and Early Palaeozoic times, in contrast to stable shelf facies for these ages in the other three provinces.

D. *Conglomerates*

Apart from tilloids discussed already, the presence and abundance of conglomerates is indicative of tectonic mobility. In the Eastern Province conglomerates other than tillites are very rare, the principal exceptions being the Kapp Hansteen Formation volcanic agglomerates and the Draken intraformational conglomerates. In the Central Province there are remarkable conglomerates at the base of the Old Red Sandstone (both Siktefjellet and Red Bay) as well as the pre-Varangian Slyngfjellet Conglomerate. In the Southern Province there are no major conglomerates. In the Western Province, on the other hand, conglomerates occur at many horizons, mostly of Silurian Age (Sutor and Bulltinden Formations), as well as thick tillites and conglomerates of Varangian age.

E. *Volcanic facies*

No Palaeozoic or Varangian volcanics are known in the Eastern, Central or Southern Provinces. In the Western Province, volcanic rocks occur in three or more horizons above the Varangian tillites, probably of both Cambrian and

Ordovician age, and at least one major volcanic episode occurs within the tillite sequence.

Similarly, in late Riphean sequences no volcanics are known from the Eastern, Central or Southern Provinces but occur in the Western Province (Løvliebreen Formation).

Because of the difficulty of correlation of earlier rocks no precise meaningful comparison can be made, but it is clear that each province is different. It is probable that the Western Province does not have very old rocks of any facies – certainly the Kongsvegen Group are not volcanic. The Central Province has limited volcanics among the older rocks of the Nissenfjella Formation in the NW and the Eimfjellet Group in the South. On the other hand the whole of the lower 12 km of the Eastern Province geosyncline has a large volcanic component (acid in the Mossel phase and both acid and basic in the earlier Atomfjella phase).

3. TECTOGENETIC

The structural sequences of the provinces are distinct.

The Eastern Province evolved from a mobile eugeosynclinal sequence in late Riphean times to a stable shelf of miogeosynclinal character, and the Ny Friesland Orogeny probably spanned late Ordovician and Silurian times with batholithic emplacement. This is a typical orthotectonic Caledonian sequence, and only the local Svalbardian faulting followed in late Devonian time before a stable Carboniferous platform cover was deposited.

The Central Province is more fragmented. The North West complex may have suffered a late Precambrian orogeny (Carolinidian of Haller 1971) before the main Caledonian sequence accumulated. The latter was associated with Old Red Sandstone continental detritus interrupted by the Haakonian diastrophism at about the end of Silurian time. In the South Central Complex the later Precambrian sequence is broken by unconformities, and was later affected by the Cenozoic West Spitsbergen Orogeny.

In both the Central and Eastern Provinces, the deposition of Billefjorden Group platform deposits began in earliest Tournaisian or late Famennian times (Cutbill, Henderson, and Wright, in press), and although minor faulting along the BFZ continued to affect sedimentation patterns, the two provinces were essentially united from that time.

The Western Province preserves a distinct sequence of 18–20 km (the Holtedahl Geosyncline) which is mobile and eugeosynclinal, and a substantial part of which is Varangian and Early Palaeozoic. The main deformation, involving metamorphism and overthrusting to the west, was late and/or post Silurian, and there is no Devonian record (cf. Ellesmerian rather than Caledonian). Stable Billefjorden Group platform deposition did not begin until Namurian times (Orustdalen Formation – see Cutbill and Challinor 1965), and it therefore seems probable that late orogenic movements continued in the Western Province after the Central and Eastern Provinces had stabilised.

In the Southern Province a major unconformity separates the older Precambrian strata from the Ordovician shelf carbonates, and some folding and faulting occurred during this episode (KRASIL'SHCHIKOV and LIVSHITS 1974). However, the Ordovician strata are almost completely unaffected by Caledonian deformation; Silurian and Devonian "Old Red Sandstone" strata are absent, and Billefjorden Group sedimentation began in Famennian times.

VIII. Discussion and conclusion

When only a little information is available simplistic correlation encourages making a coherent hypothesis at an early stage. Up to now perhaps too few data have been available for alternative models to be challenging. Even now the evidence is insufficient to decide between major alternative hypotheses; but the time is ripe to consider some of them so as to focus on critical points of difference.

