Caledonides of Svalbard and Plate Tectonics

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The Caledonian fold belt of Svalbard (Spitsbergen) representing the northern extremity of the circum-Atlantic Caledonian mountain system comprises between 15 and 20 km of sediments and metasediments with a variable share of volcanics and metavolcanics (Hecla Hoek succession). The main phase of Caledonian deformation and metamorphism occurred during the late Ordovician Ny Friesland orogeny and was followed by late-orogenic migmatisation and plutonism around the boundary of Silurian and Devonian and by late-orogenic deformations involving plate motions during the Devonian. An attempt is being made to evaluate the role of pre-Caledonian metamorphism and diastrophism using evidence from isotopic age determinations and from Precambrian unconformities so far generally neglected or underestimated in reconstructions of the evolution of the Hecla Hoek geosyncline. Three successive geosynclinal basins are analysed, the Precambrian Torellian (eugeosynclinal) and Jarlsbergian (miogeosynclinal) basins and the Early Palaeozoic Hornsundian (miogeosynclinal) basin. Diastrophic events recognised in the Precambrian column of the Hecla Hoek are tentatively correlated with igneous activity and metamorphic events within Svalbard and elsewhere.

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The Caledonian fold belt of Svalbard (fig. 1) belongs to the northern extremity of the circum-Atlantic Caledonian mountain system. It is separated from the Scandinavian Caledonian belt by a vast expanse of the Barents Sea shelf and from the East Greenland Caledonian belt by young oceanic crust of the Atlantic Ocean (Greenland Sea). The Svalbard and Norwegian belts are parts of the same Eurasiatic plate, that of East Greenland belongs to the North America-Greenland plate. Palinspastic reconstruction of relative position of these plates postulated for Late Cretaceous time by Harland (e. g. 1967, 1969) and Birkenmajer (1972b) show the Svalbard Caledonides as situated very close to northern termination of the East Greenland Caledonian belt (fig. 2).

The Caledonides of Svalbard comprise rocks of Precambrian through Ordovician age. The stratigraphic column includes between 15 and 20 km of sediments and metasediments with usually subordinate share of volcanics and metavolcanics which formed in geosynclinal basins of westward polarity. Major unconformities help define these basins, especially in marginal parts of the geosynclinal trough where they become apparent. An attempt is being made to evaluate the role of Precambrian diastrophism and metamorphism in the Caledonian structure of the belt.

The Caledonian fold belt crops out in Svalbard mainly in the western and north-central parts of its largest island Spitsbergen and in the northern part of Nordaustlandet (northeast Spitsbergen). An isolated occurrence is known from Bjørnøya (Bear Island) situated half-way between Spitsbergen and Norway. The width of the belt (between Spitsbergen and Nordaustlandet) exceeds 400 km, the length (between Nordaustlandet and Bjørnøya) is about 700 km.

The Precambrian through Ordovician rock sequences are referred to as the *Hecla Hoek succession*. The occurrences in Spitsbergen island may be subdivided into two groups: the first comprises Caledonian structures of its west coast, being part of the Tertiary thrust-fold belt; the other one comprises the north-west and north-central Spitsbergen structures (fig. 1). The most complete rock sequences of the Hecla Hoek are those of south Spitsbergen (within the Tertiary thrust-fold belt), of

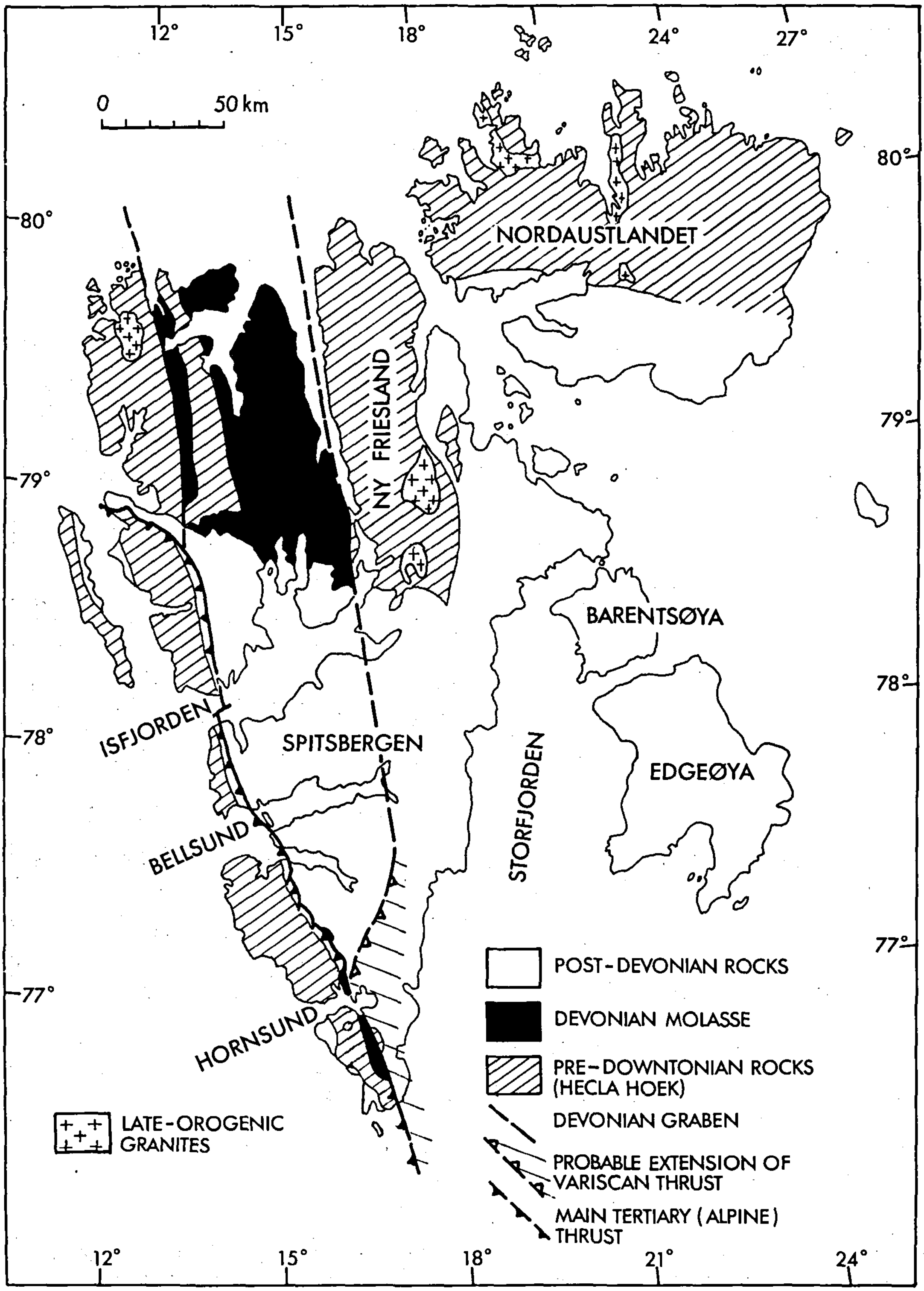


Fig. 1. Major exposures of Caledonian mountain system in Svalbard.

