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KRZYSZTOF BIRKENMAJER

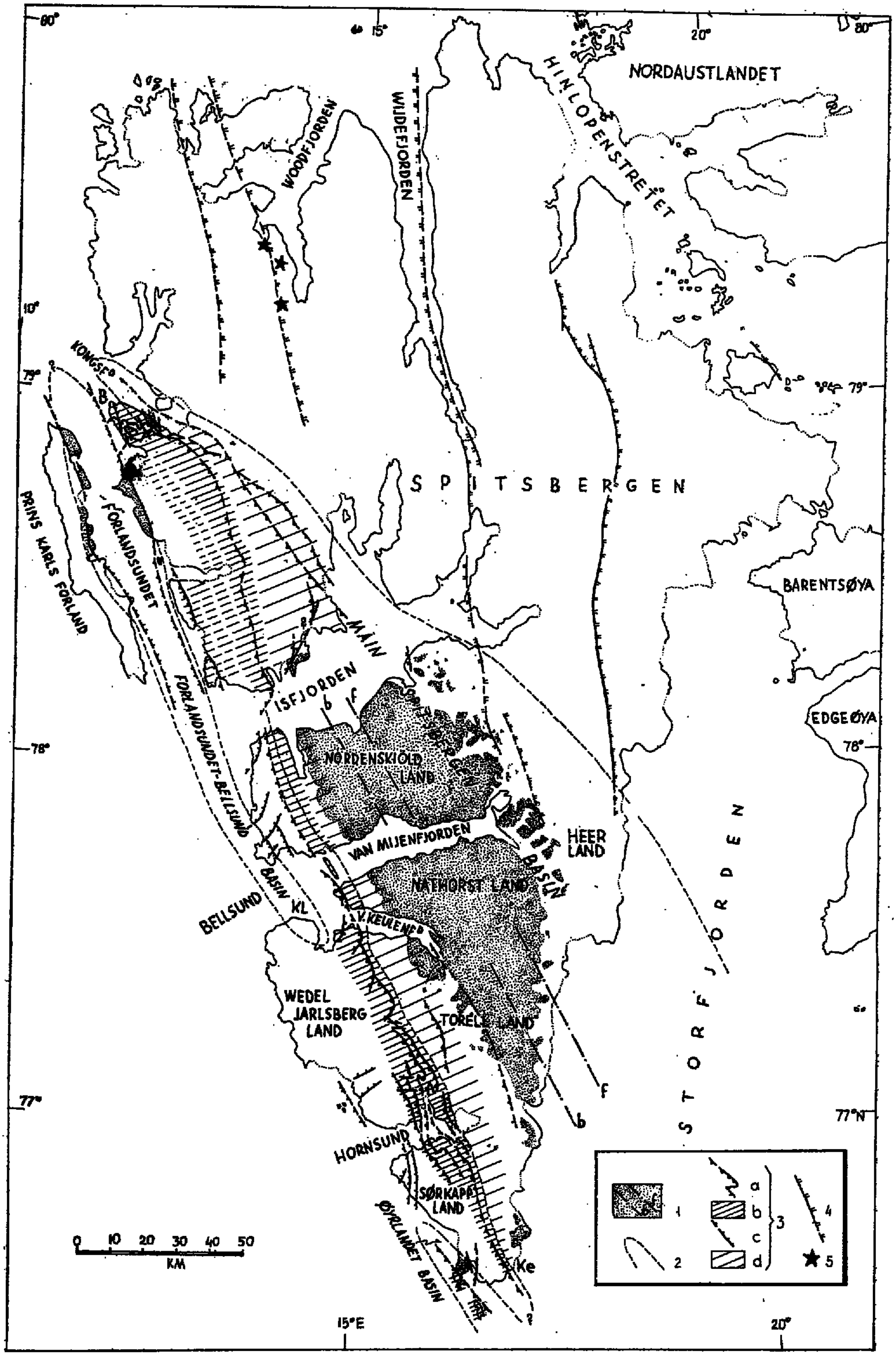
Tertiary history of Spitsbergen and continental drift

ABSTRACT: The present paper is a sequel to that dealing with the Alpine fold belt of Spitsbergen (Birkenmajer 1972). The relation of the Early Tertiary sedimentary basins to the Alpine fold belt is discussed, and the stages of Cenozoic expansion and compression recognized in Spitsbergen are tentatively related to the stages of separation and translation of the Greenland block from the Euro-Asiatic block.

TERTIARY BASINS IN SPITSBERGEN

The exposures of the Tertiary strata in the Svalbard archipelago (Fig. 1) occur only on its main, Spitsbergen island, and on Prins Karls Forland. The majority of exposures are grouped in a wide zone extending NW-SE between Isfjorden and Storfjorden where they belong to the *Main Spitsbergen Basin* (Fig. 1). The south-eastern prolongation of this basin could be expected in the area of the Barents Sea shelf to the south-east of Sørkapp Land. The north-western prolongation of the basin is represented by the Tertiary outcrops at Kongsfjorden (Ny Ålesund mines).

The palaeogeographic reconstruction of the basin (Fig. 1) indicates the length of the basin, measured along its axis between Ny Ålesund and Sørkapp Land, as exceeding 320 km. The width of the basin probably did not exceed 10—15 km near its north-west closure (Ny Ålesund) but grew up to *c*. 80 km in Nordenskiöld Land, and to more than 90 km in the southern part of Spitsbergen.



NORDAUSTLANDET
HINLOPENSTRETET
WIJDEFJORDEN
WOODFJORDEN
SPITSBERGEN
BARENTSØYA
EDGEØYA
PRINS KARLS FORLAND
FORLANDSUNDET
FORLANDSUNDET-BELLSUND BASIN
KONGSF'D
MAIN
ISFJORDEN
NORDENSKIÖLD LAND
VAN MIJENFJORDEN
NATHORST LAND
HEER LAND
BASIN
BELLSUND
KL
L.V. KEULENF'D
WEDEL JARLSBERG LAND
TORELL LAND
STORFJORDEN
HORNSUND
SØRKAPP LAND
ØYRLANDET BASIN
Ke
0 10 20 30 40 50
KM
15°E
20°
77°N
78°
79°
80°

Along the west coast of Spitsbergen another, but smaller, zone of Tertiary outcrops is known from both sides of Forlandsundet. This basin was most probably separated from the Main Spitsbergen Basin and, probably extended southwards as far as Bellsund (Kap Lyell). This basin will be further discussed as the *Forlandsundet-Bellsund Basin.* Its axis is oriented NNW-SSE, the supposed length of the basin, between the entrance to Kongsfjorden and Bellsund, amounts to a minimum of 180 km, the width being barely 10—20 km.

The third exposure of the Tertiary strata in Spitsbergen is at the Øyrlandet peninsula, Sørkapp Land. The geological relationships are here poorly known. This could be either a separate *Øyrlandet Basin,* structurally equivalent to the Forlandsundet-Bellsund Basin, or a branch of the Main Spitsbergen Basin.

Relation of the Tertiary to the Cretaceous

In the Main Spitsbergen Basin between Isfjorden and Sørkapp the Tertiary strata contact with the Lower Cretaceous Carolinefjellet Formation. This is a marine sequence of shales and sandstones, 180—850 m thick, with *Ditrupa* (hence *Ditrupa* beds of the previous authors), pelecypods, belemnites and ammonites, the latter indicating the Aptian age for the lower part, and the Albian age for the upper part (see Frebold 1951, Nagy 1970). The youngest ammonite fauna so far recorded from the formation (Nagy 1970) corresponds to the Middle Albian Euhoplites lautus Zone. The Upper Albian (Mortoniceras inflatum Zone) and the succeeding Upper Cretaceous stages are missing (Tab. 1).

The palaeogeographical reconstruction of the Aptian sea in Svalbard has been presented by Birkenmajer (1966) on the basis of sedimentological

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Fig. 1

Palaeogene basins and the Alpine fold belt in Spitsbergen. Geological features selected and re-interpreted from Orvin (1934, 1940), Dineley (1958), Różycki (1959), Harland (1961, 1969), Hjelle (1962), Challinor (1967), Barbaroux (1966, 1967, 1968), Flood & al. (1971) and the present author's own data (see Birkenmajer & al. 1971, Fig. 2; Birkenmajer 1972, Fig. 1 — slightly modified)

1 exposures of Palaeogene sediments (*f* basin axis for the basal Firkanten Fm., *b* basin axis for the successive Basilika Fm.); *2* possible maximum extensions of Palaeogene basins; *3* structures produced by the Spitsbergenian phase: *a* overthrusts and reverse faults, *b* fold belt (major thrust zone and transitional zone), *c* normal faults, *d* zone of gentle folded foreland (transitional zone); *4* faults and fractures younger than the Spitsbergenian phase; *5* centres of Late Pleistocene/Early Holocene volcanic activity; *B* Brøggerhalvøya; *Ke* Keilhaufjellet; *KL* Kapp Lyell investigations made in the basal Dalkjegla Member of the Carolinefjellet Formation. The sediments deposited in the Aptian sea were derived from a land area which covered the north-eastern and eastern parts of the Svalbard archipelago. Another land mass, along the west coast of Spitsbergen, suggested already by Frebold (1931), according to Birkenmajer

Table 1

Subdivision of the Carolinefjellet Formation in Spitsbergen (age correlation after Nagy, 1970; simplified)

Age		Southern Spitsbergen (Nagy, 1970)	Kjellströmdalen area, Van Mijenfjorden (Parker, 1967)	(Hagerman, 1925)
Maestrichtian to Cenomanian				
Albian	Upper			
	Middle	Schönrockfjellet Member		
		Zillerberget Member		
	Lower	Langstakken Member	Langstakken Member	Upper lamina sandstone
Aptian	Upper	Innkjegla Member	Innkjegla Member	Cretaceous shale
	Lower	Dalkjegla Member	Dalkjegla Member	Lower lamina sandstone
Barremian		*Helvetiafjellet Formation*		

(1966) supplied practicaly no clastic material to the Aptian-Albian sea. The above conclusions have been supported by Nagy (1970) on investigations of the sandstone Langstakken Member of the Carolinefjellet Formation.