1. A PALAEOFIXISTIC MODEL

It is generally accepted that Mesozoic and Cenozoic opening of the Atlantic and Arctic Ocean basins moved Spitsbergen, along with the Barents Shelf, away from a position north of Greenland. However, many pre-Permian reconstructions have not adopted any major pre-Permian horizontal displacement. We present as one model for comparison a minimal displacement hypothesis (Fig. 3). KRASIL'SHCHIKOV (1973) postulated a sequence of early reconstructions of the Spitsbergen archipelago on a fixistic basis but we differ in postulating different boundaries to the provinces by emphasising different fault lines.

One implication of this model is that for latest Riphean through Ordovician time the thick, flyschoid sediments of the Western Province are not likely to have been transported across the Ny Friesland geosyncline which, although near sea level, was of finer sediment. The source could be in the Central Province to the north, or more probably the west.

2. PALAEOMOBILISTIC HYPOTHESIS

As indicated at the outset the contrast between the three or four sequences suggests that the strata were formed at much greater distances apart than now. Comparisons between strata in Svalbard and elsewhere had already suggested an initial Svalbardian (late Devonian) strike slip so as to relate the Eastern pre-Devonian sequence to that of Central East Greenland and the post-Devonian sequence of Svalbard with that of the Canadian Arctic (HARLAND 1965). At that time the fault line was thought to be west of Spitsbergen. We now refer to this conceivable fault as the Greenland Svalbard Fault Zone (GSFZ). Subsequently (e.g. HARLAND 1969a) the possibility of faults both within and to the west of the archipelago, to achieve the same total displacement, was considered, and by 1974 (HARLAND et al.) the Billefjorden Fault Zone was established as a line of displacement (of between 200 and 1000 km).

The revised hypothesis here accepts a minimum displacement of 200 km for the BFZ (say 500±250 km) and postulates a further and greater displacement

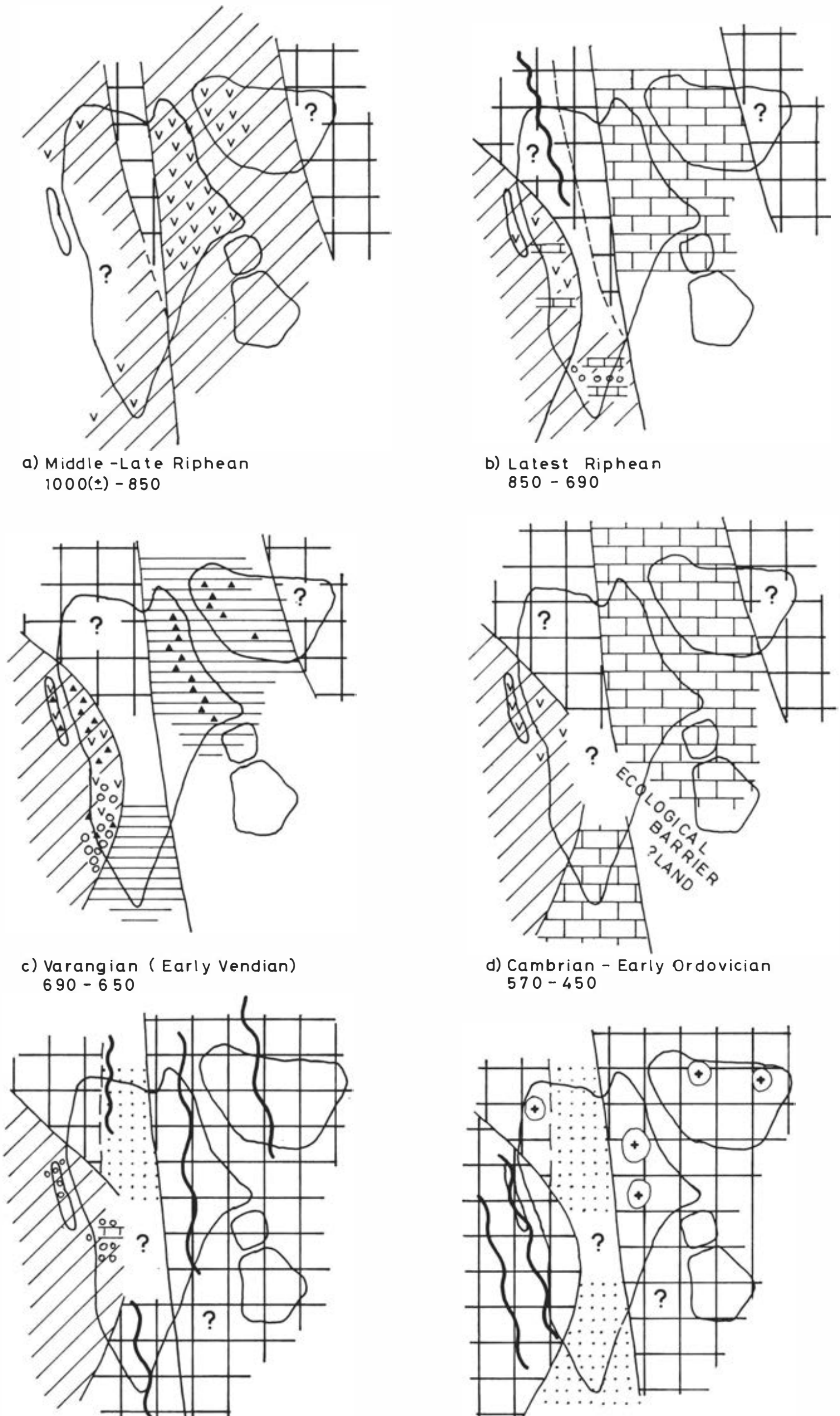
ECOLOGICAL
BARRIER
?LAND
a) Middle - Late Riphean
1000(±) - 850
b) Latest Riphean
850 - 690
c) Varangian (Early Vendian)
690 - 650
d) Cambrian - Early Ordovician
570 - 450
e) Middle - Late Silurian
420 - 400
f) Early - Middle Devonian
400 - 360
Ages very approximate, in Ma