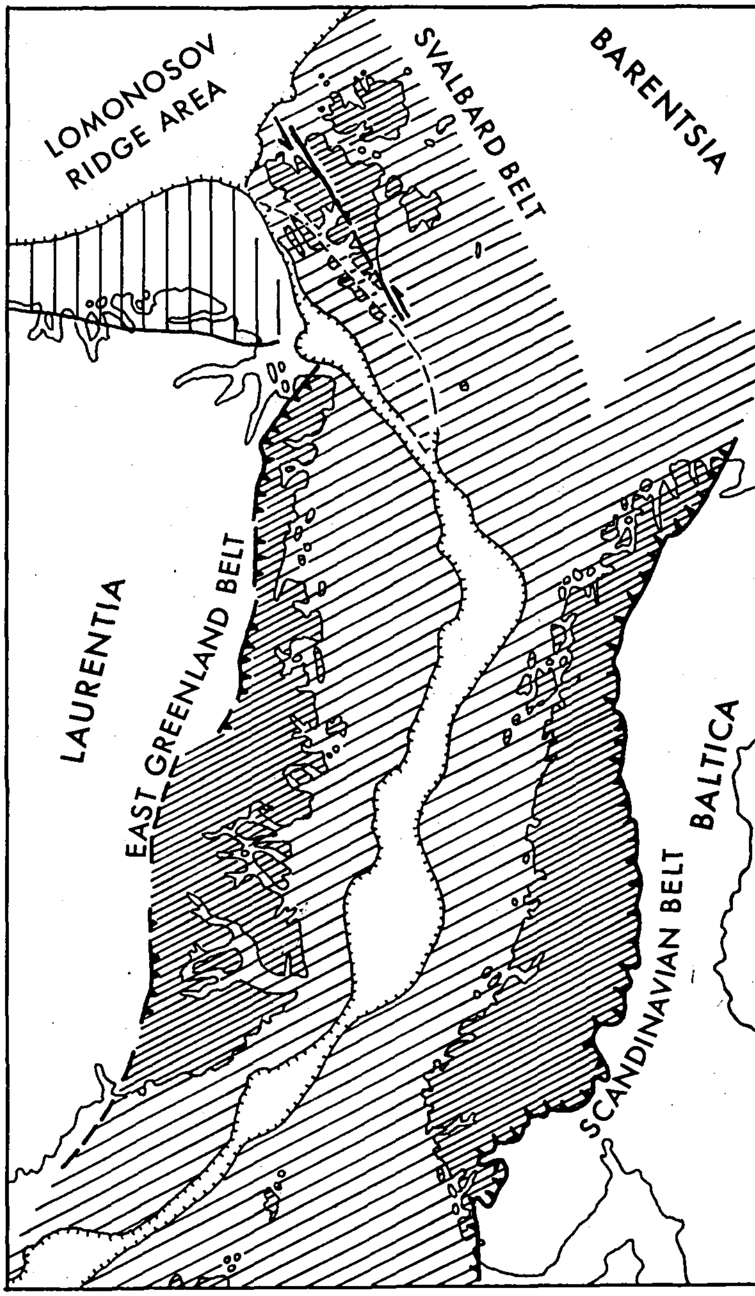


Fig. 2. Palinspastic reconstruction of circum-Atlantic Caledonian mountain system (obliquely shaded) prior to continental drifting apart, late Cretaceous time. Heavy dentated lines denote edges of Caledonian thrusts; vertical shading indicates Variscan mountain system; thin dentated lines denote margins of continental blocks.

north-central Spitsbergen (Ny Friesland and Olav V Land) and northeast Spitsbergen (Nordaustlandet), representing the westernmost, the central and the easternmost parts of the Hecla Hoek geosyncline respectively (fig. 3). These sections will serve as standard reference for correlation of events in the Precambrian through Ordovician geosynclinal basins of Svalbard.

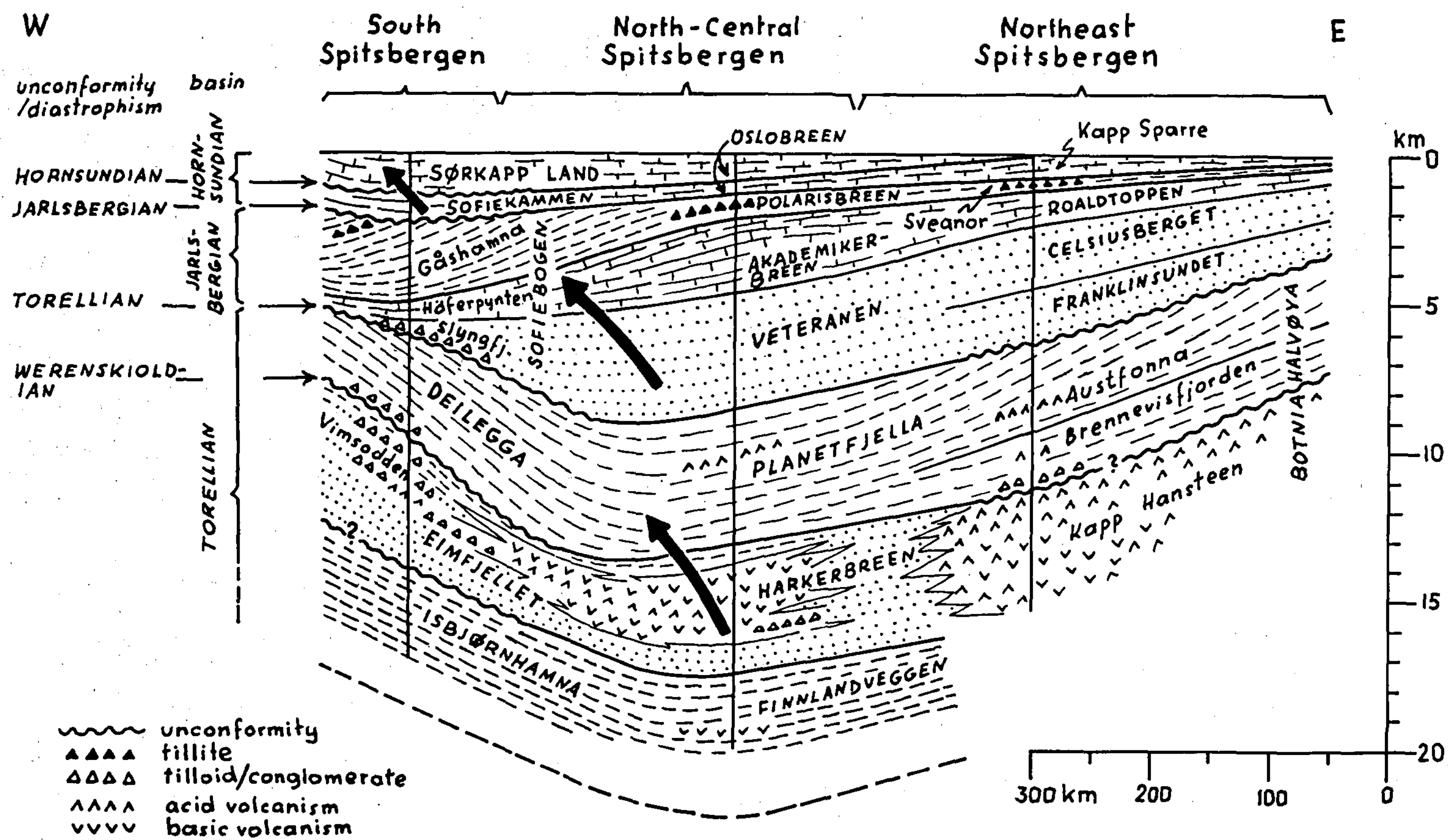


Fig. 3. Reconstruction of the Hecla Hoek geosynclinal trough in Svalbard. Width of the trough assumed to be twice that the present width of the Caledonian mountain belt. Thick arrows denote migration of basin axis (polarity of geosyncline). The thicknesses used are high values from tables 1–3.

Hecla Hoek succession

South Spitsbergen

The Hecla Hoek succession of the western coastal belt of Spitsbergen is best known in the area between Bellsund and Sørkapp (Major & Winsnes, 1955; Birkenmajer, 1958, 1959, 1960, 1972a; Birkenmajer & Narebski, 1960; Smulikowski, 1965, 1968; Winsnes, 1965; Hjelle, 1969). The thickness totals between 15 and 17 km in the Hornsund area (table 1) where the succession is characterized by occurrence of several important unconformities (figs. 3–5).

The *Isbjørnhamna Group* (max. 2,850 m) includes garnet-mica schists (Skoddefjellet Fm. and Revdalen Fm.) intercalated in the middle part of the Group by grey marbles (Ariekammen Fm.). An unconformity is possible below the overlying Eimfjellet Group.

The *Eimfjellet Group* (2,500 to 4,650 m) begins with light well-bedded quarzites with subordinate chloritic schists (Gulliksenfjellet Fm.), followed by alternating quartzite and schist with concordant amphibolite intercalations (Steinvikskardet Fm.). The upper part of the Group is regionally differentiated into the Skålfjellet Subgroup on the east, and the Vimsodden Subgroup on the west. The Skålfjellet Subgroup (1,400 m) includes layered amphibolites alternating with greenschists (Torbjørnsenfjellet Fm. and Brattegga Fm.) with a granitization zone (Gangpasset Fm.) and a coarse-grained amphibolite horizon (Angellfjellet Fm.) in the middle. A tilloid intercalation occurs near the granitization zone. The Vimsodden Subgroup (3,550 m) starts with phyllites and schists intercalated near the base with quartzite and higher up with marble and concordant amphibolite layers (Nottinghambukta Fm.). Quartzite tilloids (subaqueous slump breccia type) and rhyolite conglomerate occur near the base and albitic gneiss intercalations near the top of the Formation. The upper part of the Vimsodden Subgroup (Elveflya Fm.) consists of quartz-schists, phyllite and slate with three tilloid intercalations; green quartzite and amphibolite/greenschist intercalations occur in its upper part in the eastern area.