The Carolinefjellet Formation is thinnest at Isfjorden (Festningen section: c. 180 m — Hoel & Orvin 1937; Carolinefjellet section: 270 m — Parker 1967). Farther south, at Van Keulenfjorden, it grows to 520 m (Ulladalen) and 667 m (Suessbreen — Różycki 1959, Nagy 1970). The greatest thicknesses of the formation have been reported from the south-east part of Spitsbergen: 768 m at Kjellströmdalen (Parker 1967), 830 m in south Heer Land (Nagy 1970), 850 m in Central Torell Land (Langleiken) and north-east Sørkapp Land (Tromsøbreen — the present author's observations).

The Carolinefjellet Formation is overlain by the basal member of the Tertiary succession, *i.e.* the Firkanten Formation of Paleocene age. Hence the sedimentary break covers the whole Upper Cretaceous (Upper Albian to Maestrichtian) time span. This break is generally regarded as an evidence of regression of the Aptian-Albian sea due to earth movements, and of erosion and denudation which preceded the deposition of the basal Tertiary clastics. According to Orvin (1940) the pre-Tertiary earth movements in Spitsbergen caused an unequal rise of the region, the uplift being greatest in the northern part of Spitsbergen, and gradually diminishing towards the south. This view is also shared by Nagy (1970) who suggests that in consequence of this oblique rise of the region, the Upper Cretaceous denudation had removed an appreciably larger portion of the Carolinefjellet Formation in the north and north-west, than in the south-east. This is supported by the following evidence.

At Festningsodden at Isfjorden (see Hoel & Orvin 1937), the Carolinefjellet Formation is represented by the Dalkjegla Member c. 55 m thick (mostly sandstone, with subordinate shale), followed by the Innkjegla Member c. 125 m thick (mostly shale and marl), the latter corresponding to the lower shale-siltstone part of this member (Nagy 1970). The remaining part of the formation is considered to have been removed by denudation prior to the deposition of the Tertiary conglomerate. The conglomerate marks an apparent angular unconformity (see Birkenmajer 1966, Fig. 5*E*), but this may be partly due to Tertiary movements, as both the Lower Cretaceous and Lower Tertiary sediments are here strongly folded together.

In the Braganzavågen (east Van Mijenfjorden), Ulladalen (east Nathorst Land), Suessbreen (north-west Torell Land) and Kjølberget (west Heer Land) areas the basal Tertiary beds rest directly upon the Zillerberget Member of the Carolinefjellet Formation (Nagy 1970). Here the age gap between the Lower Cretaceous and Lower Tertiary is smaller. The Schönrockfjellet Member, the youngest member of the Carolinefjellet Formation, is preserved only in the south-eastern part of Spitsbergen (Heer Land, and northern part of Torell Land: Jemelianovbreen area). The stratigraphic positions of ammonite faunas within the Carolinefjellet Formation with respect to the lower boundary of the Tertiary strata also confirm the above picture (Nagy 1970, p. 29).

In the central part of Torell Land four sandstone members appear in the shaly sequence of the Carolinefjellet Formation. The three lower ones probably correspond to the Dalkjegla, Langstakken and Schönrockfjellet members. The fourth member is separated from the third by shales, and is overlain by shales with red-weathering clay-ironstone concretions containing *Inoceramus*. These shales form the substratum of the basal Tertiary formation (Firkanten Fm.).

In the area of Ny Ålesund coal mines (Kongsfjorden), the Tertiary beds rest on a thin shale and siltstone unit ("Bottom Shale" of Orvin 1934). Orvin believed the "Bottom Shale" to be of Cretaceous age, but its lithologic similarity to the Triassic Vardebukta Formation suggests that it is Lower Triassic (Challinor 1967). At Scheteligfjellet, Kongsfjorden, the Tertiary beds rest directly on the Permian Kapp Starostin Formation (Challinor, *op. cit.*).

The above data indicate the presence of a large-scale planation level which developed in Spitsbergen prior to the Paleocene. This planation level cut through different members of the Lower Cretaceous Carolinefjellet Formation (between Sørkapp and Isfjorden), locally down to Lower Triassic and Permian substratum (at Kongsfjorden). This is the evidence of a slight angular unconformity at the base of the Tertiary in the Main Spitsbergen Basin. Locally this unconformity may amount to as much as 10 degrees, as was suggested by the present author (*in* Birkenmajer & Narębski 1963) on field observations in the area of Hedgehogfjellet, north-west Sørkapp Land.

This pre-Tertiary denudation could also be responsible for removing some presumably still younger Cretaceous sediments, as well as some thin regressive Cretaceous beds, so far unknown from Svalbard.

Main Spitsbergen Basin

Age

The stratigraphic succession and ages of the Tertiary strata are known best from the Main Spitsbergen Basin. The scheme currently adopted follows Nathorst's (1910) subdivision into six units, for which lithostratigraphic names (formation names) have been introduced by H. Major in the map of Adventdalen (1 : 100,000) printed by Norsk Polarinstitutt in 1964 but not yet published [1] (Table 2).

The first more adequate determination of the age of particular lithostratigraphic units has been made possible on marine molluscs from the 1*st*, 3*rd* and 5*th* units ("series") of Nathorst by Ravn (1922). This indicated a Lower Palaeogene (Paleocene-Eocene) age of the strata, contrary to stratigraphic conclusions based on plant remains, for which a Miocene age was adopted by Heer in 1870. Manum (1962) confirmed the Lower Palaeogene (mostly Paleocene) age of the rocks by determination of microflora from the 1*st* and the 6*th* series of Nathorst. He has found no essential differences in the microfloral content of these two series, being the lowermost and the uppermost formations of the Tertiary in the Main Spitsbergen Basin. The apparent differences in macrofloral content of taxodiaceous remains (*Sequoia* versus *Taxodium*) as indicated by Nathorst (1910) have been eliminated by Chaney's work of 1951 through unification of these remains into *Metasequoia* (Manum 1962).

Rosenkrantz (1942) suggested the idea, based on re-examination of fossil collections from the Tertiary of Spitsbergen, that these beds could correspond to the Tertiary of West Greenland. The latter contain fossils typical for the lowermost Paleocene (*i.e.* Danian) of Denmark, and the Danian age of the Spitsbergen Tertiary finds confirmation in its pelecypod

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[1] In the legend to this map the Basilika Formation is improperly called "Basilikaen Formation". The spelling was corrected by Harland (1969, Tab. VIII).

fauna. A similar view was also shared by Vonderbank (1970) who described new faunal collections from the Tertiary deposits of the Isfjorden area, Spitsbergen. Vonderbank stressed the similarity of the Spitsbergen fauna to that of the Agatdal Formation (Danian-Montian) of West Gre-

Table 2

Tertiary succession in the Main Spitsbergen Basin

Age	Group (Harland, 1969)	Formation (Nathorst, 1910; Orvin, 1940)		Formation (Major, 1964)	Formation (Vonderbank, 1970)
(Lower Eocene?) ↑	Van Mijenfjorden	6) Upper plant-bearing sandstone series	500-600 m	Aspelintoppen	Nordenskiöldfjellet Schichten
Upper Paleocene (Landenian)?		5) Flaggy sandstone series	200m	Battfjellet	Fardalen Schichten
		4) Upper black shale series	200-300m	Gilsonryggen	
Lower Paleocene (Danian-Montian)		3) Green sandstone series	175-250m	Sarkofagen	Grumantdalen Schichten
		2) Lower dark shale series	20-130m	Basilika	
		1) Lower light sandstone series	100-130m	Firkanten	Adventfjorden Schichten
	Substratum: Aptian-Albian (Carolinefjellet Fm.), locally Triassic or Permian				

enland, and also cited some fossils common to both the Spitsbergen Tertiary and the Selandian (Upper Danian) of Denmark. His Adventfjorden Schichten (= lower and middle parts of the Firkanten Formation) and Grumantdalen Schichten (=uppermost part of the Firkanten Formation, the Basilika Formation and most of the Sarkofagen Formation) represent, therefore, the Danian-Montian stages. The upper and the uppermost formations of the Tertiary sequence in Spitsbergen did not yield any index fauna; the floral remains however, according to Vonderbank (1970, p. 115), are decidedly older than the Miocene. Here he opposed the conclusions reached by J. J. Liwschitz (unpublished manuscript 1965; see also Sokolov & al. 1965) who has assumed the topmost beds of the Tertiary in Nordenskiöld Land (central Spitsbergen) to extend into the Miocene.

Summarising the above, we can conclude that the lower four formations of the Tertiary in the Main Spitsbergen Basin represent the basal Palaeocene (Danian-Montian), the remaining two either belonging still to a higher Palaeocene (Landenian) or at least to the Eocene.

Lithologies

Of the six Tertiary formations of the Main Spitsbergen Basin four (*1st*, *3rd*, *5th* and *6th*) consist predominantly of sandstones, the remaining two (*2nd* and *4th*) of shales (see Nathorst 1910, Orvin 1940). The *Firkanten Formation* begins either with a basal conglomerate or with dark shale resting on weathered Lower Cretaceous rocks, while light coloured sandstones (predominantly fresh-water) with subordinate shale and conglomerate dominate its sequence. Coal-seams (mined at several sites) occur near the base, and shale intercalations with marine fossils appear higher in the succession. A tuff intercalation has been reported by Vonderbank (1970, p. 13) from a thicker shale intercalation.

The *Basilika Formation* consists predominantly of dark grey shale with scanty marine fossils, often passing into sandy shale and fissile sandstone. Thin tuff intercalations have been reported from the formation by Gripp (1927), Nagy (1966) and Vonderbank (1970).

The *Sarkofagen Formation* is represented mainly by homogenous, medium-grained, grey to greenish sandstone, often containing glauconite. Quartz pebbles occur sometimes in greater number giving rise to thin conglomerates. Marine fossils have been found in the upper part of the formation.