Fig. 4.

(say 1000±500 km) along a nearly parallel WCFZ. This still leaves it open as to whether the GSFZ west of Spitsbergen operated with a similar displacement.

If we accept that within the western half of Svalbard the traces of two major faults occur (BFZ and CWFZ) of which the western line passes out to sea in the west, then it is not unreasonable to suppose that another fault still further west (GSFZ) took part in the same major sinistral displacement between Greenland and Europe. Moreover, such a fundamental fault would be the locus of Cenozoic separation. Accordingly, for this model we add another 750±500 km sinistral displacement along the GSFZ.

Thus, three sinistral late Devonian transcurrent faults are proposed, of which two may be tested by the evidence given here, namely the BFZ and the CWFZ. A speculative reconstruction of palaeoposition prior to Early Palaeozoic movement is shown in Figure 4. This scheme, however, only refers to the latest pre-Svalbardian configuration (e.g. Middle Devonian) and does not accommodate any degree of orogenic compression or closure of any earlier ocean – a matter already discussed (HARLAND and GAYER 1972).

3. IMPLICATIONS OF THE PALAEOMOBILISTIC MODELS

A number of comparisons have been made in the previous chapter which suggest to us that the palaeomobilistic model is a serious contender. They will not be discussed further.

Further implications are that the two or three major Devonian sinistral faults proposed (BFZ, CWFZ and GSFZ) provided major fundamental lineaments that controlled the dextral transcurrence of the Cenozoic motions. The Cenozoic movements reactivated very slight motion on the BFZ; they were very largely concentrated on the CWFZ during the West Spitsbergen Orogeny for a limited ?mid-Eocene period of dextral transpression, and now operate along the Spitsbergen Fracture Zone. The line along which Spitsbergen and Greenland originally separated could have been the rejuvenated GSFZ.

