The Franklinian Geosyncline in the Canadian Arctic and its relationship to Svalbard

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Contents

Abstract

Development of the Franklinian Geosyncline began, perhaps earlier, but certainly by late Proterozoic time, with the deposition of clastic and carbonate rocks in the region of northeastern Ellesmere Island. Sedimentary units thicken northward, away from the exposed Aphebian

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crystalline basement. Certain metamorphic rocks of the north coast of Ellesmere Island may have been part of this early geosynclinal sequence; both volcanic and sedimentary origins are inferred for granitoid gneisses from which late Proterozoic isotopic ages have been obtained. Cambrian to Late Devonian clastic and carbonate sedimentary rocks subsequently were deposited in the geosyncline. Carbonates and some evaporites and clastic sediments dominated in the southeast, and immature clastic sediments with volcanic rocks, carbonates, and chert in the northwest. The sediments in the northwest evidently were derived from a geanticlinal welt, Pearya, which lay in the present offshore region. A distinctive basin of flysch deposition in the axial region, the Hazen Trough, received sediments from early Middle Ordovician to early Devonian time. From sole markings it is clear that sediment-bearing currents entered the trough from the northwest and were deflected to the southwest, along the trough.

Widespread deposition of clastic sediments in Middle and Late Devonian times was heralded in the Early Devonian by the development of three northerly trending, positive structural belts, of which the Boothia Uplift is the most prominent, with adjacent troughs and basins. Intrusions of ultramafic to granitic and syenitic composition possibly were emplaced in the northernmost region at this (Early) time, judging by K-Ar age determinations.

Tectonic activity in the northern geanticline in Middle and later Devonian time is inferred to have advanced southward to terminate the normal geosynclinal sequence and provide a southward-directed flood of clastic sediments. This, the Ellesmerian orogeny, involved regional folding, metamorphism, local quartz monzonite and quartz diorite intrusion, and widespread uplift. The synkinematic intrusions and metamorphism were restricted to the northernmost region, whereas folding to the south affected both earlier and later, synorogenic clastic beds. Ellesmerian structures conform to the present shape of the craton: a markedly sigmoidal pattern in the Canadian Arctic Islands lies between the related orogenic belts of northern Greenland and north shore, arctic Alaska.

Certain tectonic elements of the orogenic belt, such as the successor, Sverdrup Basin, are younger than Franklinian or Ellesmerian features but are geographically closely coincident with them. The younger elements thus appear to owe their origin to reactivation of tectonic processes that gave rise to the older features.

A comparison of the sedimentary and tectonic features of the Innuitian region and Svalbard shows that the tectonic histories of the two regions were mainly unlike before Devonian time but distinctly similar during certain periods since then. Taking into account ocean spreading, it appears probable that Svalbard and the Franklinian Geosyncline were once adjacent. A model is proposed for the earliest (Precambrian–late Paleozoic) times, in which rudely matched sedimentary basins were separated by the geanticlinal ridge, Pearya. A linear zone of younger basins formed in Carboniferous and Permian time, and by mid-Tertiary time the region was ragmented by the opening of the Atlantic and "neo-Arctic" oceans.

Introduction

The Innuitian Orogen is a continent-bordering tectonic region only somewhat less grand in scale than the better-known Cordilleran and Appalachian regions (see Figs. 1, 3). The Franklinian Geosyncline, a major component of the Innuitian Province, was a long-lived sedimentary-tectonic feature that provided a framework for subsequent events.

The purpose of this paper is to explore the history and disposition of the Franklinian Geosyncline[1] and to consider its possible relationship with the geosynclinal succession of Svalbard. The relationships between younger components of Svalbard and the Canadian Arctic orogen are also of prime interest and, although these basins will not be described here in detail they will be included in a suggested model.

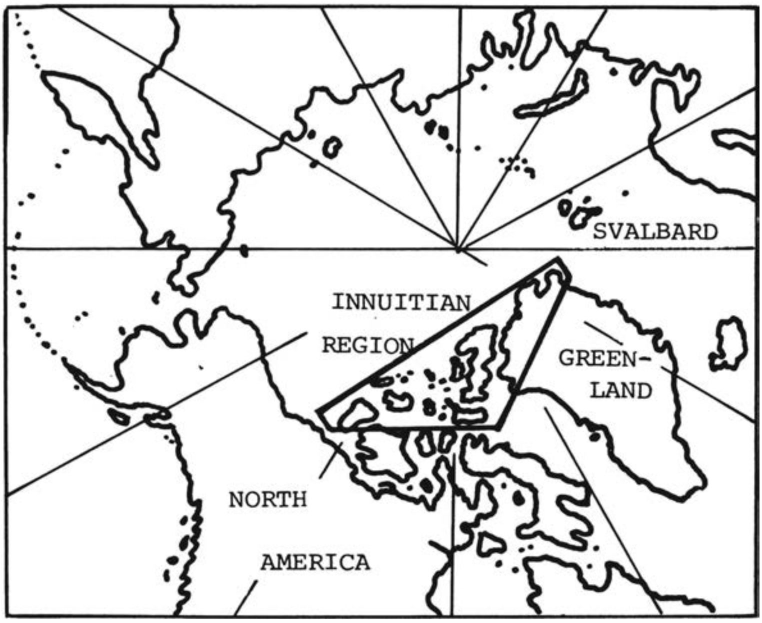

Fig. 1. *Index map of north polar regions.*

The manuscript for this paper was critically read by H. R. Balkwill and U. Mayr of the Geological Survey of Canada; discussions with them have contributed greatly to the paper presented here.