The *Gilsonryggen Formation* consists of black shales yielding marine fossils. In general there seems to be a transition between the Sarkofagen and Gilsonryggen formations, but locally (in the area of Jemelianovbreen, north-east Torell Land) a 5—10 cm thick basal conglomerate consisting of Permian chert, quartz and quartzite pebbles appears at the base of the Gilsonryggen Formation, with a slight erosional unconformity upon strongly weathered and limonitized green sandstone of the Sarkofagen Formation. This could be evidence of subaerial weathering following a regression of the sea, the conglomerate marking a new transgression which deposited the succeeding black shales.

The *Battfjellet Formation* consists of alternating black clayshale and grey to greenish fissile (flaggy) sandstone, the latter containing some marine fauna and land plant remains.

The *Aspelintoppen Formation* consists of light grey to green, usually fine-grained sandstone, fissile sandstone and siltstone, with clay-ironstone, marl and subordinate coal seams. This formation is supposed to be completely of fresh-water origin. Usually it is difficult to separate the Aspelintoppen and the Battfjellet formations (see Orvin 1940, p. 41), at least in the area south of Van Mijenfjorden.

Vonderbank (1970) has distinguished four sedimentary cycles separated by erosion (corresponding to his lithostratigraphic units — "Schichten" — see Tab. 2) within the Tertiary of the Main Spitsbergen Basin of Isfjorden, each beginning with conglomerate or coarse sandstone (resp. greywacke) and usually terminating with shale, with the exception of the first cycle which often begins with shale.

Sources of sediment

The sources of clastics supplied to the Main Spitsbergen Basin have been calculated on the basis of the distribution of drift pebbles (Birkenmajer & Narębski 1963, Birkenmajer & al. 1971) and on the facies change (Vonderbank 1970). The drift pebbles are scattered at random within the marine shale of the Basilika Formation, becoming more and more common in the succeeding marine sandstone of the Sarkofagen Formation and, especially, of marine shale of the Gilsonryggen Formation (see Nathorst 1910; Orvin 1934, 1940; Frebold 1935, 1951; Birkenmajer & Narębski 1963; Birkenmajer & al. 1971). They consist predominantly of quartz, quartzite and Permian chert, but sometimes also of Precambrian porphyry rhyolite, postorogenic Caledonian granite, and late-Mesozoic dolerite (white-trap variety). The pebbles are thought to have been brought to the sea by driftwood, kelp, and/or by floating islets of tangled growth, their major source being probably river outlets and coastal beaches of a land which included the northern part of Spitsbergen, Nordaustlandet, and the islands to the east of Storfjorden — Barentsøya and Edgeøya (see Birkenmajer & al. 1971, Fig. 2).

The distribution of fresh-water (deltaic), coastal and shallow marine sediments in the *1st, 2nd* and *3rd* Tertiary formations (Adventfjorden Schichten and Grumantdalen Schichten) as shown by Vonderbank (1970, Figs 15—16) also confirms the above pattern of land and sea distribution in Svalbard. No more detailed conclusions can be reached at present, since no statistical measurements of the direction of sediment transport on ripplemarks, cross-bedding and erosional furrows (these structures being often mentioned by Orvin 1940, and Vonderbank 1970, as frequent in the *1st* and *6th* divisions of the Spitsbergen Tertiary) have yet been published.

Rates of deposition

Table 3 shows the thickness variation of the Tertiary strata in the southern part of the Main Spitsbergen Basin (data from Birkenmajer & Narębski 1963, Nagy 1966, and the present author's own measurements) as compared with the thickness-range for the standard area of Nathorst Land and Nordenskiöld Land (see Nathorst 1910, Orvin 1940) — Tab. 2. The total thickness of the Tertiary sediments amounts to *c.* 950 m in the Isfjorden area (Vonderbank 1970, Fig. 2) but grows to *c.* 1500 m in Nathorst Land (Orvin 1940). In Torell Land the maximum thickness of the sequence is 1020 m, but here the Aspelintoppen Formation is either missing (due to subsequent erosion) or represented only in its lowest part. If we added 500—600 m for the denuded Aspelintoppen Formation to the remaining Tertiary column in Torell Land, we would obtain a sediment

Table 3

Thickness variation (in metres) of the Tertiary formations in the Main Spitsbergen Basin: Torell Land

Formation	Western border	Central area			Eastern border
		West	Centre	East	
Aspelintoppen	–	–	–	–	–
Battfjellet	–	+250	–	+170	–
Gilsonryggen	+200	240-260	+25	260	–
Sarkofagen	70-120	(100) 120-180	150-170	150-160	100-120
Basilika	50	150	200-220	170-190	150
Firkanten	15-20	+50	95-110	unknown	130

column of c. 1.5 km (1520—1620 m) for the whole Tertiary sequence of the area.

Taking into account that the Firkanten-, Basilika- and Sarkofagen formations represent Danian-Montian (see above), for which stage the absolute age limits are 65 and 58.5 m.y.b.p. (see Holmes' Symp. 1964), and that the total thickness of these three formations in Torell Land amounts to 500 m (see Tab. 3), we can obtain a mean rate of deposition of c. 0.08 m per millennium: $\frac{500\text{ m} \times 1000}{6.5\text{ m.y.}}$.

It is obvious that the real rates of deposition were lower for the marine shales than for the sandstones, especially when fluviatile. Nevertheless, the mean rate of deposition c. 0.08 m per millennium is low, and does not favour any idea of intense erosion of the neighbouring land or of rapid subsidence of the Main Spitsbergen Basin.

Migration of basin axis

The basin axis was reconstructed for the lowest, Danian-Montian deposits of Nordenskiöld Land by Vonderbank (1970, Figs 15—16). During the formation of his Adventfjorden Schichten (= major part of the Firkanten Formation) the basin axis ran from west of Colesbukta (Isfjorden) to west of Kaldbukta (Van Mijenfjorden) NNW-SSE (azimuth 150°), and during the deposition of the subsequent Grumantdalen Schichten (= uppermost part of the Firkanten Fm., Basilika Fm. and most of the Sarkofagen Fm.) it shifted some 7 km WSW, while still retaining the same direction.

The same pattern is also valid for Torell Land (see Tab. 3 and Fig. 1) for the Firkanten and the Basilika formations. The basin axis passed through the area of Jemelianovbreen during the deposition of the Firkanten Formation and shifted about 12 km towards WSW during the next, the Basilika Formation. During the deposition of the Sarkofagen Formation the basin axis lay within a 20 km broad central part of the basin where the thicknesses of the green sandstone were between 120 and 180 m (versus two border zones — eastern and western — with 70—120 m thick deposits).

The above data indicate that the direction of the basin axis NNW--SSE (azimuth 150°) did not change during the Danian-Montian but gradually migrated towards WSW, towards the later-formed Tertiary fold belt. The shift of the basin axis towards the WSW grew in the southern part of the basin (7 km for Isfjorden versus *c.* 12 km for Torell Land), possibly being accompanied by a simultaneous basin-floor spreading.

Volcanism

The appearance of thin tuff horizons predominantly in the basal Danian-Montian formations of the Tertiary in the Main Spitsbergen Basin coincides with the period of basic volcanic activity in the North Atlantic province during Paleocene-Eocene, *i.e.* 65—40 m.y. (see Beckinsale & al. 1970). In West Greenland it succeeded the Danian Agatdal Formation (see Rosenkrantz 1970), and in East Greenland it post-dated a thin sequence of estuarine sediments yielding a fauna of Senonian or very early Tertiary age (Haller 1970; Beckinsale & al. 1970). The oldest K-Ar ages for the basaltic rocks of East Greenland fall within the range 55—60 m.y. (Beckinsale & al. 1970), *i.e.* correspond to the base of the Eocene or to the top of the Paleocene.

The Danian-Montian tuffs in Spitsbergen are thus older than the dated basaltic rocks of both West and East Greenland. The Spitsbergen tuffs could therefore be wind-borne volcanic ashes derived from the then active eruptive centres of the North Atlantic province other than Greenland.

Petrological investigations of the Spitsbergen tuffs could contribute to the problem of their provenance. So far only one and that very general description is available from the Grønfjorden area, central Spitsbergen, which does not contradict the above assumptions. This was presented by Gripp (1927) who stated that the tuff appears to be basic, having mafic plagioclases and basaltic glass. Gripp, however, compared the tuff with glassy basalts from the area of Woodfjorden, north Spitsbergen, which are certainly younger, and related to the Quaternary volcanic activity centered round the Sverrefjellet volcano (see below).

Forlandsundet-Bellsund Basin

The Tertiary sediments of the Forlandsundet-Bellsund Basin crop out in two areas: (1) at Forlandsundet — along the east coast of Prins Karls Forland; at Sarsøyra and Kaffiøyra — along the west coast of Oscar II Land; and (2) at Kapp Lyell, Bellsund (see Orvin's map 1940; also Fig. 1 in this paper).

The thickness of the Tertiary strata at Forlandsundet is supposed to be 2060—2150 m (see Atkinson 1963; Harland 1969, p. 838) — Table 4.

Table 4

Tertiary succession at Forlandsundet

Age	Group (Harland, 1969)	Formation (Atkinson, 1963, corr.) West	East
Lower Eocene?	Forlandsundet	McVitiepynten c 2000 m	Sarsbukta ? m
Upper Paleocene (Landenian) ?		Selvågen Conglomerate 60-150 m	?
	Substratum: Precambrian (Hecla Hoek)		

In the west, the Tertiary begins with the Selvågen Conglomerate Formation 60—150 m thick, with boulders more than 1 m in diameter. Higher up comes the McVitiepynten Formation (conglomerates, sondstones and shales) about 2000 m thick. To the east of Forlandsundet the equivalent rocks show lithologies similar to the McVitiepynten Formation and are here distinguished as the Sarsbukta Formation [2] which also contains some coal seams. The substrate of the Tertiary is formed by the Precambrian Hecla Hoek rocks.