It will be seen that these same ancient lineaments also controlled the events between the mid-Palaeozoic and mid-Cenozoic Orogenies. Epeirogeny during the platform sequence was limited and determined by these ancient fault

---

←

Fig. 3. *Sequence of facies in the provinces arranged according to palaeofixistic model. An unknown degree of E-W compression has not been restored so that the E-W distances are reduced here.*
The account generalizes facies as follows:

oblique ruling	=	mobile sedimentary facies (often flyschoid);
brick ornament	=	shelf type carbonate;
horizontal ruling	=	shelf type shales;
stipple	=	continental sandstones (ORS facies);
square ruling	=	uplifted area;
circles	=	conglomerates;
triangles	=	tillites;
crosses	=	acid plutons;
v	=	volcanics;
sinuous curve	=	tectogenesis;

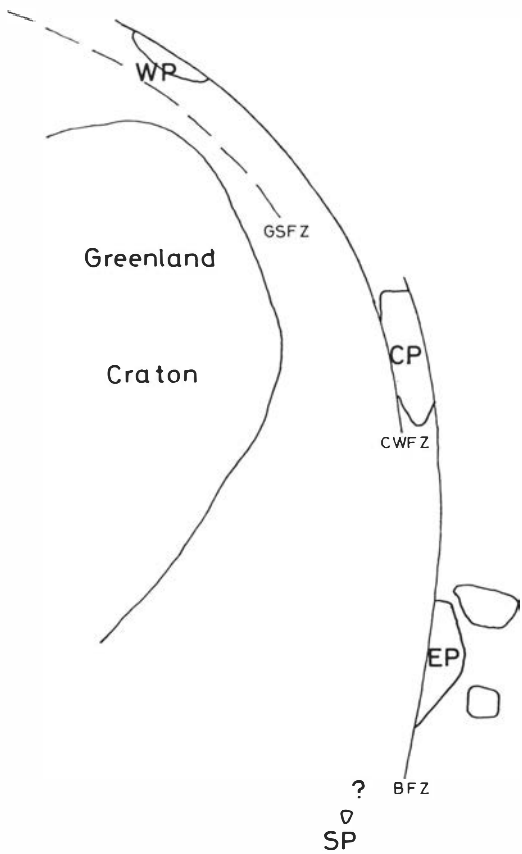

Fig. 4. *Sketch to show the later Devonian transcurrent movement that juxtaposed the separate provinces. Earlier compression or possible oceanic closure is not restored, nor Cenozoic motions shown. The facies in each province in middle Devonian and earlier times may be taken from Figure 3.*

blocks. This has been documented in detail for the BFZ (HARLAND et al. 1974) and a parallel study remains to be done for the CWFZ.

The postulated faults have further palaeogeological implications when the provinces are restored to their original positions. Studies of facies patterns, sediment sources, biological provinces and directions of tectonic transport will need to be considered.

The existence of Svalbard as a distinct land mass has at least two causes. The hot mantle that caused the separation of the Barents Shelf from Greenland also uplifted the north-west corner of the Barents Shelf that is the Svalbard archipelago (HARLAND 1969b). To this we may add the possibility that Spitsbergen contains at least two major Palaeozoic transcurrent zones that divided the Caledonian orogen and that this recurrent major tectonic zone of mobility accentuated the distinct structure of the archipelago.

4. CONCLUSION

We consider the palaeomobilistic model set out here to be reasonable and to provide a useful working assumption while the above implications are explored. It challenges renewed field work to seek out the many further critical points where it may be tested.

Acknowledgements

A major part of the field work in Svalbard was supported by Research Grants to WBH from the Natural Environment Research Council and from the Royal Society. KAY HEROD assisted with the references, C. A. G. PICKTON with the figures and tables and MAUREEN TYRRELL typed the text more than once.

References

BIRKENMAJER, K., 1958: Preliminary report on the stratigraphy of the Hecla Hoek Formation in Wedel-Jarlsberg Land, Vestspitsbergen. *Bull. Acad. polonaise Sci., Sér. chim. géol., géog.*, **6**, (2): 143–150.

— 1960: Relation of the Cambrian to the Precambrian in Hornsund, Vestspitsbergen. *Int. geol. Cong.* **21***st Session, Norden* 1960. *Rept. Section* **8**: 64–74.

— 1972. Cross-bedding and stromatolites in the Precambrian Høferpynten Dolomite Formation of Sørkapp Land, Spitsbergen. *Norsk Polarinstitutt Årbok* 1970: 128–145. Oslo 1972.

CHUMAKOV, N. M., 1968: On the character of the Late Pre-Cambrian Glaciation in Spitsbergen. *Rept. Acad. Sci. USSR, Geology* **180** (6): 1446–1449. In Russian.