The *Deilegga Group* (3,500 m) is separated from the Eimfjellet Group by an unconformity. Its lower part (Tonedalen Fm.) begins with quartzite conglomerate followed by dolomite and by a thick green phyllite-slate complex; thin dolomite and alum shale appear in its middle part (Bergnova Fm.) and light quartzite intercalations in its upper part (Bergskardet Fm.).

A major unconformity separates the Deilegga and Sofiebogen groups. The *Sofiebogen Group* (ca. 3,700 m) begins with thick conglomerates (Slyngfjellet Fm.) resting unconformably upon various formations of the Deilegga Group or even upon the Vimsodden Subgroup. A minor unconformity is marked between the conglomerate and the Höferpynten Formation, the latter consisting of limestone in the lower part and dolomite with cherts, sedimentary breccias with stromatolitic structures and oolite-pisolite rocks near the top. The dolomite passes upward into a thick phyllite-slate complex (Gåshamna Fm.) with subordinate quartzite, dolomite and limestone intercalations. At Bellsund, Isfjorden (Kapp Linné) and St. Jonsfjorden tillites have been found, presumably in the upper part of the Formation.

The *Sofiekammen Group* (935 m) begins with arenaceous-dolomitic rocks (Blåstertoppen Fm.) unconformable upon the Gåshamna Phyllite, with intercalations of sedimentary breccia, shale and Olenellid-rich limestone. Together with the overlying Olenellid-rich dark shale with sedimentary breccia and limestone intercalations (Vardepiggen Fm.) these two formations represent the basal part of the Lower Cambrian. There follow limestones (Slaklidalen Fm.) with trilobites indicative of the upper part of Lower Cambrian, overlain by unfossiliferous limestone and marble (Gnålberget Fm.) and finally by massive and platy dolomite (Nørdstetinden Fm.) with scarce *Lingulella.* A Middle or Middle-Upper Cambrian age is tentatively suggested for the upper two formations.

The *Sørkapp Land Group* (1,400 m) is separated by an unconformity from the Sofiekammen Group. Its basal quartzite-sandstone (Wiederfjellet Fm.) rests upon various formations of the latter group, often filling karst-like pockets in dolomite or limestone. Higher

Supergroup	Group	Subgroup	Formation	Thickness	Subgroup	Formation	Thickness
Hornsund	Sørkapp Land		Hornsundtind Lst. { Tsjebysjovfjellet Lst. Mbr.	400 m			
			Hornsundtind Lst. { Rasstupet Lst. Mbr.	80 m			
			Nigerbreen Lst.	120 m			
			Dusken Lst.	100 m			
			Luciapynten Dol.	400 m			
			Wiederfjellet Quartzite	300 m			
	Sofiekammen		Nørdstetinden Dol.	150 m			
			Gnålberget Marble	250 - 300 m			
			Slaklidalen Lst.	10 - 120 m			
			Vardepiggen	130 - 215 m			
			Blåstertoppen Dol.	100 - 150 m			
	Sofiebogen		Gåshamna Phyllite	1,500 -2,500 m			
			Höferpynten Dol.	120 - 710 m			
			Slyngfjellet Cgl.	10 - 500 m			
Torellbreen	Deilegga		Bergskardet	+ 500 m			
			Bergnova	1,800 m			
			Tonedalen	+ 1,200 m			
	Eimfjellet	Skål-fjellet SubGp.	Brattegga Amphibolite	300 - 500 m	Vims-odden SubGp.	Elveflya	2000 m
			Angellfjellet Amphibolite	0 - 200 m			
			Gangpasset Migmatite	0 - 100 m		Nottinghambukta	1550 m
			Torbjørnsenfjellet Amphibolite	350 - 600 m			
			Steinvikskardet	100 - 250 m			
			Gulliksenfjellet Quartzite	500 - 850 m			
	Isbjørnhamna		Revdalen	250 - 350 m			
			Ariekammen	500 -1,500 m			
			Skoddefjellet	+ 1,000 m			

Table 1. Hecla Hoek succession in south Spitsbergen – Hornsund area (revised scheme based on Major & Winsnes, 1955; Birkenmajer, 1958, 1959; and Birkenmajer & Narebski, 1960).

up there follows banded dolomite often with chert intercalations (Luciapynten Fm.) overlain by a thick sequence of limestones, laminated in the lower part (Dusken Fm.), with chert intercalations in the middle (Nigerbreen Fm.) and massive in the upper part (Hornsundtind Fm.). The upper two formations yielded Canadian fossils comparable with the Beekmantown Group. There is much doubt with respect to the position of the "Sjdanovfjellet Series" and "Arkfjellet Series" (sensu Major & Winsnes, 1955); the former seems to correlate with the Hornsundtind Formation while the other corresponds, at least partly, with the Gåshamna Formation.

Ny Friesland – Olav V Land

The Hecla Hoek succession of Ny Friesland and Olav V Land (SE of Ny Friesland) is representative for the north-central part of the Spitsbergen Caledonides (Harland & Wilson, 1956; Bayly, 1957; Wilson, 1958, 1961; Harland, 1959, 1960, 1969; Gobbett & Wilson, 1960; Wilson & Harland, 1964; Gayer & Wallis, 1966; Harland et al., 1966; Vallance & Fortey, 1968; Fortey & Bruton, 1973; Fortey, 1974). Its thickness approximates 19 to 20 km (table 2). Contrary to south Spitsbergen, the succession is claimed to de devoid of major unconformities (figs. 3–5).

The *Finnlandveggen Group* (2,700 m) is characterised in the lower part (Eskolabreen Fm.) by gneissose feldspathites associated with coarse-grained semipelites, sometimes alternating with amphibolites which are often of very coarse texture suggesting plutonic environment; the upper part (Smutsbreen Fm.) is characterised by semipelites, often garnetiferous, associated near the top with marbles.

The *Harkerbreen Group* (4,100 m) begins with pale quartzites and quartz psammites with rare bands of feldspathitic psammite, with concordant amphibolite bands (Polhem Fm.), followed by marble, quartzite and psammite-semipelite with concordant amphibolites (Rittervatnet Fm.). Two meta-tilloid horizons occur in the upper part of the latter formation. There follow gneissose feldpathites with concordant amphibolites, with some psammites and with pegmatites (Bangehuk Fm.), and again semipelites and psammites with psammitic feldspathites and concordant amphibolites (Vassfaret Fm.). At the top of the Group, quartzites, quartz psammites and plagioclase psammites predominate over amphibolites, sometimes associated with acid tuffs.

Supergroup	Group	Formation	
Hinlopenstretet (= Upper Hecla Hoek)	Oslobreen	Valhallfonna	255 m
		Kirtonryggen	+ 750 m
		Tokammane	192 m
	Polarisbreen	Dracoisen	280 m
		Wilsonbreen	280 m
		Elbobreen	270 m
Lomfjorden (= Middle Hecla Hoek)	Akademikerbreen	Backlundtoppen	360-700 m
		Draken Cgl.	25-300 m
		Svanbergfjellet	100-625 m
		Grusdievbreen	865 m
	Veteranen	Oxfordbreen	550 m
		Glasgowbreen	540 m
		Kingbreen	1,500 m
		Kortbreen	1,200 m
Stubendorffbreen (= Lower Hecla Hoek)	Planetfjella	Vildadalen	3,250 m
		Flåen	1,500 m
	Harkerbreen	Sørbreen	+ 250 m
		Vassfaret	600 m
		Bangehuk	2,000 m
		Rittervatnet	350 m
		Polhem	900 m
	Finnlandveggen	Smutsbreen	1,200 m
		Eskolabreen	1,500 m

Table 2. Hecla Hoek succession in north-central Spitsbergen – Ny Friesland and Olav V Land (after Harland et al., 1966; Harland 1969; and Vallance & Fortey, 1968).

The *Planetfjella Group* (4,750 m) consists of coarse-grained well laminated semipelitic to psammitic rocks in the lower part (Flåen Fm.) and of a repeating monotonous sequence of finely laminated psammite/semipelites, massive pure quartzites and marbles in the upper part (Vildadalen Fm.).