Orvin (1940, pp. 36, 42, Fig. 7) supposed these rocks to be either coeval with the "Upper Plant-bearing Sandstone" (= Aspelintoppen Formation) of the Main Spitsbergen Basin or younger than the latter. Harland (1961, p. 109) concluded that they were "later than the main Tertiary deposits, in which case they could represent an orogenic molasse-like deposit consequent upon the post-Palaeogene folding, uplift and erosion". A similar view was also shared by Atkinson (1962, 1963).

The palaeontological evidence to support this conclusion is insufficient. From Sarsbukta at Forlandsundet, Manum (1960, 1962) described pollen and microplanktonic fauna of little stratigraphic value. Characte-

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[2] Atkinson (1963) and Harland (1969) used improper terms "McVitie Formation" and "Sars Formation", here corrected to McVitiepynten Formation and Sarsbukta Formation.

ristic is the presence of *Tsuga* pollen not recognized by Manum in the samples from the Main Spitsbergen Basin (Manum 1962). The microfauna indicates the age as no greater than the Upper Paleocene (Manum 1960). Manum's investigations, however, did not contradict Orvin's view that the deposits at Sarsbukta (= Sarsbukta Formation) could be somewhat younger than the Aspelintoppen Formation.

The Tertiary deposits at Kapp Lyell, Bellsund, begin with basal conglomerate 4—5 m thick resting on strongly weathered Hecla Hoek rocks. There follow coal-bearing shales and sandstones with subordinate conglomerate, finally more shale and sandstone (see Nathorst 1910, Vonderbank 1970). The total thickness of the Tertiary strata amounts to about 130 m (Vonderbank 1970). Vonderbank (*op. cit.*, p. 31) correlated the beds in question with his Adventfjorden Schichten (= ± Firkanten Formation) mostly on lithological grounds. However the correlation with the Aspelintoppen Formation is equally possible.

It seems at present reasonable to retain Orvin's view that the Tertiary of Forlandsundet and Bellsund represents a sedimentary event generally post-dating the Tertiary sedimentation in the Main Spitsbergen Basin. The differences in lithology, the abundance of conglomerates and their thickness (especially at Forlandsundet), the large dimensions of boulders, the direct contact with strongly weathered Hecla Hoek rocks, all seem to favour an independent sedimentary environment, with clastics possibly supplied from the north, along the basin axis (hence thicker and coarser basal conglomerates at Forlandsundet, and thinner and finer basal conglomerates at Kapp Lyell), and north-west (see Atkinson 1963). Evidences of marine influence in this basin are slight (microplanktonic fauna, possibly also some trace fossils) and the rocks could well correspond to the orogenic molasse of an intramontane basin (rift valley).

The palaeontological arguments provided by Manum (1960, 1962) may speak in favour of an Upper Paleocene (Landenian) and (partly?) Eocene age of the Tertiary strata in the Forlandsundet-Bellsund Basin versus Lower Paleocene (Danian-Montian) to Upper Paleocene (Landenian) ages of the Tertiary in the Main Spitsbergen Basin.

Tertiary strata at Øyrlandet

Little is known about the Tertiary strata at Øyrlandet (in Sørkapp Land) marked on geological maps by Orvin (1940), Major and Winsnes (1955, Fig. 1) and Flood & al. (1971). These beds occur to the west of the Tertiary fold belt, possibly in a small graben, and are separated from the south-west by a fault or thrust-fault (see Fig. 1). South-west of this fault occur vertically dipping Permian rocks (see Siedlecki 1964) exposed at

Øyrlandsodden and Tokrossøya. Thus the Tertiary at Øyrlandet could represent the fragment of a basin equivalent to the Forlandsundet-Bellsund Basin or a branch of the Main Spitsbergen Basin (see Fig. 1).

ALPINE STRUCTURAL PATTERN IN SPITSBERGEN

During the Tertiary the area of Spitsbergen was subject to strong tectonic deformations. The Alpine structural pattern includes the zone of most intense deformations, the fold belt, and the zones of less intense deformations: the foreland (central depression) and the hinterland (western block) — see Figs 1—2.

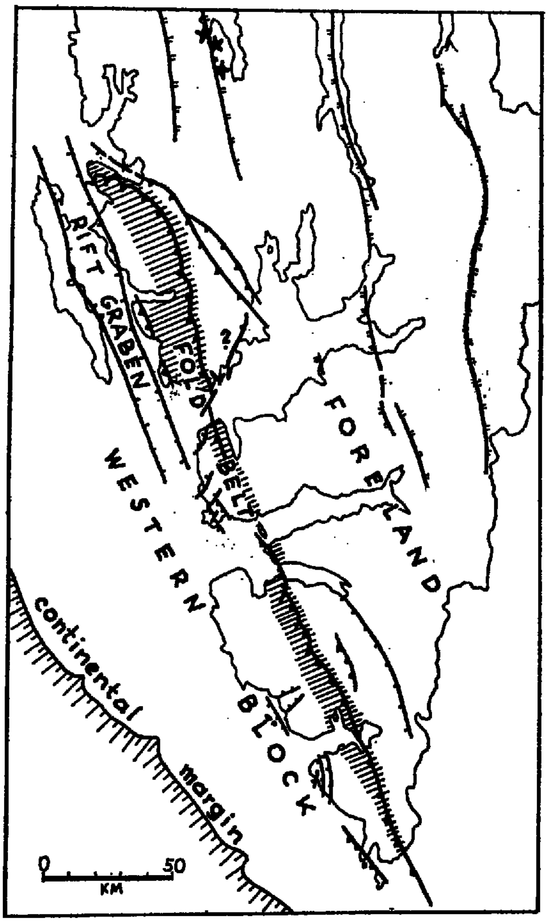


Fig. 2
Alpine structural elements of Spitsbergen (for explanations see Fig. 1)

Fold belt

The Alpine fold belt of Spitsbergen is regarded as an extreme case of frame tectonics affecting a post-Caledonian platform (Birkenmajer 1972). It stretches NNW-SSE from Brøggerhalvøya (Kongsfjorden) on the north to Keilhaufjellet (Sørkapp Land) on the south, over a distance of nearly 300 km. The belt of most intense deformations involving low-angle thrusting is maximum 10 km wide between Sørkapp Land and Van Keulenfjorden, but seems to increase to 20 km between Isfjorden and Kongsfjorden (Fig. 1).

The fold belt consists of two structurally different units, namely the *major thrust zone* (*i.e.* the easternmost part of the overthrust western block), and the *transitional zone* (*i.e.* the western margin of foreland) (*op. cit.*).

The major thrust zone has been studied in most detail at Brøggerhalvøya (Orvin 1934; Barbaroux 1966, 1967, 1968; Challinor 1967), and in the area between Van Keulenfjorden and Hornsund (Różycki 1959; Birkenmajer 1960, 1964, 1972). At Brøggerhalvøya the folding was generally from south to north or south-west to north-east involving thrusting of the Precambrian metamorphic rocks (Hecla Hoek) over the Lower Carboniferous to Upper Permian and Palaeogene sediments. Up to three (according to Challinor) or five (according to Barbaroux) thrust--sheets were formed, translated one over another from 1 to 4 km.

Between Van Keulenfjorden and Hornsund the folding was from south-west (or WSW) towards north-east (or ENE) involving thrusting of the Hecla Hoek rocks (mainly Eocambrian, Cambrian and Ordovician) over the Devonian to Lower Cretaceous sediments, some of which are penetrated by dolerite sills (Upper Jurassic-Lower Cretaceous). One or two thrust-sheets formed between Bellsund and Kopernikusfjellet (Torell Land), and up to five thrust-sheets between Kopernikusfjellet and Hornsund (and still farther south), translated one over another at a distance up to 6 km.

The intensity of tectonic deformations rapidly diminishes towards the north-east of the thrust zone, in the foreland. Only the westernmost margin of the foreland, some 1—1.5 km wide, shows the presence of small-scale thrusts, disharmonic folding and reverse faults.

Two sets of vertical wrench faults cut through the fold belt between Kopernikusfjellet and Hornsund. The first set is directed WNW-ESE, and the second set WSW-ENE. These sets form a pair of cross-faults intersecting at an angle of *c.* 30°. The direction of the greatest principal stress would be horizontal, almost exactly west-east, thus differing by *c.* 45° from the direction of tectonic transport in the zone of thrusting which is towards north-east (Birkenmajer 1972).

Foreland

The foreland includes platform sediments of Lower Carboniferous to Palaeogene age unconformable upon the folded and denuded Caledonian structure (Precambrian to Ordovician) and the Devonian molasse.

Only the narrow western margin of foreland is involved in intense tectonic deformations (see above). Farther east, within the western flank of the central depression, two to three major anticlines appear between Van Keulenfjorden and Hornsund parallel to the zone of thrusting (Różycki 1959; Birkenmajer 1964, 1972). They are steeper and more complex close to the fold belt, but become increasingly gentle further away. Gentle undulations (depressions and swells) with axes parallel to the fold belt have been recognized in the axial part of the central depression between Isfjorden and Van Keulenfjorden (Sokolov & al. 1968), but only in central Torell Land does a major anticline appear (Birkenmajer 1972). In the eastern part of Torell Land the strata lie horizontally, forming a typical table-land structure, gently up-tilted at the eastern flank of the central depression.

The north-eastern part of the central depression is often disturbed by generally N-S-striking faults (inner Isfjorden area and still farther east), which continue northwards in the Devonian and pre-Devonian basement. These faults are regarded as a tectonic event younger than the main folding phase.