COWIE, J. W., 1974: The Cambrian of Spitsbergen and Scotland. **In**: C. H. HOLLAND (ed.): *Cambrian of the British Isles, Norden and Spitsbergen.* **2**, Lower Palaeozoic Rocks of the World, p. 123–155. John Wiley & Sons, London.

CUTBILL, J. L., and A. CHALLINOR, 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* **102** (5): 418–439.

CUTBILL, J. L., W. G. HENDERSON, and N. J. R. WRIGHT, 1976: The Billefjorden Group (Early Carboniferous) of Central Spitsbergen. **In**: Some coal-bearing strata in Svalbard. *Norsk Polarinst. Skrifter* Nr. 164: 57–89.

DINELEY, D. L., 1960: The Old Red Sandstone of Eastern Ekmanfjorden, Vestspitsbergen. *Geol. Mag.* **97** (1): 18–32.

FLOOD, B. D. G. GEE, A. HJELLE, T. SIGGERUD, and T. S. WINSNES, 1969: The geology of Nordaustlandet, northern and central parts. *Norsk Polarinst. Skrifter* Nr. 146. 139 pp.

FORTEY, R. A., 1974: The Ordovician trilobites of Spitsbergen. I Olenidae. *Norsk Polarinst. Skrifter* Nr. 160. 129 pp.

FORTEY, R. A. and D. L. BRUTON, 1973: Cambrian-Ordovician rocks adjacent to Hinlopenstretet, North Ny Friesland, Spitsbergen. *Bull. geol. Soc. Am.* **84** (7): 2227–2242.

FØYN, S. and A. HEINTZ, 1943: The Downtonian and Devonian vertebrates of Spitsbergen. VIII. The English–Norwegian–Swedish Expedition, 1939. Geological results. *Norges Svalb. og Ishavsunders. Skrifter* N. 85. 51 pp.

FRIEND, P. F., 1961: The Devonian stratigraphy of North and Central Vestspitsbergen. *Proc. Yorks. geol. Soc.* **33** Part 1 (5): 77–118.

FRIEND, P. F., NATASCHA HEINTZ, and M. MOODY-STUART, 1966. New unit terms for the Devonian of Spitsbergen and a new stratigraphical scheme for the Wood Bay Formation. *Norsk Polarinstitutt Årbok* 1965: 59–64. Oslo 1966.

FRIEND, P. F. and M. MOODY-STUART, 1972: Sedimentation of the Wood Bay Formation (Devonian) of Spitsbergen: Regional analysis of a late orogenic basin. *Norsk Polarinst. Skrifter* Nr. 157. 77pp.

GARWOOD, E. J. and J. W. GREGORY, 1898: Contributions to the glacial geology of Spitsbergen. *Q. Jl. geol. Soc. Lond.* **54**: 197–225.

GAYER, R. A., D. G. GEE, W. B. HARLAND, J. A. MILLER, H. R. SPALL, R. H. WALLIS, and T. S. WINSNES, 1966: Radiometric age determinations on rocks from Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 137. 39 pp.

GEE, D. G., 1972: Late Caledonian (Haakonian) movements in northern Spitsbergen. *Norsk Polarinstitutt Årbok* 1970: 92–101. Oslo 1972.

GEE, D. G. and A. HJELLE, 1966: On the crystalline rock of northwest Spitsbergen. *Norsk Polarinstitutt Årbok* 1964: 31–45. Oslo 1966.

GEE, D. G., and M. MOODY-STUART, 1966: The base of the Old Red Sandstone in central north Haakon VII Land, Spitsbergen. *Norsk Polarinstitutt Årbok* 1964: 57–68. Oslo 1966.

GOBBETT, D. J., and C. B. WILSON, 1960: The Oslobreen Series, Upper Hecla Hoek of Ny Friesland, Spitsbergen. *Geol. Mag.* **97** (6): 441–457.

GOLOVANOV, N. P., 1967: Stromatolites of Riphean Age in the Region of Murchisonfjord (North East Land). **In**: SOKOLOV, V. N. (Ed.): *Materials on the Stratigraphy of Spitsbergen, NIIGA Leningrad*: 6–20. In Russian.