The Franklinian Geosyncline

The Franklinian Geosyncline is well exposed in northernmost Ellesmere Island and Greenland, but nearly disappears to the southwest, hidden by younger sedimentary basins, by coastal plain sediments, and by marine water. From exposures available, the geosyncline appears to encompass a nearly complete suite of characteristics now considered to be typical of mountain belts that border large cratonic masses. The important aspects of the Franklinian Geosyncline have been described recently by Thorsteinsson (1974, p. 6–10; and in Thorsteinsson and Tozer 1970), Trettin (1973, 1972, and other papers), and by Kerr (1967b, 1968, 1976).

GENERAL TECTONIC PATTERN

The most complete cross-section of the Franklinian Geosyncline is exposed between central Ellesmere and the north coast of the island. Trends in this region are fairly consistently northeast, and the structures pass without major apparent dislocation into northern Greenland. To the southwest, the Franklin-

[1] The Canadian part of the geosyncline is considered here. An account of the Franklinian Geosyncline in northern Greenland was given, at the Svalbard symposium in Oslo, by P. R. Dawes, who has recently compiled a full review of the geology of that region (Dawes 1976).

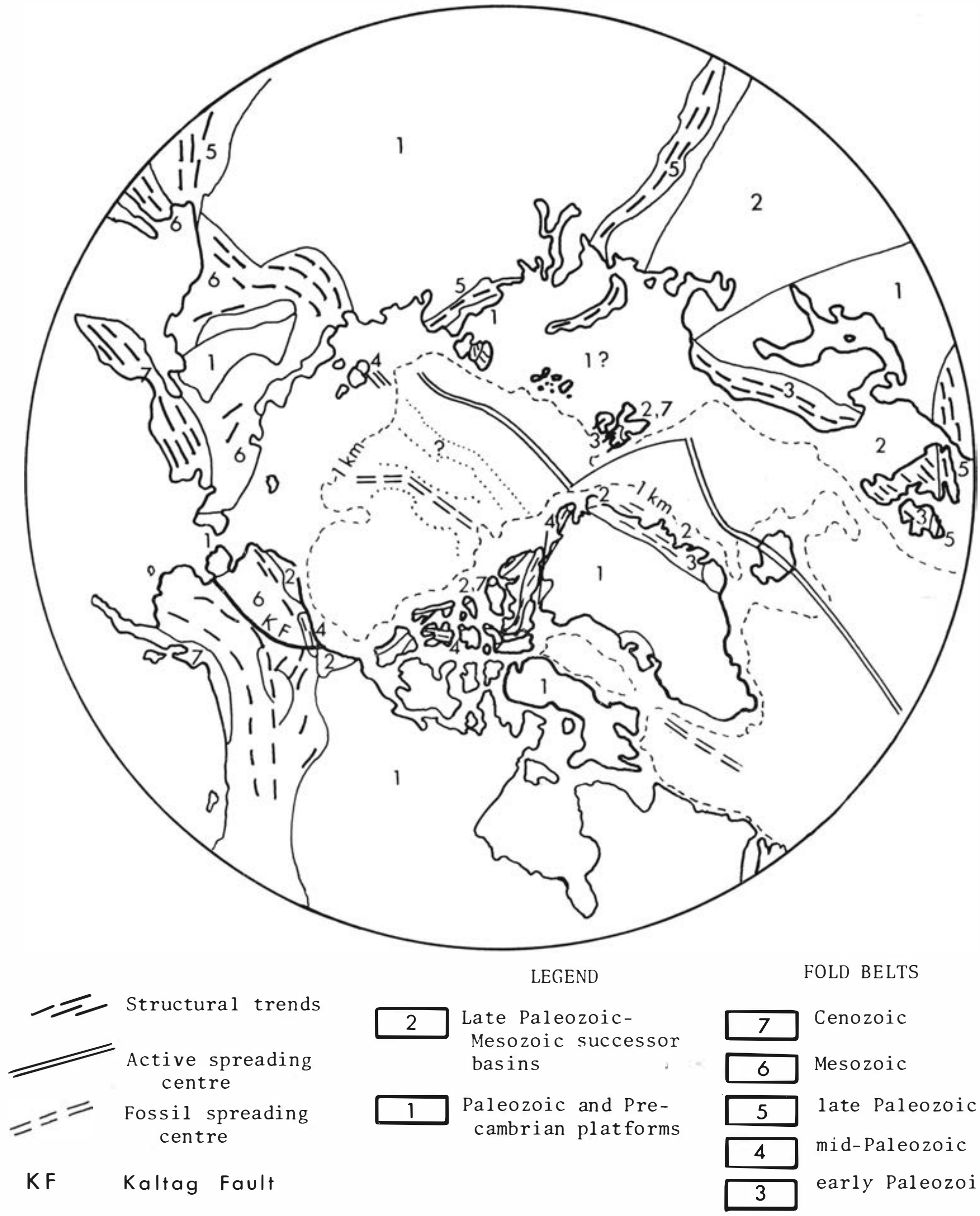

Fig. 2a. *Major tectonic features of the Arctic (modified from* CHURKIN *1972;* OSTENSO *1974).*

ian rocks are covered in the axial region by a large successor basin, the Sverdrup Basin. Miogeosynclinal parts of the Franklinian basin are exposed south and east of the Sverdrup Basin, and Franklinian sedimentary and structural trends there trace a marked sigmoidal or double bend, swinging south, then west. Structural trends at the westernmost exposures, where they disappear beneath the Arctic Coastal Plain, are heading approximately toward the northern tip of Alaska, across the Beaufort Sea.