The *Veteranen Group* (3,790 m) begins with flaggy limestone with dolomite bands, interbedded with dark shale and quartzose flags, followed by a uniform sequence of dark or light-coloured quartzite with subordinate darker shale bands (Kortbreen Fm.). There follow: (a) quartzites and greywackes with phyllitic and quartzose shales, (b) black flaggy limestones interbedded with dark shale and phyllite, (c) impure quartzites with subordinate greywacke and shale (*a–c: Kingbreen* Fm.). The highest part of the Group is formed by pale thickly-bedded quartzites passing into a greywacke-quartzite complex (Glasgowbreen Fm.), finally by quartzose shales and flags with subordinate quartzite and dolomitic shale (Oxfordbreen Fm.).

The *Akademikerbreen Group* (2,490 m) consists predominantly of carbonates: (a) limestone, often dolomitic or silicified, sometimes with stromatolites (Grusdievbreen Fm.), (b) stromatolitic dolomite and cherty dolomite (Svanbergfjellet Fm.), (c) dolomite conglomerate and microconglomerate with cherts (Draken Fm.), (d) dark oolitic-pisolitic, often silicified limestone and dolomite with stromatolites (Backlundtoppen Fm.).

The *Polarisbreen Group* (830 m) consists mainly of dark paper shales with black shaly limestone and siltstone intercalations at the bottom (Elbobreen Fm.) and with sandstone intercalations near the top (Dracoisen Fm.), with marine tillites in the middle (Wilson-breen Fm.).

The *Oslobreen Group* (ca. 1,400 m) begins with basal quartzite followed by dolomite and dolomitic limestone with intraformational carbonate conglomerate (Tokammane Fm.). The presence of *Salterella* indicates Lower Cambrian age of the carbonates. There follow limestones, often cherty, with stromatolites and intraformational carbonate conglomerate intercalations, and again more limestones and intraformational conglomerates (Kirtonryggen Fm.); the fossils indicate Lower to Upper Canadian age of the formation. The highest part of the succession is built of black bituminous limestone and shale, often graptolitic, sometimes with chert bands, followed by bioclastic and algal limestone with subordinate shale (Valhallfonna Fm.); the formation yielded rich assemblages of fossils indicating Arenigian age for its lower part and Whiterock stage (latest Arenig-early Llanvirn) for its upper part.

Nordaustlandet

The Hecla Hoek succession of Nordaustlandet (table 3) is representative for the northeastern area of the Svalbard Caledonides (Kulling, 1934; Sandford, 1950, 1956, 1963; Krasilschikov, 1965; Krasilschikov et al., 1965; Flood et al., 1969). Its thickness exceeds 15 km. There is a close resemblance of the high-

Supergroup	Group	Formation	
		Kapp Sparre	700-800m
		Sveanor	200-300m
Murchisonfjorden	Roaldtoppen	Ryssö	750m
		Hunnberg	500m
	Celsiusberget	Raustup-Sälodd	550m
		Norvik	340m
		Flora	1,250m
	Franklinsundet	Kapp Lord	c.1,000m
		Westmanbukta	625m
		Persberget	+ 150m
	Botniahalvøya	Austfonna (+ Kapp Platen)	c.3,000m
		Brennevisfjorden	c. 2,000m
		Kapp Hansteen	c.4,000m

Table 3. Hecla Hoek succession in northeast Spitsbergen – Nordaustlandet (after Kulling, 1934; and Flood et al., 1969).

er part of the Nordaustlandet succession to that of Ny Friesland, but several major unconformities are present, possibly correlating with those of south Spitsbergen.

The *Botniahalvøya Group* (ca. 9,000 m) begins with a huge acid volcanic complex ranging from volcanic breccias and agglomerates to tuffs and tuffaceous rocks, with quartz porphyry intrusions (Kapp Hansteen Fm.). It is followed by a monotonous sequence of quartzite, siltstone and shale (Brennevisfjorden Fm.) with quartz porphyry plugs and dykes. A conglomerate at the base of the Brennevisfjorden Formation may suggest an unconformity. The upper part of the Group consists of quartzite and calcareous rocks intercalated in a monotonous sequence of dark phyllites, with some intrusive porphyry and amphibolite layers (Austfonna Fm. and Kapp Platen Fm.).

The *Franklinsundet Group* (ca. 1,780 m) rests unconformably upon the Botniahalvøya Group which is marked by a basal quartzite conglomerate overlain by light quartzite with subordinate dark shale (Persberget Fm.). There follow mudstones with some quartzite intercalations (Westmanbukta Fm.) and alternating mudstone, quartzite and limestone beds (Kapp Lord Fm.).

The *Celsiusberget Group* (2,140 m) begins with predominantly light-coloured quartzose sandstones with subordinate siltstone and shale (Flora Fm.) followed by a shale-siltstone-sandstone complex (Norvik Fm.) and that in turn by multicoloured shales with some quartzose sandstone and light dolomite (Raustup-Sälodd Fm.).

The *Roaldtoppen Group* (1,250 m) is predominantly carbonate: dark limestone with chert concretions and conglomerate, with some oolite in the lower part (Hunnberg Fm.), and light-grey massive dolomite with stromatolitic structures, oolitic limestone, chert and subordinate clayshale in the upper part (Ryssö Fm.).

The *Sveanor Formation* (200–300 m) consists of alternating variably coloured shale, sandstone, marl and arenaceous limestone, with tillites near the top.

The *Kapp Sparre Formation* (700–800 m) consists of calcareous-dolomitic and psammitic-pelitic rocks in the lower part, and of dolomites and often oolitic limestones in the upper part. The presence of *Obolus* and *Lingulella* is indicative of Cambrian age of the Formation.

Correlation within Svalbard

Correlation of the Precambrian Hecla Hoek succession is most difficult for its lowest units owing to strong metamorphic alteration of the sediments. Late Precambrian rocks are easier to correlate on lithological grounds, and for Early Palaeozoic strata faunistic criteria become most important. Correlation criteria used for the Precambrian complex include, besides lithologies, the presence of acid and basic igneous activity, tilloids and tillites (e. g. Harland, 1960, 1969; Birkenmajer & Narebski, 1960; Winsnes, 1965; Harland et al., 1966; Flood et al., 1969; Krasilschikov, 1973). So far little attention was paid to unconformities and basal conglomerates which, though not distinguished in Ny Friesland, are well recognisable in south Spitsbergen and certainly also in Nordaustlandet (figs. 3–5). The correlation is possible usually at group level, less frequently also at formation level; some marker horizons (e. g. tillites and tilloids) may also be used.

The basal Isbjørnhamna and Finnlandveggen groups correlate on common occurrence of garnet-mica schists with marble intercalations. The following volcanic-sedimentary complexes of the Eimfjellet and Harkerbreen groups and Kapp Hansteen Formation seem to correlate with one another on the common occurrence of basic concordant rocks (amphibolites) in the former two units, and acid volcanics in the Kapp Hansteen Formation and the Eimfjellet (Vimsodden Subgroup) and Harkerbreen groups. Another criterion is derived from the presence of meta-tilloids within the Harkerbreen Group (Rittervatnet meta-tilloids) and the Eimfjellet Group (Vimsodden meta-tilloids).

The Deilegga and Planetfjella groups on the one hand and the Brennevisfjorden and Austfonna formations on the other correlate on lithologies; acid volcanism is present in the Planetfjella Group, Brennevisfjorden and Aust-