Western block

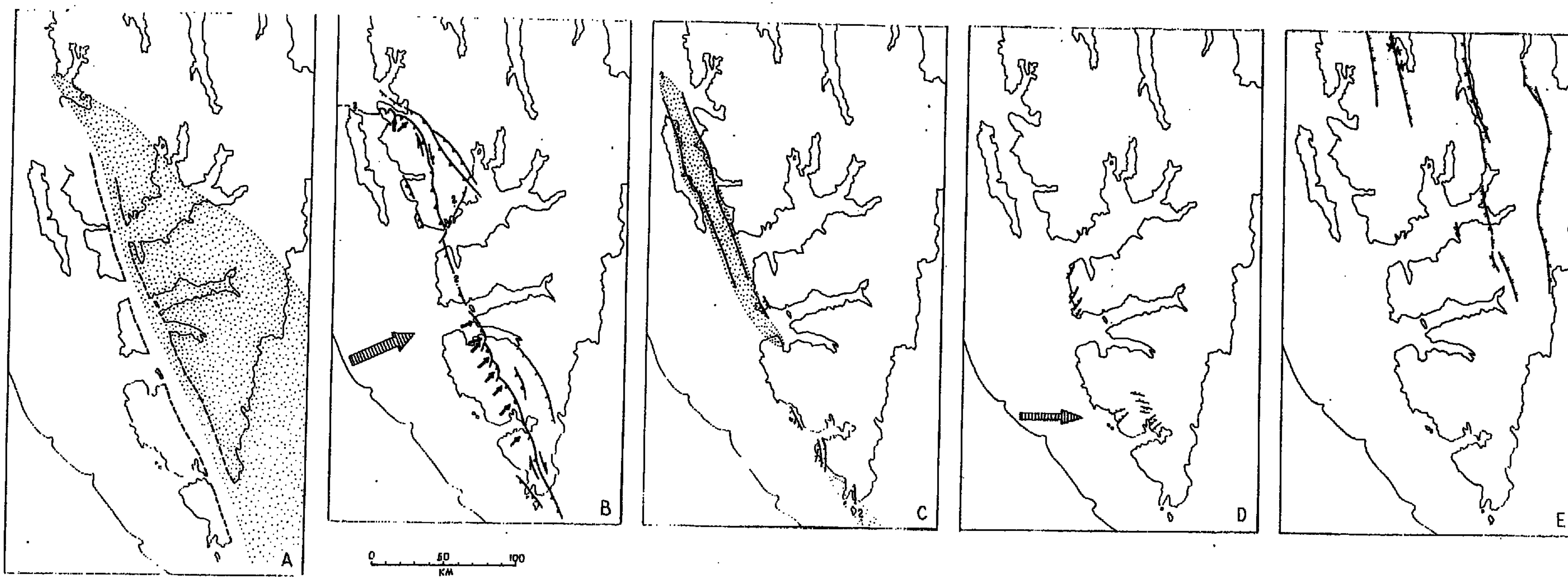
The western block (along the west coast of Spitsbergen between Brøggerhalvøya and Sørkapp) represents the hinterland with respect to the fold belt. It is 285 km long and 15—40 km wide — including the Forlandsundet graben and Prins Karls Forland, and 75—100 km wide if the whole western land strip and the submarine continental platform of Spitsbergen (some 60 km wide) is also taken into account. The area is built principally of folded Hecla Hoek rocks (Precambrian to Ordovician) and, to a much less extent, of Lower Carboniferous to Lower Cretaceous sediments.

Two systems of faults are recognized in the western block. The first one is directed NNW-SSE, parallel to the fold belt, and includes *i.a.* normal faults bordering the Forlandsundet graben filled with Palaeogene sediments. The second system is directed SW-NE and may correspond to the second set of wrench faults from the fold belt.

Succession and age of deformations

Spitsbergenian phase

The main Tertiary deformation phase in Spitsbergen has been defined as the "West Spitsbergen Orogeny" (Harland 1969) or the "Spitsbergenian phase" (Birkenmajer 1972). Birkenmajer regards this as a stage within the Alpine cycle of folding and suggests a Paleocene age (boun-



Supposed stages of Tertiary diastrophism in Spitsbergen

A possible position of the western block with respect to the Main Spitsbergen Basin (stippled); *B* Spitsbergenian phase, first stage — formation of the fold belt (thick arrows indicate direction of tectonic transport in the zone of folding; thin arrows indicate direction of translation along the supposed transcurrent fault); *C* Spitsbergenian phase, second stage — formation of the rift graben (sediments in the Forlandsundet-Bellsund Basin and Öyrlandet Basin stippled); *D* Spitsbergenian phase, third stage — formation of wrench faults; *E* post-Palaeogene events: normal faulting and volcanic activity. Big hatched arrows indicate direction of principal orogenic stress. For other explanations see Figs 1 and 2 dary of Lower and Upper Paleocene?) for the phase which thus could correspond to the youngest phase of the Laramide orogeny, as recognized in the Alpine-Carpathian orogenic belt.

The Spitsbergenian phase has been subdivided into three stages of deformations (Birkenmajer *op. cit.*). The *first stage* involved a forceful push from the SW of the western block which was thrust over the south-west margin of the central depression. The folding took place most probably above sea level. The crustal shortening in the fold belt amounted to *c.* 10 km on the north (Brøggerhalvøya) growing to *c.* 15 km on the south (between Bellsund and Sørkapp). The whole NNW-SSE-trending strip of the west coast of Spitsbergen between Kongsfjorden and Sørkapp, including the major thrust zone and its hinterland (western block and continental shelf), had been translated to the NNW possibly some tens of kilometres (Fig. 3). At Kongsfjorden it collided with the rigid land mass of NW Spitsbergen thus producing an anti-clockwise rotation of the Alpine and Caledonian structures at Brøggerhalvøya (hence the axes of Alpine thrust-sheets are here W-E and the apparent tectonic transport towards the north). It seems that the contact of the major thrust zone with the western margin of foreland is thus that of a dextral strike-slip (transcurrent) fault.

The *second stage,* subsequent to tne above described deformations, involved vertical arching of the western block where a rift valley (graben) formed between Forlandsundet and Bellsund (possibly also at Øyrlandet), simultaneously being filled with orogenic molasse.

The *third stage* could have been marked by the formation of two sets of wrench faults in the fold belt, and analogous systems of faults in the western block, reflecting a horizontal stress from the west.

Post-Palaeogene events

No palaeontologically dated Late Palaeogene or Neogene deposits have so far been reported from Svalbard. This was the period of intense erosion and planation of the whole area. No foredeep developed to the east of the fold belt and, consequently, no molasse deposits formed there. The post-Spitsbergenian phase tectonic events include the formation of great N-S-trending normal faults present mostly in the northern, central and north-eastern part of Spitsbergen (Fig. 1). These faults are parallel to the Spitsbergen Fracture Zone, the major feature of the ocean-floor structure between Svalbard and Greenland. The deep fracture (fault) line passing through Bockfjorden, NW Spitsbergen, served as a feeder for basaltic central volcanoes active during the Late Pleistocene to Early Holocene times (Hoel & Holtedahl 1911; Gjelsvik 1963; Harland 1969, p. 841).

CENOZOIC DEFORMATIONS IN SPITSBERGEN AND CONTINENTAL DRIFT

Within the last few years Wegener's concept of continental drift has progressed from heresy to a theory virtually unanimously accepted by the scientific community (Johnson & al. 1970, p. 14). The fit of the opposing coast-lines and, especially, of the continental shelf margins of the Atlantic, has been the strongest piece of evidence for the drift (Friend 1967, p. 579). Bullard, Everett and Smith (1965 — *fide* Friend 1967) used a computer to establish the best fit for the longitude and latitude co-ordinates of points along both edges, and used the 500-fathom isobath as the margin of continental blocks (Fig. 4).

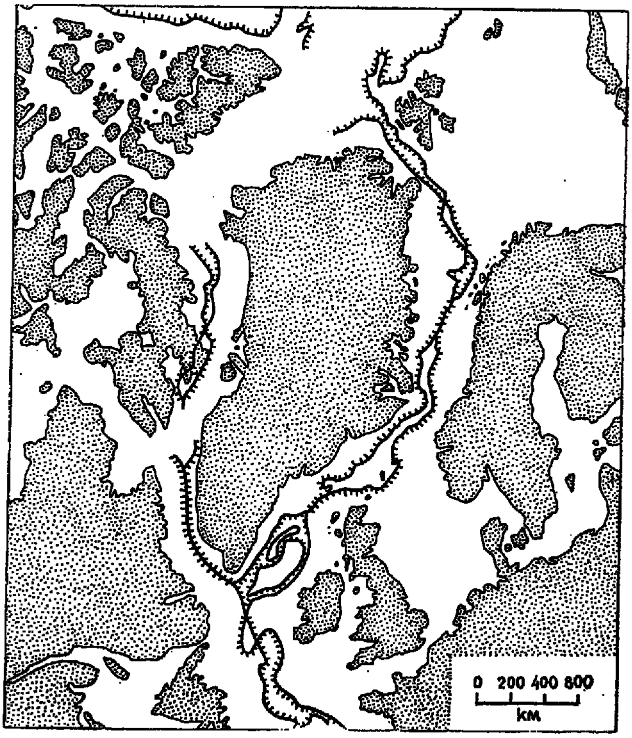
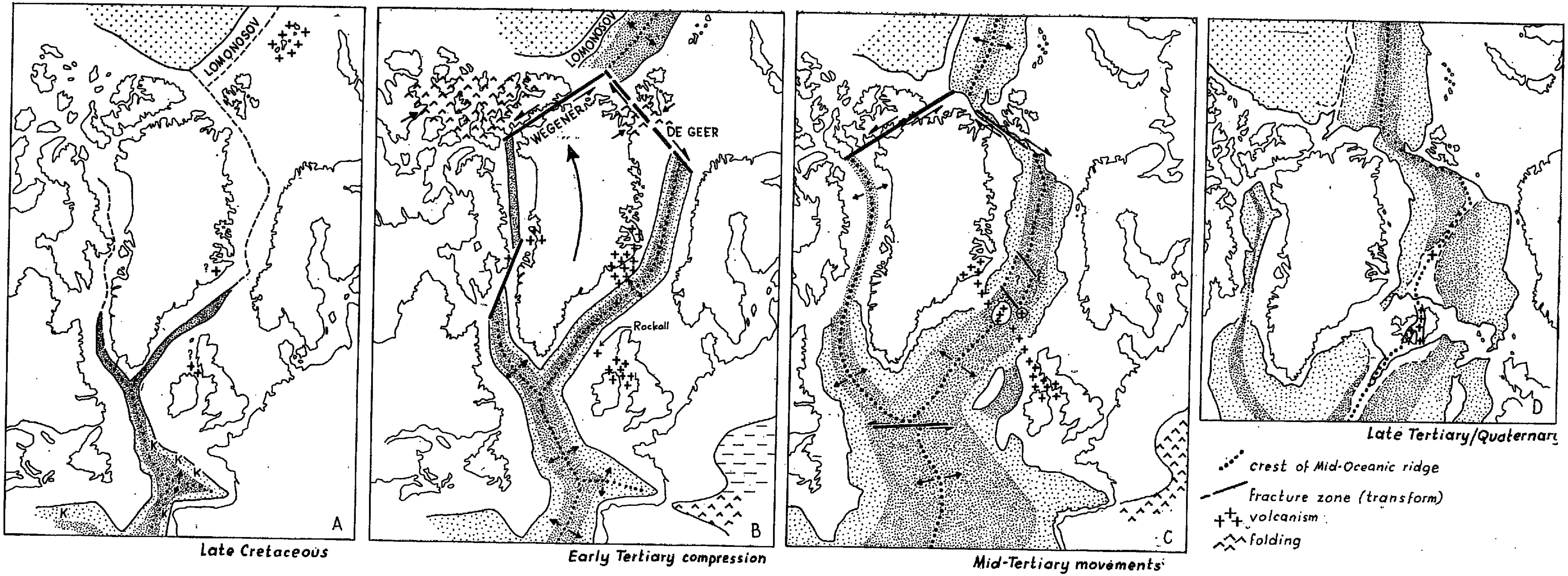