Fig. 2b. *Tectonic and geographic features of the Arctic. For legend, see Figure 2a.*

STRATIGRAPHY

Geosynclinal development began, perhaps earlier, but certainly by late Proterozoic time, with the deposition of more than 1700 m of clastic and carbonate rocks now exposed on eastern Ellesmere Island (Kennedy Channel and Ella Bay Formations).[1] These rocks are miogeosynclinal in character: fine-grained, dark-coloured clastic rocks with some limestone and dolomite, passing toward the craton into cleaner, fine-grained sandstone. Upper units are sugary, slightly shaly dolomite.

The geosynclinal sequence is broken by an uncomformity, in the miogeosynclinal sections studied, and formations containing Cambrian fossils and organic-appearing markings (Ellesmere Group, Scoresby Bay and Parrish Glacier Formations) overlie the Proterozoic beds. The Cambrian units, up to

[1] Certain formation names are noted in this discussion to aid those who may read other accounts of the same sequences.

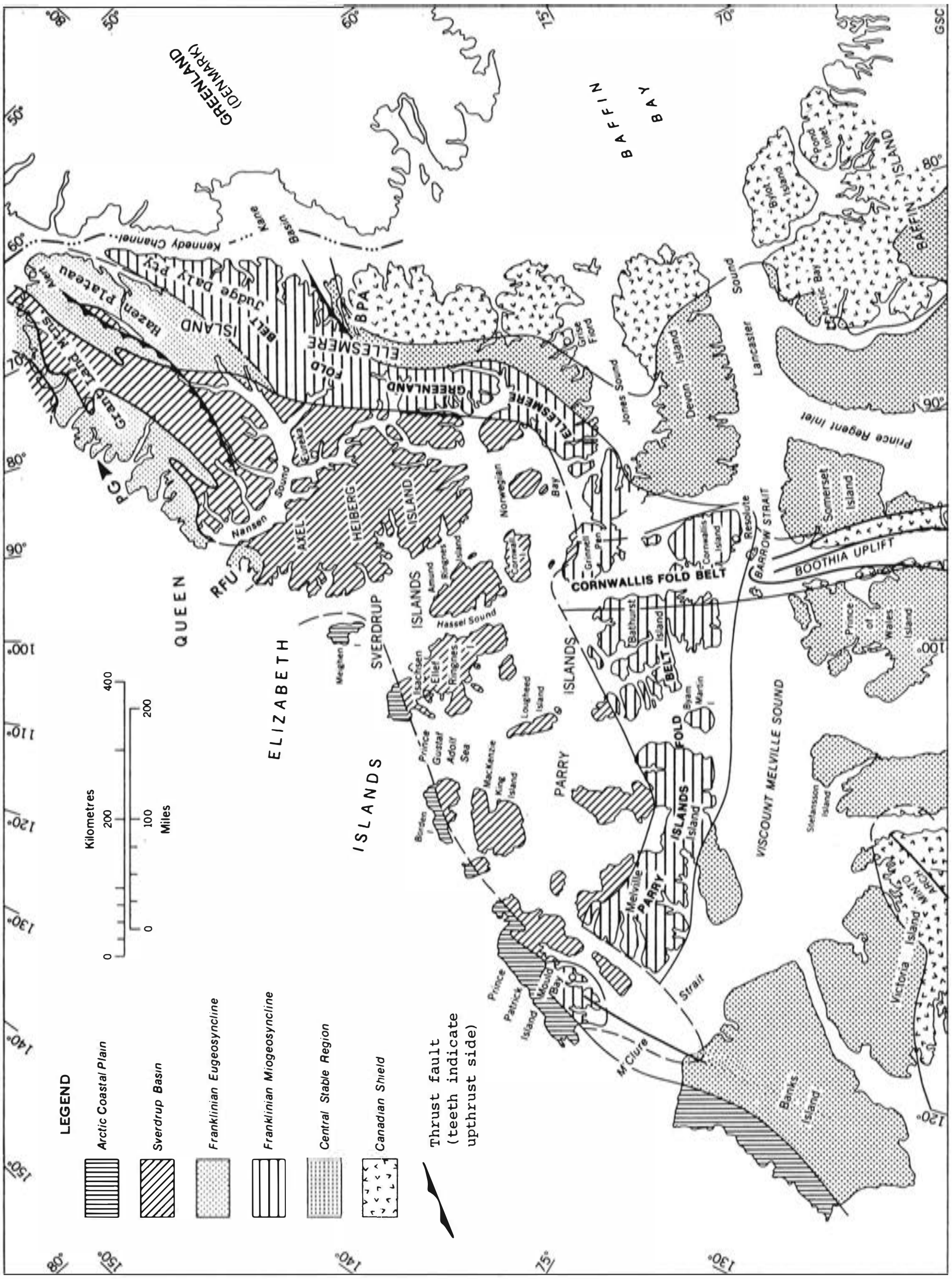

Fig. 3a. *Structural Provinces, Canadian Arctic Islands. BPA: Bache Peninsula Arch. RFU: Rens Fiord Uplift. PG: Pearya Geanticline.*