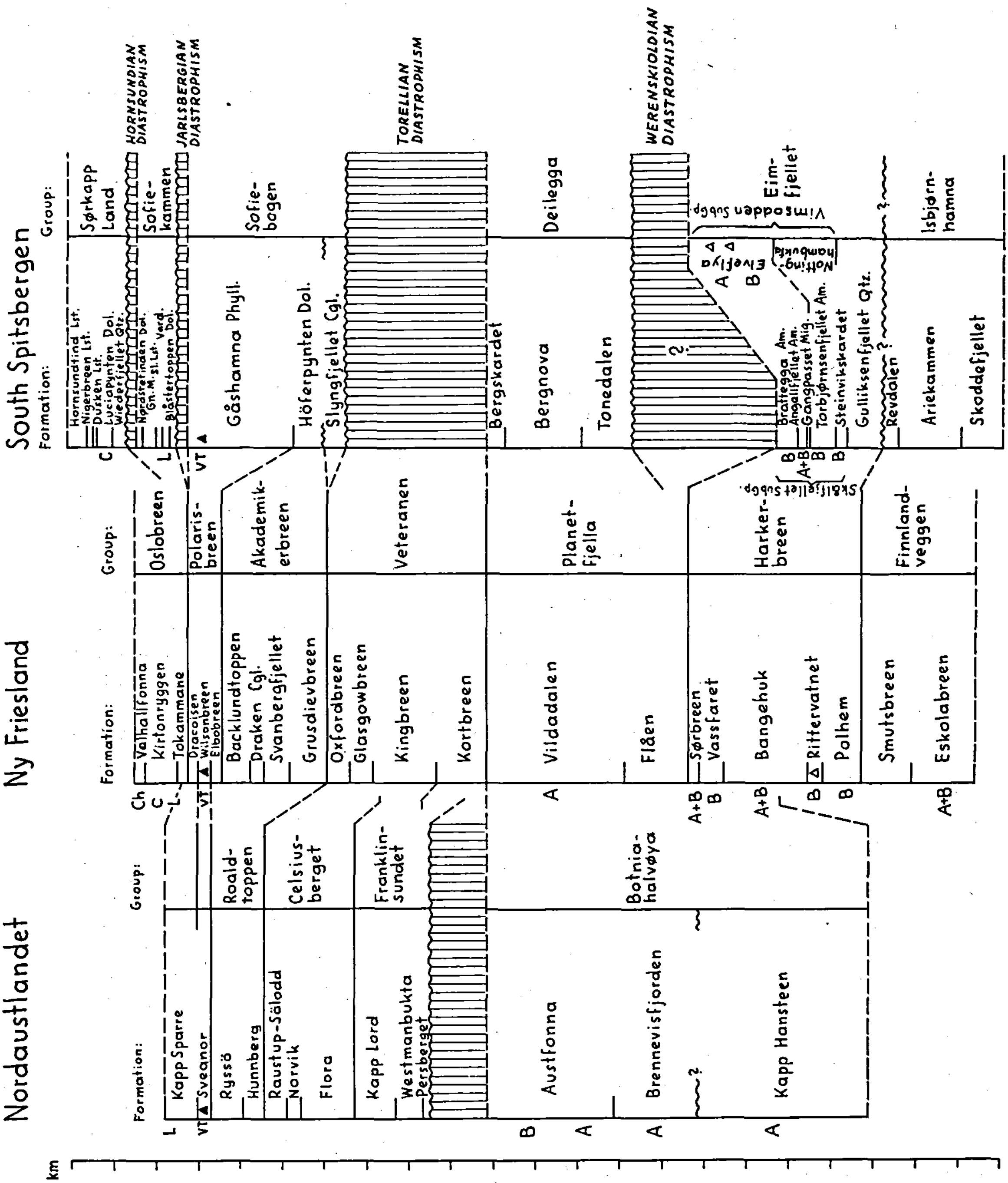


Fig. 4. Correlation of the Hecla Hoek rocks in Svalbard. The thicknesses used are high values from tables 1-3. A – acid igneous activity; B – basic igneous activity; Faunas: Ch – Champlainian, C – Canadian, L – Lower Cambrian; VT – Varangian tillites. Tillites marked by full triangles, metatilloids by open triangles. Wavy lines denote unconformities; vertical shading – erosional breaks.

fonna formations. The unconformity and basal conglomerate known from the bottom of the Deilegga Group could correlate with those below the Brennevisfjorden Formation.

The Veteranen, Franklinsundet and Celsiusberget groups correlate on lithological grounds. Farther south (Hornsund area) there is a long erosional break at the base of the Slyngfjellet Conglomerate. An important unconformity at the base of the latter may correlate with that at the base of the Franklinsundet Group.

The Roaldtoppen and Akademikerbreen groups and the Höferpynten Formation easily correlate with one another on common lithology and the presence of oolitic and stromatolitic rocks. The Varangian tillites of the Sveanor Formation and Polarisbreen Group probably occupy a similar position in southwest Spitsbergen near the top of the Gåshamna Phyllite.

The Cambrian Sofiekammen Group correlates with the lower part of the Oslobreen Group and with the Kapp Sparre Formation. An important unconformity at the base of the Cambrian recognised in south Spitsbergen could probably also be detected in other areas of Svalbard.

The Ordovician Sørkapp Land Group correlates with the upper part of the Oslobreen Group, the latter containing the youngest Ordovician strata so far known from Svalbard. A well marked unconformity at the base of Ordovician recognised in south Spitsbergen, probably occurs also in Ny Friesland.

Correlation outside Svalbard

Correlation outside Svalbard (table 4) including the main sequences of the circum-Atlantic Caledonian mountain system is based on similar criteria to those discussed above. Each succession is placed with reference to the Varangian tillite horizon (Harland et al., 1966). The similarities between the East Greenland and Spitsbergen successions become apparent.

Evolution of the Hecla Hoek geosyncline and plate tectonics

Problem of Precambrian basement

Sandford (1950, 1956) postulated that much of Nordaustlandet consists of Archaean basement rocks unconformably underlying the Hecla Hoek. By comparison with central-north Spitsbergen (Harland, 1961; Harland et al., 1966) and with new evidence from Nordaustlandet (Flood et al., 1969; Krasilschikov, 1973) this is open to doubt. "Basement has yet to be established" (Harland et al., 1966, p. 78).

Torellian basin (eugeosyncline)

The lower part of the Hecla Hoek comprising between 9 and 11.5 km of metasediments and metavolcanics (Botniahalvøya Gp.: 9 km; Finnlandveggen, Harkerbreen and Planetfjella groups: 11.5 km; Isbjørnhamna, Eimfjellet and Deilegga groups: 9–11 km) shows features of eugeosynclinal development. This geosyncline is here named the Torellian basin, the name derived from the succeeding Torellian diastrophism.

Basic volcanics of the Eimfjellet and Harkerbreen groups could be considered to have been formed close to the spreading centre of an oceanic rift. The occurence of eclogites in equivalent rocks in northwest Spitsbergen (Gee, 1966) would agree with this assumption. The thick pile of acid effusives and intrusives in the Botniahalvøya Group of Nordaustlandet could indicate the presence of a continental-type crust below the eastern margin of the geosyncline.

Werenskioldian diastrophism

An important unconformity at the base of the Deilegga Group separates highly metamorphosed Eimfjellet sediments and volcanics from much less metamorphosed Deilegga sediments. This unconformity is best recognised in the area close to Werenskioldbreen (north of Hornsund), from where the name Werenskioldian diastrophism introduced here is derived. Metamorphism under conditions of amphibolite facies (staurolite-kyanite subfacies, e. g. Isbjørnhamna Group) and albite-epidote-amphibolite and greenschist facies (e. g. Eimfjellet Group), followed by some migmatisation (granitization) in the central and western parts of the geosynclinal trough, associated with some folding and with subsequent uplift and erosion along eastern and western margins of the trough, are the main events sug-