Fig. 4

Computed best fit for Canada, Greenland and Eurasia (after Bullard, Everett & Smith, 1965; redrawn from Friend 1967)

Heavy lines denote 500-fathom line on continental slope; short lines indicate down slope

The ocean-floor spreading as a cause of growth of the North Atlantic Basin has extensively been discussed in recent years by many authors (see review by Friend 1967; also papers presented in 1967 at the symposia in Reykjavik — Björnsson *ed.* 1967, and in Gander, Newfoundland — Kay *ed.* 1969). The central hypothesis is that oceanic crust is created by dyke injection with some volcanism and normal faulting at the axis of the



Stages of evolution of the North Atlantic-Arctic Basin area according to Harland (1967; redrawn from Harland 1969)

Mid-Oceanic Ridge (Dietz 1961; Heezen 1960; Johnson & al. 1970). The proof for the ocean-floor spreading is provided *i.a.* on study of magnetic anomalies over mid-oceanic ridges (*e.g.* Vine 1960, Vine & Matthews 1963, Heirtzler & al. 1966, Avery & al. 1968, Vogt & al. 1970).

Johnson & Heezen (1967) and Harland (*e.g.* 1967, 1969) presented the most complete accounts of the tectonic evolution of the North Atlantic Basin, and Johnson & al. (1970) and Vogt & al. (1970) supplied valuable new evidence to support this. Harland's concept is here summarized as in Fig. 5*A*—*D*.

The present attempt, following the same train of thought, offers some re-interpretations of tectonic data presented by Harland (*op. cit.*), with the use of data on the present structure and evolution of the North Atlantic Basin (see Johnson & Eckhoff 1966; Johnson & Heezen 1967; Johnson 1968; Johnson & al. 1968, 1970; Vogt & al. 1970), the Alpine fold belt of Spitsbergen (Birkenmajer 1972), and the tectonic structure of North-East Greenland (see Haller 1969, 1970).

Protoforms, mid-oceanic ridges and transform faults

The role of great faults resp. fracture (shear) zones separating Ellesmere Island from Greenland — the Wegener Fault, and Greenland from Spitsbergen — the De Geer Line (shear zone) resp. Spitsbergen Fracture Zone, has been discussed particularly by Wilson (1963, 1965) and Harland (1967, 1969). These major tectonic lines (now: strike-slip faults resp. fracture zones) correspond to great scars of separation of continents, and have persisted during the evolution of the North Atlantic Basin and the Arctic Basin (see Figs 5 and 6).

Another fracture zone, parallel to the continental margins of Norway and North-East Greenland, is here termed the Harland Fracture Zone (Fig. 6*A*). It is considered a proto-fracture for the major part of the Mid-Oceanic Ridge in North Atlantic (see Fig. 5*A*).

Such great tectonic lines (faults or fracture zones) may be termed *protoforms* on analogy with Wilson's (1965) transforms. The transform fault is a strike-slip (transcurrent) fault or fracture zone which offsets the mid-oceanic ridge (see Wilson *op. cit.*), thus being subsequent to protoform which pre-dates the formation of mid-oceanic ridge. It is supposed that protoforms may either persist as fracture zones (strike-slip faults) or evolve into mid-oceanic ridges and transform faults (Tab. 5). According to Johnson & al. (1969) the transform faults may appear and disappear repeatedly in the history of an ocean basin.

Both Wilson (1965) and Harland (1969) suggested that the Spitsbergen Fracture Zone (term introduced by Johnson & Eckhoff 1966), resp. the De Geer Line (shear zone) is a transform fault. Vogt & al. (1970, Fig. 10*a*) interpreted its northern termination (between 80 and 85° N) as a

Table 5

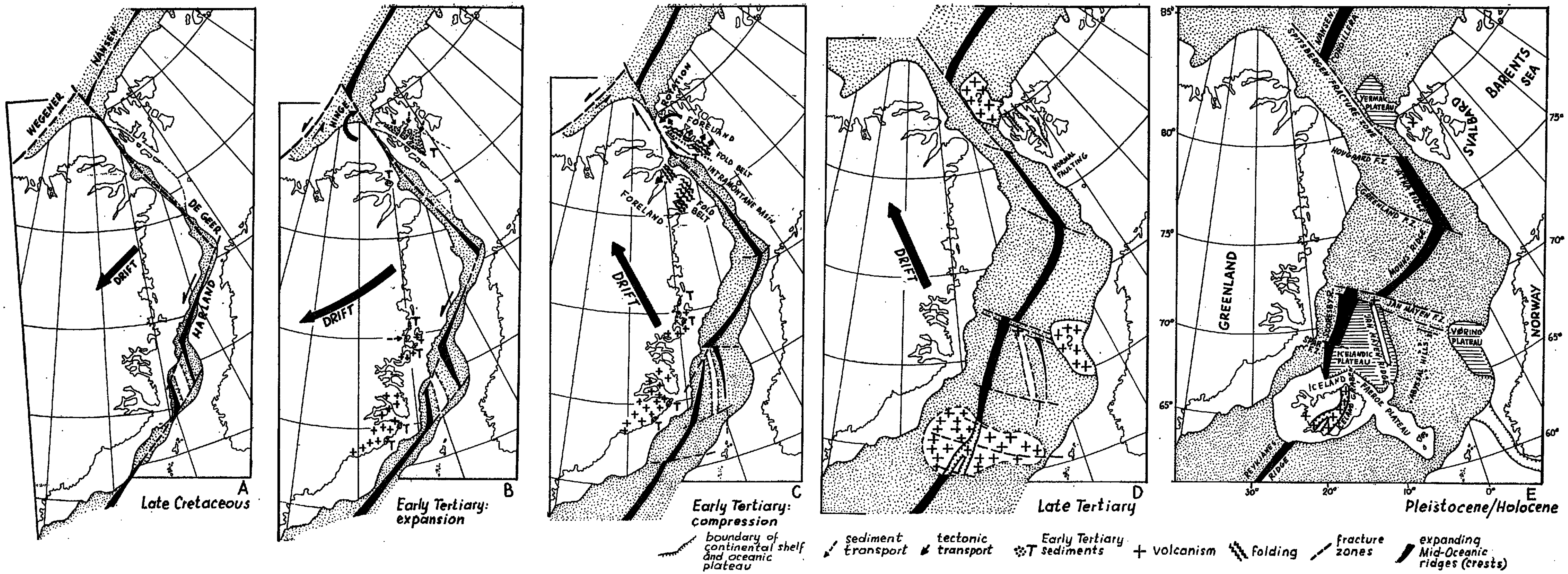
Supposed transformation of the tectonic-plate structures into ocean-bottom structures: North Atlantic-Arctic Basins

Initial structure	Present structure	
Wegener Fault resp. Fracture Zone (protoform)	Wegener Fault resp. Fracture Zone (strike-slip fault)	
De Geer Fault resp. Line (shear zone) (protoform)	De Geer Fault resp. Spitsbergen Fracture Zone (strike-slip fault or ridge crest dissected by transform faults)	Hovgaard Fracture Zone (transform fault)
	Atka Ridge (mid-oceanic ridge)	
		Greenland Fracture Zone (transform fault)
Harland Fracture Zone resp. Line (protoform)	Mohns Ridge (mid-oceanic ridge)	
		Jan Mayen Fracture Zone (transform faults)
	Scoresby Ridge resp. North Iceland — Jan Mayen Ridge (mid-oceanic ridge)	
		Spar Fracture Zone (trans-from fault)
	Iceland Ridge resp. South Iceland — Jan Mayen Ridge (mid-oceanic ridge)	

very narrow ridge crest dissected by NW-SE directed transform faults. In the writer's interpretation the present Spitsbergen Fracture Zone still retains the character of a shear zone (De Geer Line = protoform), which has not yet been transformed into the Mid-Oceanic Ridge. On the contrary, the segment of the Ridge between the Hovgaard Fracture Zone and the Greenland Fracture Zone (*i.e.* the Atka Ridge — see Fig. 6*E*) can be regarded as transformed southern termination of the De Geer Line (protoform).