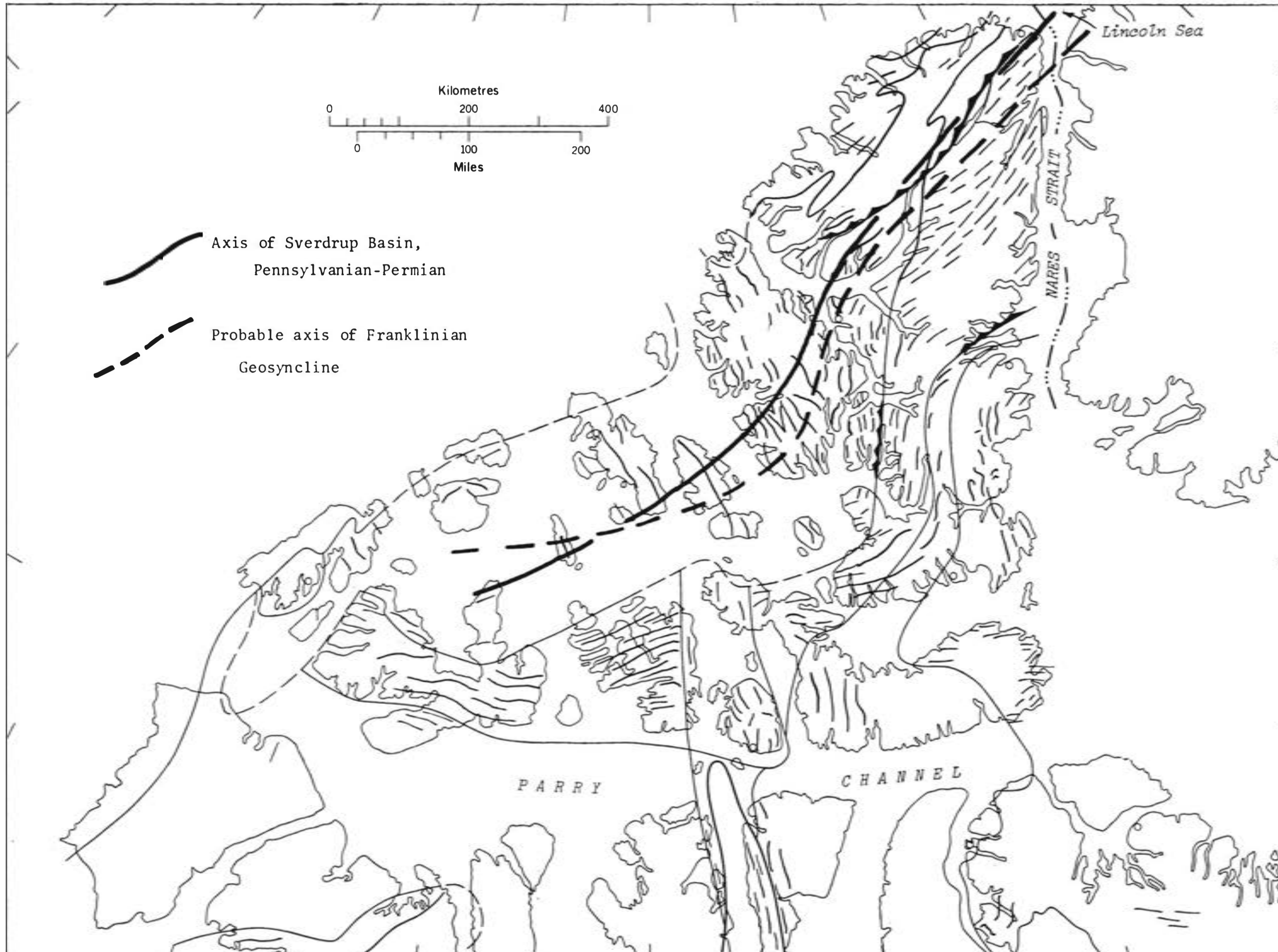

Fig. 3b. *Structural trends, Precambrian to Tertiary, Canadian Arctic Islands. Structural provinces of Figure 3a are outlined. Axis of Sverdrup Basin after* THORSTEINSSON *and* TOZER *1970, p. 570 (facies boundary); probable axis of Franklinian Geosyncline conforms to exposed sedimentary and structural trends.*

2400 m thick, are almost entirely land-derived clastic rocks that were deposited in a marine environment, and rather pure sandstone units of the platform grade northwestward into more shaly sands, then to black phyllite of the geosyncline (KERR 1967b, p. 19). There appears to have been onlap southeastward, with Proterozoic units perhaps thin or even absent toward the craton.

A Cambrian age is proposed for a clastic unit (Grant Land Formation) more than 1100 m thick in the northern coastal region of Ellesmere Island (TRETTIN 1971). This unit consists of quartzose and feldspathic sandstones, red, green, and grey-weathering siltstones and shales, and some pebble conglomerate and carbonate rocks. The detrital mineralogy and some paleocurrent determinations suggest a northern, gneissic provenance. The presence of this widespread clastic unit and the evident northern bordering lands (Pearya) complete the picture of a geosyncline bordered by cratonic platform on one side and by tectonic lands on the opposite side (see Fig. 4B).