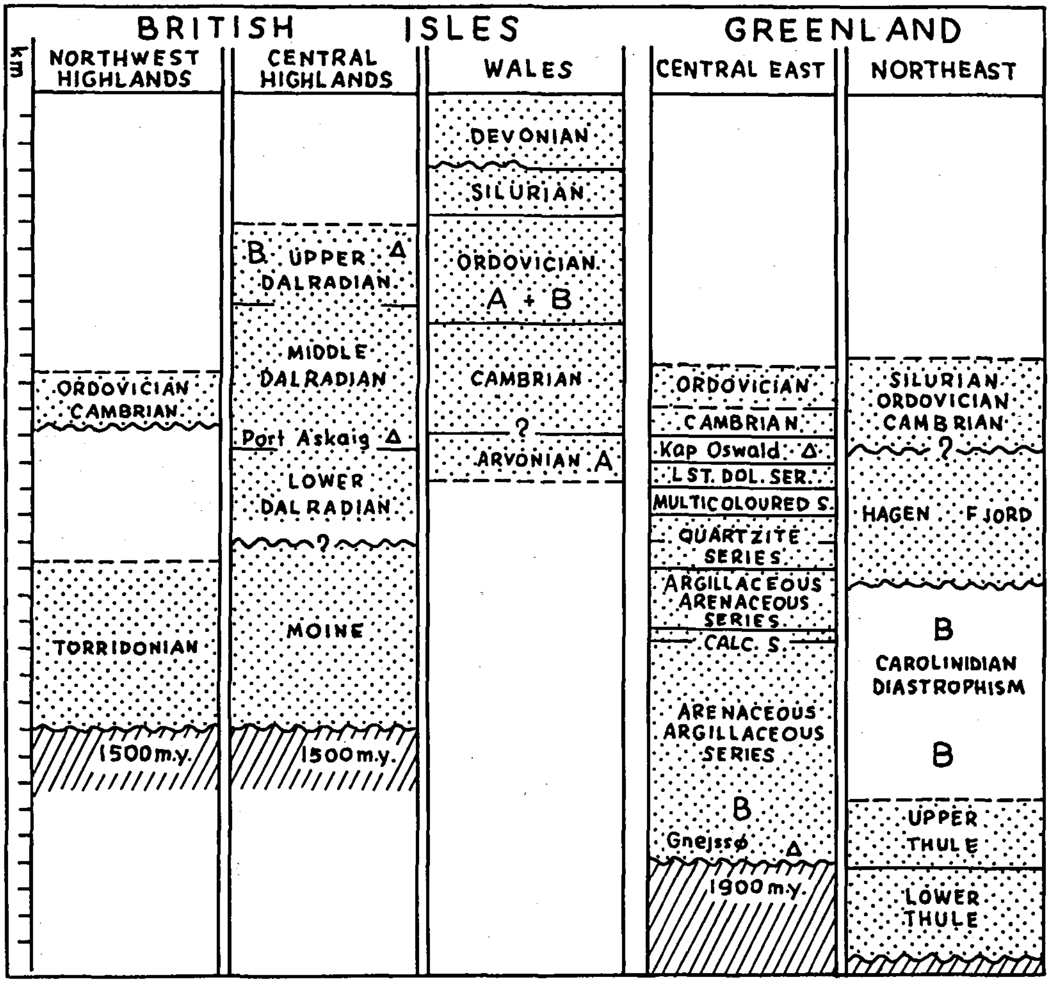


Table 4. Comparison of schematized Caledonian successions and thicknesses (after Harland et al., 1966, supplemented). Acid and basic igneous activity is indicated by A and B; tillites and meta-tilloids marked by open triangles; wavy lines denote major unconformities. The thicknesses used are high values from known published sources.

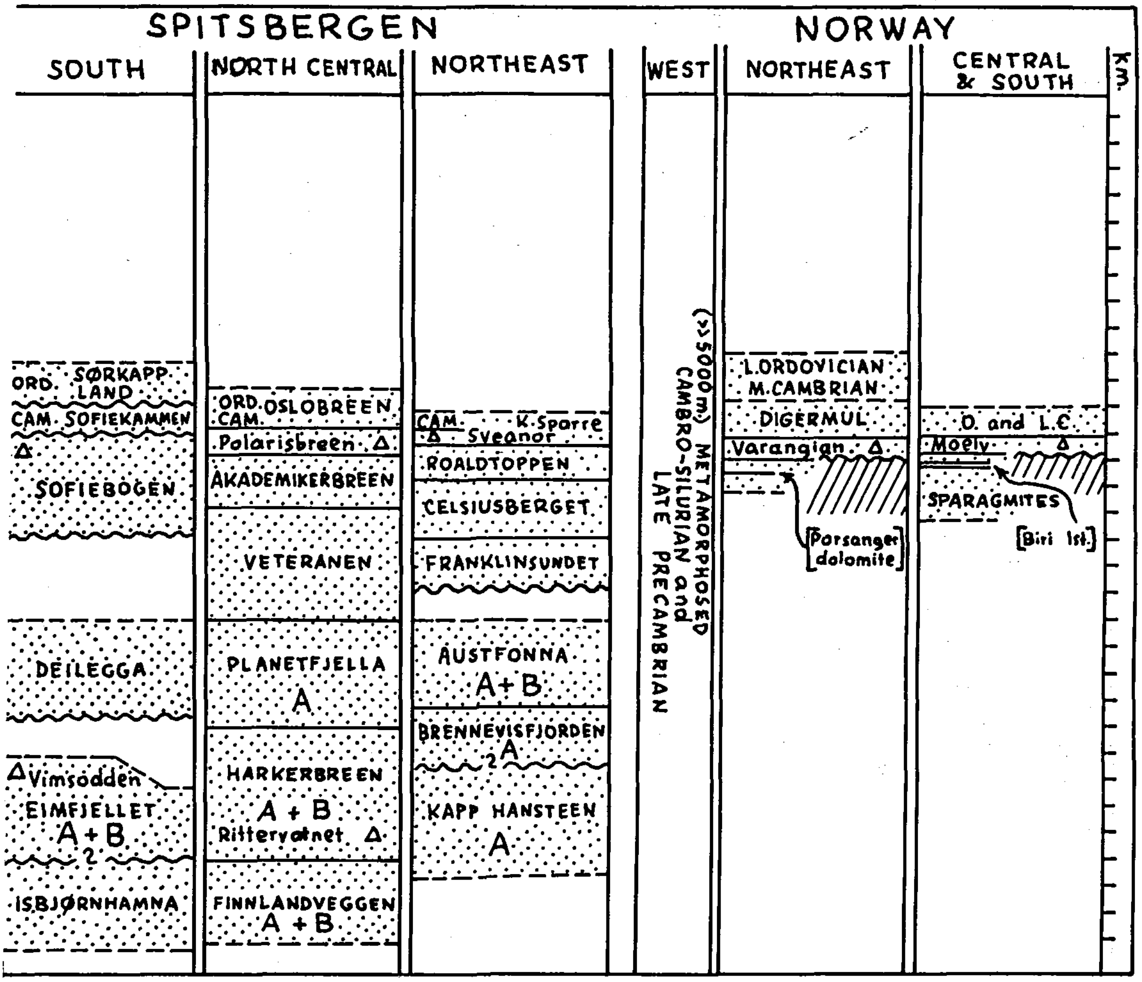
gested for the Werenskioldian diastrophism.

Isotopic ages of the oldest Hecla Hoek rocks usually show overprinting by younger, late Precambrian and Caledonian metamorphism (Gayer *et al.*, 1966). However some high pyroxene ages from eclogites of northwest Spitsbergen, 1393 to 1939 m.y., generally disregarded in the discussion on pre-Caledonian metamorphic events (e. g. Harland et al., 1966; Harland, 1969) might well correspond with postulated Werenskioldian diastrophism and related metamorphism, as seems also to have been accepted by Krasilschikov (1973).

As the result of the Werenskioldian diastrophism the axis of the geosynclinal basin in Svalbard shifted westward (fig. 3), which is evidenced by the increase of sediment pile in that direction (Planetfjella Gp.).

Torellian diastrophism

Another important unconformity at the base of the Slyngfjellet Conglomerate and Franklinsundet Formation is best evidenced from the area close to Austre Torellbreen (north of Hornsund), from where the name Torellian diastrophism introduced here is derived. In marginal parts of the geosynclinal trough, the Torellian diastrophism produced uplift and deep erosion, the axial part of the trough being



seemingly unaffected by these events. Appearance of granite and contact rock pebbles in the Slyngfjellet Conglomerate may be an indication of plutonism subsequent to Werenskioldian diastrophism. If correctly correlated with diastrophic events in East Greenland (table 4), the Werenskioldian and Torellian diastrophisms would correlate with the Carolinidian diastrophism.

Jarlsbergian basin

The middle part of the Hecla Hoek comprising between 1.5 and 7 km of slightly metamorphosed sediments (Roaldtoppen Gp. and Sveanor Fm.: 1.5 km; Veteranen, Akademikerbreen and Polarisbreen groups: 7.1 km; Sofiebogen Gp.: 3.7 km) shows features of miogeosynclinal development. This geosynclinal trough is here referred to as the Jarlsbergian basin, the name derived from the succeeding Jarlsbergian diastrophism.