Late Cretaceous stage

The Late Cretaceous time witnessed in Spitsbergen the regression of the sea due to unequal uplift of the land, strongest on the north. The palinspastic reconstruction of the Svalbard area prior to the Alpine (late



Stages of evolution of the North Atlantic Basin. Author's interpretation with the use of data presented *i.a.* by Harland (1969) and Johnson & Heezen (1967)

Elements of the ocean bottom morphology simplified from the latter source. Stippled — undifferentiated ocean bottom (continental rise, abyssal plains, slopes of mid-oceanic ridges etc.); blank — continental blocks and insular shelf; hatched — submarine plateaux

Laramide) folding (Fig. 3*A*) indicates a 10—15 km broader shelf to the west of Spitsbergen. A splinter of the continental platform comprising the future fold belt and its hinterland (western block) is shown in a position farther south than at present. Thus we obtain a better fit of the continental margins of Eurasia and Greenland (Fig. 6*A*) than that shown in Fig. 4.

Early Tertiary expansion

The Early Tertiary (Danian-Montian) palinspastic map (Fig. 6*B*) shows clockwise rotation of Greenland (of the order of 5 degrees). The hinge zone (pivot) is indicated close to the north-west corner of Spitsbergen and the corresponding northern terminus of the North Greenland shelf. The expanding mid-oceanic ridges situated along the De Geer- and Harland protoforms caused the opening of the Greenland-Norwegian Basin, and the west drift of Greenland. Along the south-east and north-east coasts of Greenland small sedimentary basins were formed. These are mainly fluvio-lacustrine deposits, and their source area of the clastics (at 74—75° N) lies west (see Haller 1970).

In Svalbard, the Main Spitsbergen Basin was formed, with lacustrine (coal-bearing) and shallow marine clastics at the base, followed by shallow marine shales and sandstones, altogether *c.* 1.5 km thick. The clastic material was derived from the north and north-east (see Vonderbank 1970, Birkenmajer & al. 1971, Birkenmajer 1972). The basin axis migrated towards SW (Fig. 1), apparently in the same direction as the drifting Greenland.

The rotation of Greenland resulted in sinistral translation of Ellesmere Island with respect to North Greenland (Wilson 1965, Harland 1969).

In the middle sector of the Harland Fracture Zone (protoform), the south-western drift and clockwise rotation of the Greenland block correlates with a clockwise rotation of two short, parallel mid-oceanic ridges and the corresponding transform faults (the future Jan Mayen and Spar Fracture Zones). A rhomboidal splinter of continental shelf between these elements is the future Jan Mayen Ridge. Johnson and Heezen (1967) interpret the Jan Mayen Ridge as a fragment splintered from the Greenland block. In the writer's interpretation it could equally belong to either the Greenland or the Norwegian continental shelf (Fig. 6*A*).

Early Tertiary compression

The Early Tertiary compression (Fig. 6*C*) or the Spitsbergenian phase (West Spitsbergen Orogeny of Harland 1969) is tentatively dated here (see also Birkenmajer 1972) as a higher Paleocene (boundary of Lower and Upper Paleocene?). The dextral translation of the Greenland block respective to the Svalbard-Barents Sea block along the De Geer Line causes compression on both sides of the fracture zone (see Harland 1967, 1969). The folding in North Greenland (in Kronprins Christians Land and Peary Land) has NNW-SSE directions of fold axes, with tectonic transport towards SW. The folding is here gentle as compared with that of Spitsbergen, and thrusts are infrequent (see Haller 1970).

In Spitsbergen a splinter of the continental block (representing the western block or hinterland with respect to the Alpine fold belt — see Figs 2 and 3*A*) was translated northwards, along the De Geer Line, and sandwiched between the continental blocks of Greenland and Svalbard. There the compression produced strong folding and overthrusting along the western margin of the post-Caledonian platform, with tectonic transport principally towards NE. The collision of the splinter with rigid crystalline land mass of NW Spitsbergen produced a counter-clockwise rotation of Alpine structures at Brøggerhalvøya. Hence the apparent tectonic transport is there towards the north.

The second and third stages of the Spitsbergenian phase, *i.e.* the formation of the rift graben (resulting from extension), and wrench-fault system (compression) respectively, can also be considered as effects of dextral translation of the Greenland and Svalbard blocks along the De Geer Line. The alternating compression (stages *1* and *3*) and extension (stage *2*), along with the change in the direction of principal stress in Spitsbergen (from south-westerly during stage *1* to westerly during stage *3* — see Fig. 3), might reflect oscillatory compression/extension regime along the zone of colliding continental blocks.

Late Tertiary and Pleistocene/Holocene stages

During the Late Tertiary, the volcanic centres migrated to Iceland and, possibly to Jan Mayen, *i.e.* to the mid-oceanic ridges and transform faults (Fig. 6*D*). In this stage of ocean-floor spreading we can show the presence of submarine plateaux, the Vøring Plateau and the Yermak Plateau, which so far did not fit into the "jigsaw puzzle" of continental drift.

The Vøring Plateau, some 21,000 square kms, is situated at the terminus of the Jan Mayen Fracture Zone (transform fault). Hence the existence of volcanoes here is probable (Johnson & al. 1968, p. 117). Seismic reflection profiles revealed at least 1000 m of generally horizontal strata (probably sediments) below the surface of the plateau which lies between 1190—1460 m below sea level (Johnson & Heezen 1967, Johnson & al. 1968).

The volcanic activity is also suggested for the Yermak Plateau situated very close to the Spitsbergen Fracture Zone (= De Geer Line).

Little is known about the structure of this plateau, previously considered to be part of the "Nansen Ridge" (see Ahlmann 1933, Heintz 1962). Its surface lies at about 500 m below sea level. The supposed Late Tertiary volcanism at the Yermak Plateau could have been related to deep faults of approximately the same age parallel to the Spitsbergen Fracture Zone (see Figs 6*D* and 1). As the last stage of this volcanic activity we could consider the Late Pleistocene/Early Holocene central basaltic volcanoes (Figs 6*E* and 1) and the Recent hot springs in the area of Bockfjorden, NW Spitsbergen. On the occurrence of olivine and peridotite nodules in the basaltic (trachydoleritic) lava of Sverrefjellet volcano, Bockfjorden, Gjelsvik (1963, p. 54) supposed that the fault zone in Bockfjorden represents a very deep fracture, reaching perhaps even to the Moho discontinuity.

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Geological Laboratory
of the Polish Academy of Sciences
Kraków, ul. Senacka 3
Kraków, January 1972

REFERENCES

AHLMANN H. W. 1933. Scientific results of the Swedish-Norwegian Arctic Expedition in the summer of 1931. Pt. V: Geomorphology. — Geogr. Annaler, 15 (2—3), 89—116. Stockholm.

ATKINSON D. J. 1962. Tectonic control of sedimentation and the interpretation of sediment alternation in the Tertiary of Prince Charles Foreland, Spitsbergen. — Bull. Geol. Soc. Am., 73, 343—364. Baltimore.

— 1963. Tertiary rocks of Spitsbergen. — Bull. Am. Ass. Petrol. Geol., 47, 302—323. Tulsa.

AVERY O. E., BURTON G. D. & HEIRTZLER J. D. 1968. An aeromagnetic survey of the Norwegian Sea. — Jour. Geophys. Res., 73, 4583—4600. Washington.

AVERY O. E., VOGT P. R. & HIGGS R. H. 1969. Morphology, magnetic anomalies and evolution of the Northeast Atlantic and Labrador Sea. Pt. III. Magnetic anomalies. — Trans. Am. Geophys. Union, 50 (4), p. 184 (Abstr.). Washington.

BARBAROUX L. 1966. Contribution à l'étude tectonique de la Presqu'île de Brøgger (Spitsbergen). — Bull. Soc. Géol. France (7e sér.), 8, 560—566. Paris.

— 1967. Étude géologique et sédimentologique de la Presqu'île de Brøgger, Baie du Roi, Vestspitsbergen. Thèse, Fac. Sc. Univ. d'Aix, Marseille, Pts. I (1—185 + 1—6) & II (Annexe). Marseille.

— 1968. Superposition de styles tectoniques et virgation forcée au Vestspitsbergen (79° lat. Nord). — C. R. Acad. Sc. Paris, 266, 871—874. Paris.