Deep subsidence took place by early Middle Ordovician time to form a tectonic trough, the Hazen Trough, in the axial region of the geosyncline (TRETTIN 1971, 1972, 1973). Deposited in this elongate trough were distinctive, deep-water sequences comprising a lower, "starved basin" graptolitic shale facies and an upper, clastic and calcareous flysch facies. The lower unit, about 500 m thick, consists of graptolitic shales, chert, carbonate rock, and minor amounts of breccia (Hazen Formation). These beds conformably overlie the older clastic rocks. Carbonate rocks of this unit are thin-bedded to laminated, are partly graded, and contain redeposited carbonate material, probably derived from adjacent shelves and carried into deep water of the Hazen Trough by turbid flows. Conformably overlying the graptolitic rocks is a uniform succession, locally more than 2 700 m thick, of alternating calcareous greywacke, calcareous siltstone, and calcareous shale with minor amounts of conglomerate and breccia (mainly Imina Formation). Many bottom features, such as ripple marks, flute casts, longitudinal furrows and ridges, and groove marks are present, characteristic of sediments deposited in deep water under turbid conditions. From more than 2200 determinations of directional structures, TRETTIN (1971) has shown that the turbid flows entered the trough from the northwest and were deflected along the trough to the southwest.

Meanwhile, clastic deposition was taking place in the present north coastal region, which was then a coastal plain and shelf environment. Clastic sedimentation was interrupted by brief intervals during which carbonate accumulation prevailed (see Fig. 4C). Repeated floods of clastic material (in which the proportion of debris from metamorphic rocks increases upward in the stratigraphic succession), and the presence of siliceous to intermediate volcanic rocks and sedimentary suites derived from volcanic rocks, suggest tectonic activity in an anticlinal welt. This tectonic zone has been named the Pearya Geanticline (see TRETTIN 1969b, 1971, 1972).

Unfossiliferous, metamorphosed rocks are overlain unconformably by beds containing late Middle Ordovician (Wildernessian) fossils in northern Ellesmere Island and, in northern Axel Heiberg Island, Middle Silurian rocks are overlain with angular unconformity by Lower Devonian beds. These features