The basal psammite-pelite to psephite beds (Franklinsundet, Celsiusberget and Veteranen groups) are partly shallow-marine (Veteranen Gp.), with current bedding and ripplemarks (Franklinsundet and Celsiusberget groups), partly molassic in character (Slyngfellet Conglomerate). There follows a shallow-marine

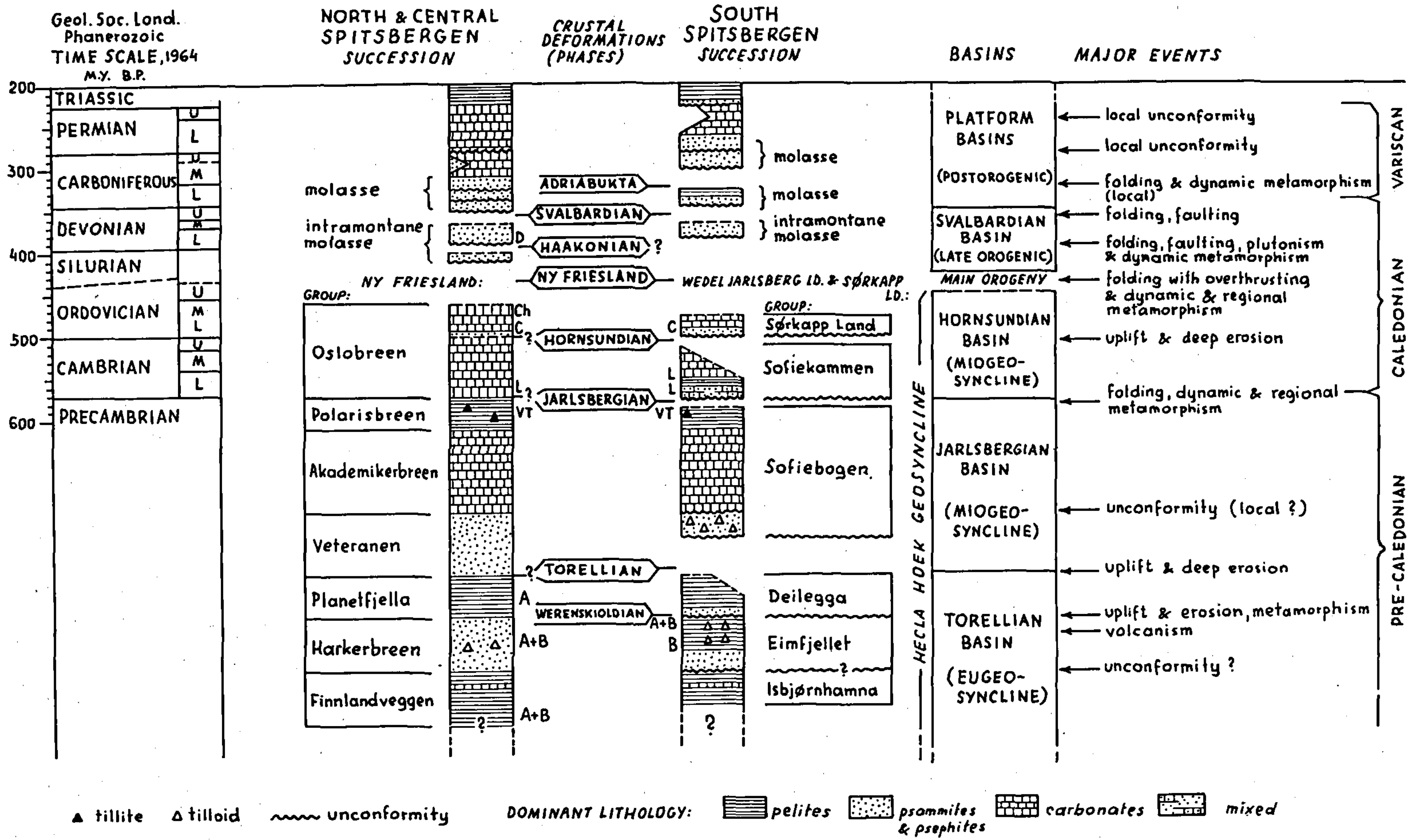


Fig. 5. Major events in the development of the Hecla Hoek geosyncline, late-orogenic and post-orogenic basins in Spitsbergen. D – Downtonian fish. Other explanations as in fig. 4.

carbonate facies with stromatolites, oolites and intraformational conglomerates (Roaldtoppen and Akademikerbreen groups and Höferpynten Fm.) passing upward into monotonous, predominantly pelite-psammite shallow-marine sequence with tillite horizons near the top, corresponding with the Varangian glaciation (Sveanor Fm., Polarisbreen Gp. and Gåshamna Fm.). The thickest sediments occur in south Spitsbergen (Gåshamna Fm.: up to 2.5 km) indicating a further westward shift of the sedimentary trough axis (fig. 3).

Jarlsbergian diastrophism

An important unconformity at the base of the Cambrian Sofiekammen Group separates the Gåshamna Phyllite from almost unmetamorphosed Sofiekammen sediments. This unconformity was recognised best in Wedel Jarlsberg Land (north of Hornsund), from where the name Jarlsbergian diastrophism introduced here is derived. Folding, dynamic and regional metamorphism of the whole Precambrian Hecla Hoek, and subsequent uplift and erosion are the main events of the Jarlsbergian diastrophism. The age evidence of the metamorphism is found i. a. in the presence of sedimentary breccias containing phyllite fragments from the Gåshamna Formation in the Lower Cambrian Blåstertoppen Dolomite. Isotopic determinations from 529 to 636 m.y. of the rocks older than Cambrian, from south, northwest and northeast Spitsbergen (see Gayer et al., 1966; Gee & Hjelle, 1966; Harland et al., 1966; Harland, 1969, 1972; Gee, 1972), though possibly showing some overprinting by Caledonian metamorphosis, could indicate the age of the Jarlsbergian diastrophism as around 600 m.y. ago, i. e. close to the boundary of Cambrian and Precambrian.

Hornsundian basin

The upper part of the Hecla Hoek comprising between 0.8 and 2.3 km of generally unmetamorphosed sediments (Kapp Sparre Fm.: 0.8 km; Oslobreen Gp.: 1.3 km; Sofiekammen and Sørkapp Land groups: 2.3 km) shows also features of miogeosynclinal development. This geosynclinal trough is here referred to as the Hornsundian basin, the name derived from the Hornsundian unconformity well marked between the Cambrian and Ordovician in south Spitsbergen.

Apart from the basal psammitic rocks best recognized in south Spitsbergen, the lower ones succeeding the Jarlsbergian unconformity and the upper ones – above the Hornsundian unconformity, the sediments of the Hornsundian basin represent a thick carbonate succession with maximum thicknesses in south Spitsbergen (fig. 3), with subordinate share of shale (trilobitic in Cambrian, graptolitic in Ordovician) indicating deeper sedimentary conditions. Occurrence of algal structures, oolites and sedimentary breccias in various parts of the succession indicate prevailing shallow-marine conditions.

The Hornsundian unconformity was caused by uplift along the western margin of the basin and the following deep erosion of the Cambrian strata. It has not been recognised in other areas of Svalbard.

Main Caledonian orogeny

The main Caledonian orogeny, the Ny Friesland orogeny (Harland, 1961) is responsible for fold structures, dynamic and regional metamorphism within the Hecla Hoek succession of Svalbard. Radiometric ages (Gayer et al., 1966) 430 to 450 m.y. occur in all the main metamorphic areas of northern Spitsbergen and Nordaustlandet and may suggest that the main metamorphic event occurred at ca. 440–450 m.y. This would imply a late Ordovician orogenesis (Gee, 1972), and would fit the stratigraphic gap between the latest Arenig-early Llanvirn youngest strata of the Valhallfonna Formation (Fortey & Bruton, 1973) and the Downtonian or late Silurian Siktefjellet Group of the Old Red Sandstone (Gee & Moody-Stuart, 1966).

The structure resulting from Ny Friesland orogeny is often complex showing folds and thrust-folds as generally corresponding to a west-east compression. Along the west coast of Spitsbergen there has been much reorientation by Tertiary orogeny. In the Svalbard area as a whole no attempt has yet been made to separate the Caledonian and pre-Caledonian structural patterns. Harland (1966) suggested a shortening of at least 200 km across