BECKINSALE R. D., BROOKS C. K. & REX D. C. 1970. K-Ar ages for the Tertiary of East Greenland. — Meddr. Dansk Geol. For., 20 (1), 27—37. København.
BIRKENMAJER K. 1960. Geological sketch of the Hornsund area (Supplement to the Guide for Excursion A 16 "Aspects of the Geology of Svalbard"). — Int. Geol. Congr. 21 Sess. Norden (1960), 12 p. Oslo.
— 1964. Devonian, Carboniferous and Permian formations of Hornsund, Vestspitsbergen. — Studia Geol. Polon., 11, 47—123. Warszawa.
— 1966. Lower Cretaceous tidal deposits of central Vestspitsbergen. — Norsk Polarinstitutt Årbok 1964, 73—85. Oslo.
— 1972. Alpine fold belt of Spitsbergen. — Int. Geol. Congr. 24 Sess. Canada (1972), Reports. (*In press*). Montreal.
BIRKENMAJER K., FEDOROWSKI J. & SMULIKOWSKI W. 1971. Igneous and fossiliferous sedimentary drift pebbles in marine Tertiary of Torell Land, Spitsbergen. — Norsk Polarinstitutt Årbok 1970, 146—164. Oslo.
BIRKENMAJER K. & NAREBSKI W. 1963. Dolerite drift blocks in marine Tertiary of Sørkapp Land and some remarks on the geology of the eastern part of this area. — Norsk Polarinstitutt Årbok 1962, 68—79. Oslo.
BJÖRNSSON S. (*ed.*) 1967. Iceland and Mid-Oceanic Ridges (Report of a symposium held by the Geoscience Society of Iceland, Feb. 27 — March 8, 1967). — Vísindafélag Íslendinga (Soc. Sci. Islandica), 38, 1—209. Reykjavík.
DIETZ R. S. 1961. Continent and ocean basin evolution by spreading of the sea floor. — Nature, 190, 854—857. London.
CHALLINOR A. 1967. The structure of Brøggerhalvøya, Vestspitsbergen. — Geol. Mag., 104 (4), 322—336. Hertford.
DINELEY D. L. 1958. A review of the Carboniferous and Permian rocks of the west coast of Vestspitsbergen. — Norsk Geol. Tidsskr., 38 (2), 197—217. Bergen.
FLOOD B., NAGY J. & WINSNES T. S. 1971. Geological map — Svalbard 1 : 500,000, Sheet 1 G (Spitsbergen, southern part). — Norsk Polarinstitutt. Oslo.
FREBOLD H. 1931. Fazielle Verhältnisse des Mesozoikums im Eisfjordgebiet Spitzbergens. — Skr. om Svalb. og Ish., 37, 1—126. Oslo.
— 1935. Geologie von Spitzbergen, der Bäreninsel, des König Karl- und Franz-Joseph-Landes (*In:* Geologie der Erde, E. Krenkel ed.). Borntraeger Verl. Berlin. pp. 1—195.
— 1951. Geologie des Barentsschelfes. — Abh. Deut. Akad. Wiss., Kl. Math. allg. Naturw., Jg. 1950 (5). Abh. Geotekt., 4, 1—151. Berlin.
FRIEND P. F. 1967. The growth of the North Atlantic Ocean by the spreading of its floor. — The Polar Record, 13 (No. 86), 579—588. Cambridge.
GJELSVIK T. 1963. Remarks on the structure and composition of the Sverrefjellet volcano, Bockfjorden, Vestspitsbergen. — Norsk Polarinstitutt Årbok 1962, 50—54. Oslo.
GRIPP K. 1927. Beiträge zur Geologie von Spitzbergen. — Abh. Naturv. Ver. Hamburg, 21 (3), 1—38. Hamburg.
HAGERMAN T. H. 1925. Stratigraphic and structural investigations within south-western Spitsbergen. — Geogr. Ann., 7, 195—221. Stockholm.
HALLER J. 1969. Tectonics and neotectonics in East Greenland — Review bearing on the drift concept. *In:* North Atlantic — Geology and Continental Drift (a symposium, M. Kay *ed.*). — Am. Ass. Petrol. Geol., Mem., 12, 852—858. Tulsa.
— 1970. Tectonic map of East Greenland (1 : 500,000). An account of tectonism, plutonism, and volcanism in East Greenland. — Meddr. om Grønland, 171 (5), 1—286. København.
HARLAND W. B. 1961. An outline structural history of Spitsbergen. *In:* Geology of the Arctic (G. O. Raasch *ed.*). Univ. Toronto Press, pp. 68—132. Toronto.

— 1967. Early history of the North Atlantic Ocean and its margins. — Nature, 216, 464—466. London.

— 1969. Contribution of Spitsbergen to understanding of tectonic evolution of North Atlantic region. *In:* North Atlantic — Geology and Continental Drift (a symposium, M. Kay *ed.*). — Am. Ass. Petrol. Geol., Mem., 12, 817—851. Tulsa.

HEEZEN B. C. 1960. The rift in the ocean floor. — Sci. American, 203, 98—110. New York.

HEINTZ N. 1962. The Nansen Ridge has become the Nansen Trough (A review of some recent Soviet-Russian papers on oceanographic conditions in the Greenland Sea). — Norsk Polarinstitutt Årbok 1960, 66—74. Oslo.

HJELLE A. 1962. Contribution to the geology of the Hecla Hoek Formation in Nordenskiöld Land, Vestspitsbergen. *Ibidem,* Årbok 1961, 83—95.

HOEL A. & HOLTEDAHL O. 1911. Les nappes de lave, les volcans et les sources thermales dans les environs de la Baie Wood au Spitzbergen. — Vid.-Selsk. Skr. (Kristiania), Mat.-naturv. Kl., 1, (8), 1—38. Kristiania (Oslo).

HOEL A. & ORVIN A. K. 1937. Das Festungsprofil auf Spitzbergen. Karbon-Kreide. I. Vermessungsresultate. — Skr. om Svalb. og Ish., 18, 1—59. Oslo.

HOLMES' SYMPOSIUM 1964. The Phanerozoic time-scale. A symposium dedicated to Professor Arthur Holmes. — Quart. J. Geol. Soc. Lond., 120. London.

JOHNSON G. L. 1968. Marine geology in the environs of Jan Mayen. — Norsk Polarinstitutt Årbok 1966, 105—111. Oslo.

JOHNSON G. L., BALLARD J. A. & WATSON J. A. 1968. Seismic studies of the Norwegian continental margin. — Norsk Polarinstitutt Årbok 1966, 112—119. Oslo.

JOHNSON G. L. & ECKHOFF O. B. 1966. Bathymetry of the North Greenland Sea. — Deep Sea Res., 13, 1161—1173. Oxford.

JOHNSON G. L., FREITAG J. S. & PEW J. A. 1970. Structure of the Norwegian Basin. — Norsk Polarinstitutt Årbok 1969, 7—16. Oslo.

JOHNSON G. L. & HEEZEN B. C. 1967. The morphology and evolution of the Norwegian-Greenland Sea. — Deep Sea Res., 14, 755—771. Oxford.

JOHNSON G. L., VOGT P. R. & SCHNEIDER E. D. 1969. Morphology, magnetic anomalies and evolution of the Northeast Atlantic and Labrador Sea. Pt. I. Morphology. — Trans. Am. Geophys. Union, 50 (4), p. 184 (Abstr.). Washington.

KAY M. (*ed.*) 1969. North Atlantic — Geology and Continental Drift (a symposium). — Am. Ass. Petrol. Geol., Mem., 12, 1—1082. Tulsa.

MAJOR H. & WINSNES T. S. 1955. Cambrian and Ordovician fossils from Sørkapp Land, Spitsbergen. — Norsk Polarinstitutt Skrifter, 106, 1—47. Oslo.

MANUM S. 1960. Some dinoflagellates and hystrichospherids from the Lower Tertiary of Spitsbergen. — Norsk Polarinstitutt Medd., 85 (repr. from Nytt Mag. Bot., 8, 17—26). Oslo.

— 1962. Studies in the Tertiary flora of Spitsbergen, with notes on Tertiary floras of Ellesmere Island, Greenland, and Iceland. — Norsk Polarinstitutt Skrifter, 125, 1—127. Oslo.

NAGY J. 1966. Preliminary report on the geology of Eastern Torell Land, Vestspitsbergen. — Norsk Polarinstitutt Årbok 1964, 69—72. Oslo.

— 1970. Ammonite faunas and stratigraphy of Lower Cretaceous (Albian) rocks in southern Spitsbergen. — Norsk Polarinstitutt Skrifter, 152, 1—58. Oslo.

NATHORST A. G. 1910. Beiträge zur Geologie der Bären-Insel, Spitzbergens und des König-Karl Landes. — Uppsala Univ. Geol. Inst. Bull., 10, 261—416. Uppsala.

ORVIN A. K. 1934. Geology of the Kings Bay region, Spitsbergen. — Skr. om Svalb. og Ish., 57, 1—196. Oslo.

— 1940. Outline of the geological history of Spitsbergen. — *Ibidem*, 78, 1—57.
PARKER J. R. 1967. The Jurassic and Cretaceous sequence of Spitsbergen. — Geol. Mag., 104, 487—505. Hertford.
RAVN J. P. J. 1922. On the Mollusca of the Tertiary of Spitsbergen. — Result. Norske Spitsbergeneksped. 1 (2), 1—28. Oslo.
ROSENKRANTZ A. 1942. Das geologisches Auftreten der Gattung *Thyasira*. — Dansk Geol. For. Meddr., 10, 277—278. København.
— 1970. Marine Upper Cretaceous and lowermost Tertiary deposits in West Greenland. *Ibidem*, 19 (4), 406—453.
RÓŻYCKI S. Z. 1959. Geology of the north-western part of Torell Land, Vestspitsbergen. — Studia Geol. Polon., 2, 1—98. Warszawa.
SIEDLECKI S. 1964. Permian succession on Tokrossöya, Sörkapplandet, Vestspitsbergen. — *Ibidem*, 11, 155—168.
SOKOLOV V. N., KRASILTCHIKOV A. A. & LIVSHITZ J. J. 1968. The main features of the tectonic structure of Spitsbergen. — Geol. Mag., 105 (2), 95—115. Hertford.
VINE F. J. 1966. Spreading of the ocean floor: new evidence. — Science, 154, 1405—1415. New York.
VINE F. J. & MATTHEWS D. H. 1963. Magnetic anomalies over oceanic ridges. — Nature, 199, 947—949. London.
VOGT P. R., AVERY O. E., MORGAN W. J., JOHNSON G. L., SCHNEIDER E. D. & HIGGS R. H. 1969. Morphology, magnetic anomalies and evolution of the Northeast Atlantic and Labrador Sea. Pt. III. Evolution. — Trans. Am. Geophys. Union, 50 (4), p. 184 (Abstr.). Washington.
VOGT P. R., OSTENSO N. A. & JOHNSON G. L. 1970. Magnetic and bathymetric data bearing on sea-floor spreading north of Iceland. — Jour. Geophys. Res., 75, 903—920. Washington.
VONDERBANK K. 1970. Geologie und Fauna der Tertiären Ablagerungen Zentral-Spitzbergens. — Norsk Polarinstitutt Skrifter, 153, 1—119. Oslo.
WILSON J. T. 1963. Continental drift. — Sci. American, 208, 86—100. New York.
— 1965. A new class of faults and their bearing on continental drift. — Nature, 207, 343—347. London.

K. BIRKENMAJER

TRZECIORZĘDOWA HISTORIA SPITSBERGENU A DRYFT KONTYNENTALNY

(Streszczenie)

Autor omawia historię rozwoju basenów paleogeńskich Spitsbergenu i ich stosunek do alpejskiej strefy fałdowej tego obszaru. Rozważane są stadia kenozoicznej ekspansji i kompresji rozpoznane na Spitsbergenie, które są próbnie odniesione do stadiów rozdzielania się i wzajemnego przemieszczania bloków kontynentalnych Grenlandii i Eurazji.

Pracownia Geologii Młodych Struktur
Zakładu Nauk Geologicznych PAN
Kraków, ul. Senacka 3
Kraków, w styczniu 1972 r.