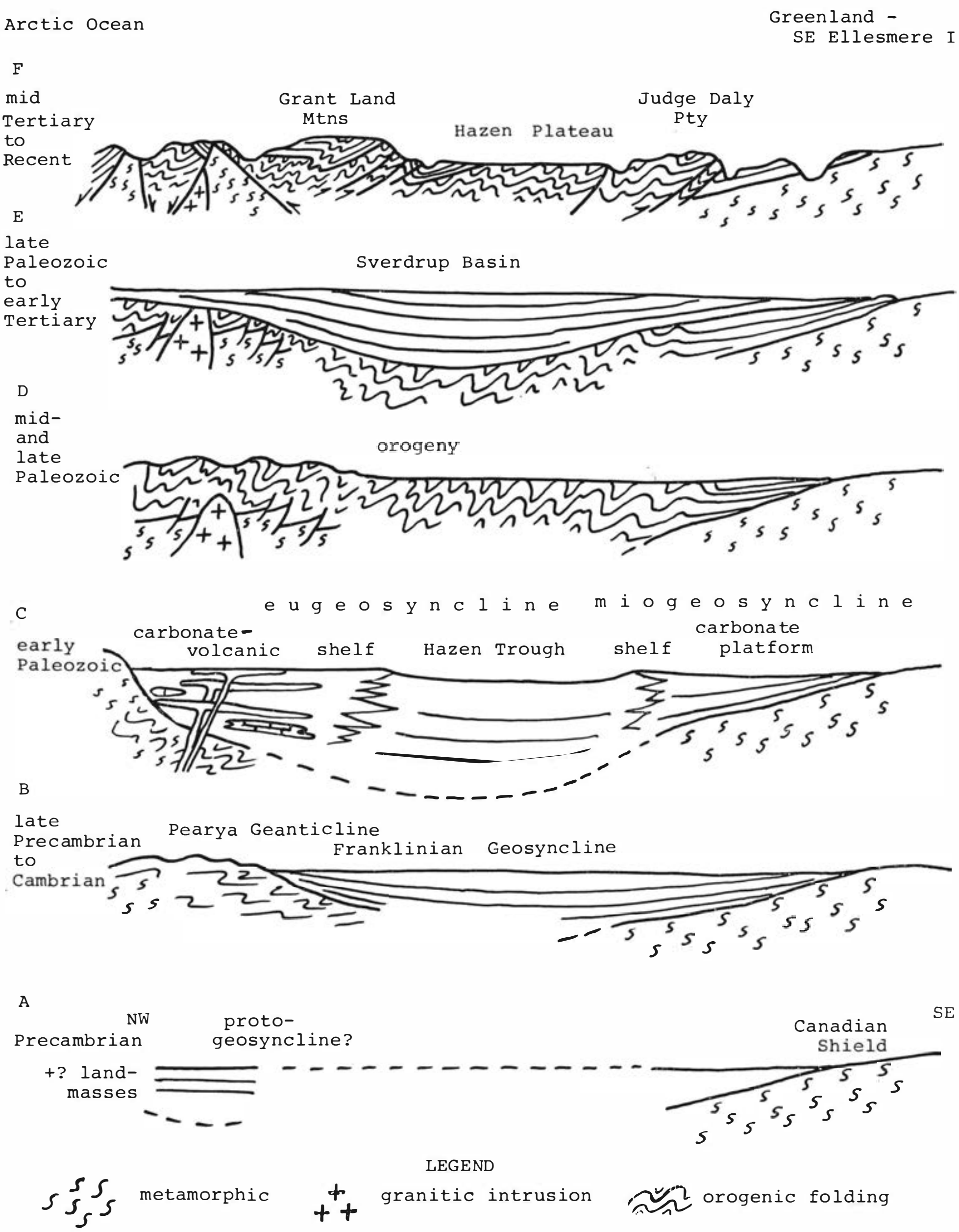

Fig. 4. *Innuitian sedimentary and tectonic episodes, northern Ellesmere Island.*

show that uplift in northern regions at times advanced southward so that areas of northern Ellesmere and Axel Heiberg Island were exposed to erosion.

The Hazen Trough expanded to both the north and south until about mid-Silurian time, then evidently shifted to the southeast. Silurian reefs in the southeast (e.g. in Greenland, see NORFORD 1972) appear to have been inundated by shaly, flysch facies sediments. The sedimentary pattern of the trough in later

Ordovician and Silurian time appears to have been: graptolitic shales, siltstones, and limestones on the flanks, and the thick, flysch-like suites of calcareous, rocks (Imina Formation) in the axial parts. Great thicknesses of flysch deposits may be present, but efforts to measure these are frustrated by complex folding. A thickness of 4500 m is estimated at a locality not in the axial region.

Deep-water (siliceous shale, argillaceous chert) sedimentary rocks of middle Early Devonian age have been found in the subsurface on Banks Island, and this area is considered by MIALL (1976, p. 57, Fig. 11) to be part of the Hazen Trough. Sedimentary trends (but not later, structural trends) of the Franklinian Geosyncline thus may swing southward from Melville Island, at least for this late stage of the geosyncline's history.

In Early Devonian time, coarse flysch deposits (Imina Formation, upper part) accumulated in the northeastern part of the Hazen Trough. Similar sediments are absent, apparently, in the southwestern regions, though they may be hidden by younger cover. About 3000 m of Lower Devonian clastic red beds (Stallworthy Formation) on northern Axel Heiberg Island appear to represent a delta complex that prograded into the Hazen Trough (TRETTIN 1969a).

The account, to this point, emphasizes the historical geology of the section of the Franklinian Geosyncline exposed on northern Ellesmere Island. Ordovician and Silurian sedimentation in the miogeosynclinal part of the basin, widely exposed from central Ellesmere Island through Grinnell Peninsula and Bathurst Island to Melville Island, is represented mainly by carbonate and evaporite facies (Copes Bay, Baumann Fiord, and Eleanor River Formations, Cornwallis Group, Allen Bay and Read Bay Formations). These facies interfinger northward with graptolitic shale and siltstone units (Cape Phillips, Ibbett Bay Formations). Both the carbonate-evaporite and the shale belts are overlain by clastic rocks (described below) representing changing tectonic conditions in Early Devonian and later times.

The main orogeny closing the history of the Franklinian Geosyncline began after rocks as young as Early Devonian age were deposited (in northern Axel Heiberg Island), but other disturbances took place at earlier times, as determined by the presence of unconformities and fossiliferous clastic formations. Certain of the earlier uplifts, which took place in Late Silurian to Early Devonian time, have resulted in anomalous or interfering patterns. Other structural trends may have been produced, of course, but now are masked by younger structures. Three such northerly-trending structural-stratigraphic regions have been identified: i) Boothia uplift, ii) Rens Fiord Uplift; iii) central eastern Ellesmere Island, including the Bache Peninsula Arch (Fig. 3a, b).

The Boothia Uplift and Cornwallis Fold Belt (Fig. 3a) form an elongate, horst-like structural high that extends northward some 1000 km from well within the Arctic Platform region in the south to cross the Franklinian miogeosyncline. The northern continuation of the structural high is hidden by the younger, Sverdrup Basin. Late Silurian to Early Devonian movements of the uplift in the platform region are recorded in syntectonic red sandstone and conglomerate beds of the Peel Sound Formation, a unit assigned a Pridolian to

Gedinnian age (THORSTEINSSON pers. com.). Northward, in the Franklinian Geosyncline, Early Devonian formations (Bathurst Island, Stuart Bay Formations) contain clastic tongues derived from the uplift zone, and other formations of the same age comprise clastic and carbonate conglomerate rocks that lie with local unconformity or disconformity on older beds, the unconformities disappearing away from the uplift (KERR and CHRISTIE 1965).

The Rens Fiord Uplift is a north-trending structural high of early Paleozoic rocks on northern Axel Heiberg Island. Steeply dipping faults separate a structurally complex core of the uplift from flanking rocks, which include beds as young as Early Devonian. An angular unconformity separates upper Middle Silurian strata from Early Devonian or older red beds. Thus, stratigraphic evidence suggests that the Rens Fiord Uplift became a positive feature during Late Silurian to Early Devonian time (TRETTIN 1969a, 1972).