GOLOVANOV, N. P., and M. E. RAABEN, 1967: Upper Riphean analogues in the Spitsbergen Archipelago. *Dokl. Akad. Nauk. USSR.* **173** (5): 1141–1144. In Russian.

HALLER, J., 1971: Geology of the East Greenland Caledonides. **In**: SITTER, L. U. DE (Ed.): *Regional Geology Series, Wiley-Interscience.* Chichester. 413 pp.

HARLAND, W. B., 1960: The development of Hecla Hoek in rocks in Spitsbergen. *Int. geol. Cong. 21st Session, Norden* 1960, *Rept Part* **19**: 7–16.

— 1964: Evidence of Late Precambrian glaciation and its significance. **In**: NAIRN, A. E. M. (Ed.): *Problems of Palaeoclimatology.* Interscience Publishers (John Wiley & Sons): 119–149 and 179–184 (refs.).

— 1965: The tectonic evolution of the Arctic–North Atlantic region. *Phil. Trans. R. Soc.* **258**: 59–75.

— 1969a: Contribution of Spitsbergen to understanding of tectonic evolution of North Atlantic region. *Am. Ass. Petrol. Geol. Mem.* **12**: 817–851.

— 1969: Mantle changes beneath the Barents Shelf. *Trans. N.Y. Acad. Sci. Ser. II*, **31** (1): 25–41.

— 1972a: Early Paleozoic faults as margins of Arctic plates in Svalbard. *Int. geol. Cong.*, **24***th Session* (Montreal 1972), *Section* 3: 230–237.

— 1972b: The Ordovician Ice Age. *Geol. Mag.* **109**: 451–456.

HARLAND, W. B., J. L. CUTBILL, P. F. FRIEND, D. J. GOBBETT, D. W. HOLLIDAY, P. I. MATON, J. R. PARKER, and R. H. WALLIS, 1974: The Billefjorden Fault Zone, Spitsbergen. The long history of a major tectonic lineament. *Norsk Polarinst. Skrifter* Nr. 161. 72 pp.

HARLAND, W. B., and R. A. GAYER, 1972: The Arctic Caledonides and earlier Oceans. *Geol. Mag.* **109** (4): 289–384.

HARLAND, W. B., and K. N. HEROD, 1975: Glaciations through time. **In**: WRIGHT, A. E., and F. MOSELEY (Eds.): Ice Ages: Ancient and Modern. *Geological Journal, Special Issue* No. 6, Seel House Press, Liverpool: 189–216.

HARLAND, W. B., and W. T. HORSFIELD, 1974: West Spitsbergen Orogen. **In**: A. M. SPENCER (Ed.) Mesozoic-Cenozoic Orogenic Belts, Data for Orogenic Studies. *Geol. Soc. Lond. Spec. Pubn* No. 4: 747–755.

HARLAND, W. B., W. T. HORSFIELD, G. M. MANBY, and A. P. MORRIS, 1978: An outline pre-Carboniferous stratigraphy of central western Spitsbergen. Symposium on Svalbard Geology, Oslo, June 1975. *Norsk Polarinstitutt Skrifter* Nr. 167 (this volume).

HARLAND, W. B., R. H. WALLIS, and R. A. GAYER, 1966: A Revision of the Lower Hecla Hoek succession in Central North Spitsbergen and correlation elsewhere. *Geol. Mag.* **103** (1): 70–97.

HARLAND, W. B., and C. B. WILSON, 1956: The Hecla Hoek succession in Ny Friesland, Spitsbergen. *Geol. Mag.* **93** (4): 265–286.

HJELLE, A., 1962: Contribution to the geology of the Hecla Hoek Formation in Nordenskiöld Land, Vestspitsbergen. *Norsk Polarinstitutt Årbok* 1961: 83–96. Oslo 1962.

— 1969: Stratigraphical correlation of Hecla Hoek successions north and south of Bellsund. *Norsk Polarinstitutt Årbok* 1967: 46–51. Oslo 1969.

HOLTEDAHL, O., 1920: On the Paleozoic Series of Bear Island, especially on the Heclahook System. *Norsk geol. Tidsskr.* **5** (II): 121–148.