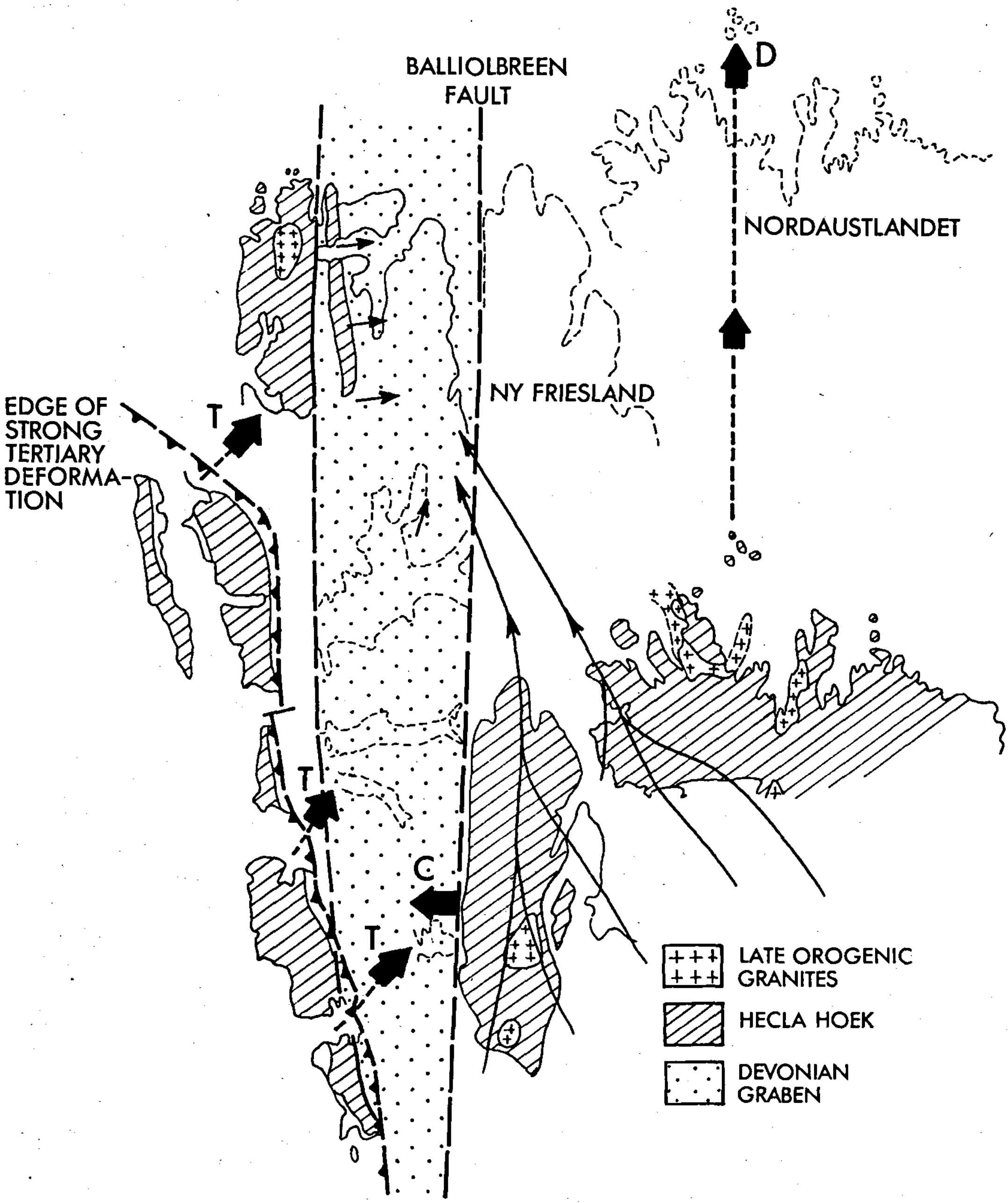


Fig. 6. Palinspastic map of Spitsbergen and Nordaustlandet in Lower Devonian time before Upper Devonian left-lateral movement along the Balliolbreen fault – D (after Friend & Moody-Stuart, 1972, modified and supplemented). Caledonian mountain belt of west coast of Spitsbergen shown in a position prior to Tertiary diastrophism (Spitsbergenian phase) – T; southern termination of the Devonian graben shown in a position prior to mid-Carboniferous thrust (Adriabukta phase) – C. Small arrows indicate Lower Devonian river directions.

the whole zone but this seems to be a minimum value.

Late orogenic plutonism

Late orogenic plutonism is known from the northwest, north-central and northeast areas of Svalbard (fig. 1). Granite plutons in north-central area are known to post-date the main Caledonian tectogenesis. Isotopic determinations give age of plutonism apparently between 420 and 340 m.y. (Gayer et al., 1966) with a peak for migmatisation and plutonism at 390 to 400 m.y., i. e. around the boundary of Silurian and Devonian. Lamprophyre dykes are sometimes associated with the plutons. Ore-bearing quartz-ankerite mineralisation was possibly subsequent to granite emplacement (Birkenmajer & Wojciechowski, 1964).

Late orogenic Svalbardian basin

The Ny Friesland orogeny was followed by extensive denudation, strongest to the north where, prior to Gedinnian, it removed some 15 km of overburden from northwest Spitsbergen (Gee, 1972), and nearly 20 km prior to Tournaisian (Harland, 1969). The late-orogenic Old Red Sandstone molasse was formed in a narrow, fault-bordered intramontane basin some 400 km long, possibly widening from south to north to about 70 km (fig. 6). This graben could be interpreted as a failed arm of triple junction, the other arms causing opening of an oceanic basin situated farther north. The sediments started to accumulate to the north in late Silurian or Downtonian (Siktefjellet Gp.: 1.5 to 2 km), and were folded and thrust already prior to Gedinnian during the Haakonian movements (Gee, 1972). The Gedinnian to Lower Frasnian succession is about 6 km thick in the north (Friend, 1961), while only about 1 km of sediments accumulated in the south during higher Siegenian to Eifelian times (Birkenmajer, 1964). Palinspastic reconstruction of the Devonian graben prior to the Svalbardian movements (fig. 6), shows north-central and northeast Svalbard Caledonides as situated some 250 km farther south than at present (Friend & Moody-Stuart, 1972).

The Svalbardian (late Devonian) movements caused folding and faulting in the Old Red Sandstone and a transcurrent sinistral strike-slip movement along the Balliolbreen fault (Harland, 1965, 1969; Friend & Moody-Stuart, 1972) (fig. 6), and possibly also along other transcurrent faults as postulated by Harland (1971, 1972). Strike-slip movements along these faults could have caused separation of the eastern plate including central-north and northwest, west and southwest Spitsbergen craton, from the western Greenland plate, through a set of slices in intermediate area now represented by Hecla Hoek rocks of northwest, west and southwest Spitsbergen (Harland, 1971, 1972). The amount of this transcurrence is unknown but it seems to have been overestimated by Harland and Gayer (1972), whose reconstruction prior to the main Caledonian compression placed west and east Spitsbergen far apart, despite obvious analogies in the development and succession of the Hecla Hoek rocks in both areas (see figs. 3–5) suggesting much closer connections.

Postorogenic platform basins

Beginning with the Carboniferous, the Svalbard area became a continental platform subject to recurrent denudation and accumulation of mainly terrigenous deposits (see reviews by Orvin, 1940; Harland, 1961, 1969; Sokolov *et al.*, 1968). Local post-orogenic molasse basins developed during Lower Carboniferous to Lower Permian times, and some folding and thrusting took place along the Balliolbreen fault during mid-Carboniferous Adriabukta phase, e. g. at Hornsund (Birkenmajer, 1964) (fig. 6). Permian to Tertiary times witnessed repeated ingressions and regressions of shallow seas, and the stratigraphic column shows numerous breaks in sedimentation caused by vertical movements, especially close to the western border of the basins. A major tectonic event was the Tertiary diastrophism which caused dextral strike-slip translation and strong thrusting in the western Caledonian belt, with tectonic transport to NE and E, with some anticlockwise rotation of the Caledonian structures (Birkenmajer, 1972b).

Dansk sammendrag

Svalbards Kaledonske foldebælte udgør den nordligste del af det cirkum-atlantiske Kaledonske bjergkædesystem. Det omfatter mellem 15 og 20 km mægtige sedimenter og metasedimenter med varierende mængder af vulkaniter og metavulkaniter. Den sen-Ordoviciske Ny Friesland orogenese er hovedfasen i den Kaledonske deformation og metamorfose. Den efterfulgtes af senorogenetisk migmatitisering og plutonisme nær grænsen mellem Silur og Devon, og af sen-orogenetiske deformationer; hertil hører plade-tektoniske bevægelser i Devon. Det er forsøgt her at vurdere betydningen af præ-Kaledonsk metamorfose og deformation på grundlag af istop-aldersbestemmelser og på grundlag af hoveddiskordanser i den Prækambriske bjergartsserie. Disse diskordanser er hidtil blevet forbigået eller undervurderet i studierne af Hecla Hoek geosynklinalen. 3 geosynklinale bassiner gennemgås, det Prækambriske Torellian eugeosynklinale bassin, det Prækambriske Jarlsbergian miogeosynklinale bassin, og det tidligt Palæozoiske Hornsundian miogeosynklinale bassin. De deformationsfaser som kan erkendes i Hecla Hoek bjergartsserien er forsøgt kædet sammen med magmatiske og metamorfe faser på Svalbard og andre steder.

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Bulletin of the Geological Society of Denmark, vol. 24.

Errata.

Page 17, column 2, line 10 should read:
northeast Spitsbergen adjacent to the Barents

Page 18, column 2, line 44 should read:
Harland, W. B. *1965. The tectonic evolution of the*