The uplift region of central eastern Ellesmere Island is marked by a narrow, south-trending belt of probably early Middle Devonian red beds, (Vendom Fiord Formation), including conglomerate, of both syntectonic and post-tectonic origin. The red beds grade basinward into siltstone and shale, and indicate a source to the east, where now lies Precambrian crystalline terrain. The Bache Peninsula Arch at the north end of this region forms a northwest-trending projection into the Franklinian miogeosyncline; a local angular unconformity at the base of the Vendom Fiord Formation indicates contemporary tectonism in that area (KERR 1967c, 1967d). The early Devonian uplift may have trended parallel to the local (and regional) Franklinian depositional trends; if so, then unlike the Boothia and Rens Fiord uplifts, the eastern Ellesmere uplift lay parallel to the regional Franklinian trends. As with the Boothia Uplift, however, the younger structures of central eastern Ellesmere Island apparently conform to a Precambrian structural "grain".

The youngest phase of sedimentation of the Franklinian Geosyncline is that represented by sequences, up to 2900 m thick, of clastic rocks of late Middle Devonian to Late Devonian ages. These rocks are nonmarine to shallow marine, commonly deltaic sandstone, siltstone, and shale with coal; the widespread units are named the Okse Bay Formation and the Melville Island Group. Sedimentological evidence indicates northern and northwestern sources for the clastic deposits,[1] which are thus apparently a "clastic wedge" derived from northern tectonic lands (TOZER and THORSTEINSSON 1964, p. 206). (These positive, tectonic lands that presumably lay along the northern edge of the continent constitute "Pearya" of SCHUCHERT 1923, or the Pearya Geanticline of recent literature – see TRETTIN 1971. The geanticlinal belt will be discussed later in this paper.) The thick clastic sections pass southward and southeastward into thinner carbonate and clastic sequences of the platform; a syn-form belt of foreland basins (see KING 1959, p. 28) thus lies along the southeastern boundary of the folded part of the Franklinian Geosyncline. These basins have been referred to as the Melville and the Devon Basins, respectively, west and east of the Boothia Uplift (see FORTIER, McNAIR, and THORSTEINSSON 1954; CHRISTIE 1972).

[1] But see also EMBRY 1976, and a later footnote in this paper.

A volcanic and clastic sequence (Svartevaeg Formation) some 3200 m thick overlies the lower Devonian red beds of northern Axel Heiberg Island. The overlying unit includes volcanic arenite, tuff, siltstone, conglomerate, volcanic breccias, and keratophyric and spilitic flows. Turbidites and submarine slides appear to be represented; the region evidently lay near the margin of the Pearya tectonic borderland (TRETTIN 1969a).

TECTONIC EVENTS

The Ellesmerian orogeny in Middle Devonian to Early Mississippian time produced the most widespread and intensive deformation in the Franklinian region (Fig. 4D), but other periods of deformation both preceded and succeeded it, and the resulting structural picture is complex. Earlier tectonic events took place in: a) late Precambrian time (north coast of Ellesmere Island); b) Middle Ordovician or earlier time (northern Ellesmere Island); c) Late Silurian to Early Devonian time (Boothia and Rens Fiord uplifts, and central Ellesmere Island); and d) Middle Devonian time (northern, eugeosynclinal terrain). The principal subsequent tectonic period is that of the latest Cretaceous to middle Tertiary, Eurekan Orogeny, the main event of which took place in mid-Eocene time (see THORSTEINSSON 1974, p. 6–9).

a) *Late Precambrian orogeny*

Gneisses and schists of the north coast of Ellesmere Island have resulted from regional metamorphism to greenschist and amphibolite facies. From field structural and stratigraphic studies it is clear that the metamorphic rocks are older than Middle Ordovician beds. Several K/Ar isotopic age determinations that have been obtained are too young, apparently having been reset by later events, but whole-rock Rb/Sr age determinations recently carried out indicate a late Precambrian (minimum 742 ± 12 m.y.) age of regional metamorphism. This metamorphic terrain probably was the source of detritus that makes up the clastic formations in the lower part of the Franklinian geosynclinal sequence (SINHA and FRISCH 1975; FRISCH 1974).

b) *Middle Ordovician or earlier orogeny*

An orogenic episode of this age in northern Ellesmere Island is suspected from the presence, as noted earlier, of fossiliferous upper Middle Ordovician beds unconformably overlying weakly metamorhposed beds from which no fossils have yet been obtained. The underlying rocks, quartz-muscovite-chlorite schists, are part of a complexly deformed area of metamorphic rocks of presumed sedimentary and volcanic origin. The precise age, extent, and importance of this orogenic event are unknown (TRETTIN 1969b; 1972).

c) *Late Silurian to Early Devonian orogeny*

Caledonian orogenic activity in the Canadian Arctic Islands is represented by the stratigraphic records of the Boothia and the Rens Fiord uplifts and the synorogenic red beds of central Ellesmere Island. Additional evidence is the presence of volcanic rocks of Late Silurian age in northern Ellesmere Island.

Supporting evidence for the Caledonian age of these events has been provided by isotopic age determinations that cluster about 390 m.y. for several plutons on north coastal Ellesmere Island.

Uplift occurred repeatedly throughout the long history of the Boothia Uplift. The structural relief on this cross-trending zone of uplifts and basins increases from about 500 m in the platform region to 5300 m in the geosyncline (KERR and CHRISTIE 1965; KERR 1977). (The relief is due primarily to high-angle faulting in the platform region; to the north, in the miogeosyncline, KERR (in press) suggests a vertical complex of faults and folds). The Boothia structural zone appears to have acted as a "buttress" and to have resisted younger (Ellesmerian) deformation, structural trends of which lie nearly at right angles to the older structures.