HORN, G., and A. K. ORVIN, 1928: Geology of Bear Island, with special reference to the coal deposits, and with an account of the history of the island. *Skrifter Svalb. og Ishavet* Nr. 15. 152 pp.

HORSFIELD, W. T., 1972: Glaucophane schists of Caledonian age from Spitsbergen. *Geol. Mag.* **109** (1): 29–36.

KAISER, H., 1970: Die Oberdevon-Flora der Bäreninsel. 3. Mikroflora des Höheren Oberdevons und des Unterkarbons. *Palaeontographica* **129**, Abt. B, Lfg 1–3: 71–124.

— 1971. Die Oberdevon-Flora der Bäreninsel. 4. Mikroflora der Misery-serie und der Flözleeren Sandstein-serie. *Palaeontographica* Band **135** Abt. B: 127–164.

KRASIL'SHCHIKOV, A. A., 1973: Stratigraphy and palaeotectonics of the Precambrian and early Palaeozoic of Spitsbergen. Scientific Research Institute for Geology of the Arctic, Leningrad. *Transactions* **172**: 1–120. In Russian.

KRASIL'SHCHIKOV, A. A., N. P. GOLOVANOV, and V. E. MIL'SHTEIN, 1965: The stratigraphy of the Upper Proterozoic deposits around Murchisonfjorden, Nordaustlandet. **In**: SOKOLOV, V. N. (Ed.): *Materials on the Geology of Spitsbergen.* Institute for Geology of the Arctic, Leningrad. In Russian. (English translation by National Lending Library, Boston Spa, Yorkshire 1970).

KRASIL'SHCHIKOV, A. A., and YU. YA. LIVSHITS, 1974: The tectonics of Bjørnøya. *Geotectonics* No. 4: 39–51. Acad. Sci. USSR, Moscow. In Russian.

KULLING, O., 1934: The "Hecla Hoek Formation" round Hinlopenstredet. *Geogr. Annaler. Stockh* 16 (4): 161–254.

LOWELL, J. D., 1972: Spitsbergen Tertiary orogenic belt and Spitsbergen fracture zone. *Bull. geol. Soc. Am.* **83** (10): 3091–3101.

MAJOR, H., and T. S. WINSNES, 1955: Cambrian and Ordovician fossils from Sørkapp Land, Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 106. 47 pp.

PRINGLE, I. R., 1973: Rb-Sr age determinations on shales associated with the Varanger Ice Age. *Geol. Mag.* **109**: 465–472.

RAABEN, M. E., and V. E. ZABRODIN, 1969: The Biostratigraphic determination of the Upper Riphean in the Arctic. *Acad. Sci. USSR, Repts* **184** (3). In Russian.

SCHWEITZER, H. J., 1969: Die Oberdevon-Flora der Bäreninsel. 2. *Lycopodiinae. Palaeontographica* Abt. B, 126, Liefg. 4–6: 101–137. Stuttgart.

SCRUTTON, C. T., W. T. HORSFIELD, and W. B. HARLAND, 1976: A Silurian fauna from western Spitsbergen. *Geol. Mag.* **113**: 519–523.

THORSTEINSSON, R., and E. T. TOZER, 1970: Geology of the Arctic Archipelago. **In**: R. J. W. DOUGLAS (Ed.): Geology and economic minerals of Canada. *Geol. Surv. Can., Econ. Geol. Rept* No. 1: 548–590.

VIGRAN, J. O., 1964: Spores from Devonian deposits, Mimerdalen, Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 132. 32 pp.

WHITTINGTON, H. B., 1965: Ordovician faunas from Ny Friesland, north-central Spitsbergen. *Proc. geol. Soc. Lond.* No. 1648: 74.

WILSON, C. B., and W. B. HARLAND, 1964: The Polarisbreen Series and other evidences of late Precambrian Ice Ages in Spitsbergen. *Geol. Mag.* **101** (3): 198–219.

WINSNES, T. S., 1965: The Precambrian of Spitsbergen and Bjørnøya. **In**: K. RANKAMA (Ed.) *The Precambrian* 2: 1–24. Interscience, London.

— 1975: Geological background: Svalbard. *Contributions du Centre d'Études Arctiques* **12**: 56–78. (Fondation Française d'Études Nordiques, V congres international, 1973, Rapports Scientifiques.)