The Rens Fiord Uplift, as noted earlier, has a northerly trending, structurally complex core. Existing structural trends are dominantly those of the later, Ellesmerian orogeny, but complex folds peculiar to the Silurian and older rocks are attributable to the Late Silurian – Early Devonian (Caledohian) deformation (TRETTIN 1969a; 1972, p. 129).

Both the Boothia Uplift and the Rens Fiord Uplift are overlain by a thick successor basin, the Sverdrup Basin, structural trends in the central part of which are aligned with structures in the older uplifts. Thus, the latest Cretaceous and Tertiary structures in parts of the Sverdrup Basin appear to represent a reactivation of earlier structural trends, and perhaps of earlier tectonic processes. KERR 1977 describes an arch and an anticlinal structure lying north of the Cornwallis Fold Belt (Fig. 3b) as the youngest, or highest structural expressions of the Boothia Uplift. The presence of Tertiary strata in small grabens within the boundaries of the Boothia Uplift provides some record of movement continuing into later times.

d) *Middle Devonian?, Acadian orogeny*

The precise age or ages of the climactic orogeny or orogenies that affected the Franklinian Geosyncline are not known directly from biostratigraphic data, particularly in the eugeosynclinal part of the sedimentary basin. In northern Axel Heiberg Island, for example, the basal beds of the Sverdrup Basin (Early Carboniferous, or Viséan) unconformably overlie rocks as young as Early Devonian. An Acadian (that is, pre-Ellesmerian) age of deformation in this region is possible, and is suspected because of the widespread presence of a clastic wedge of late Middle Devonian to Late Devonian age to the southeast, in the miogeosynclinal region. Supporting evidence for an early orogeny in the northern regions is provided by isotopic age determinations of about 360 m.y. for plutonic rocks, and the apparent absence of sediments of Middle Devonian age throughout the northern, eugeosynclinal part of the Franklinian basin. Further evidence, recently discovered in northern Ellesmere Island, is bios stratigraphic: palynomorphs recovered from relatively undisturbed clastic bed-overlying the folded geosynclinal sequence have been assigned a Frasnian (early Late Devonian) age (U. MAYR pers. com.). This assignment supports the supposition that the cycle of orogeny was completed earlier in the northern parts of the Franklinian region. (However, some caution might be used here until corroberating evidence shows that the palynomorphs were contemporary and not recycled).

A southeastward expansion of the Pearya Geanticline in Late Silurian time has been inferred by TRETTIN (in press) from changes of detrital mineralogy upward in stratigraphic sections. Such a shift of exposed tectonic lands would have coincided with the southeastward shift, noted earlier, of the Hazen Trough after mid-Silurian time.

e) *Latest Devonian to Early Mississippian, Ellesmerian orogeny*

The principal orogeny that deformed the Franklinian Geosyncline, and particularly the miogeosynclinal part, is the Ellesmerian orogeny (THORSTEINSSON 1970). The elastic wedge deriving from the earlier, Acadian orogeny in the northern, eugeosynclinal regions was folded during the Ellesmerian event and later was overlain with angular unconformity by the basal beds of the Sverdrup Basin. The youngest beds of the essentially concordant geosynclinal sequence are Famenian in age, and the oldest beds of the successor basin, Viséan.[1] That Ellesmerian activity occurred also in the northern regions is suggested by isotopic age determinations of 335 ± 25 m.y. from plutonic rocks there.

The sedimentary history of the Franklinian Geosyncline thus appears to have been closed by tectonic episodes that extended over a rather wide interval of time: as early as early Middle Devonian to as late as Early Mississippian. Tectonic activity probably commenced in the north and advanced southward so that the detritus from early phases was incorporated in younger fold structures. Precise limits of areas affected by the older and younger climactic orogenies are not known; certain areas may have been affected by both.

Structural features of the Innuitian orogen

The Innuitian orogen[2] comprises the Franklinian Geosyncline, Pearya Geanticline, and Sverdrup Basin (see FORTIER, MCNAIR, and THORSTEINSSON, 1954; TRETTIN 1972). The Franklinian Geosyncline, already described, and the Pearya Geanticline form older elements of the orogen, and the superimposed Sverdrup Basin, a younger part. The older elements appear to range in age between late Precambrian and Devonian, and the younger, Mississippian to Tertiary. Orogenies affected the orogen, as noted, in late Precambrian time, in mid-Paleozoic time (Ellesmerian), and in late Cretaceous to early Tertiary time (Eurekan). The existing orogenic belt thus incorporates structural features of many ages. Younger structural trends conform to older in most parts of the orogen, and it is often unclear, locally, either how many events have taken place or to which event should be assigned the principal deformational features.

[1] The Frasnian beds noted in the preceding section appear to underlie the Sverdrup Basin with slight angular unconformity.

[2] The Innuitian Province includes northern Greenland; as noted in an earlier footnote, however, this paper is concerned mainly with the Canadian portion of the orogen.

The structural pattern of the Franklinian Geosyncline appears to be that of an open sigmoid; the axial line of the superimposed Sverdrup Basin is also sigmoidal, if perhaps slightly less pronounced (Fig. 3b). The Innuitian Orogen thus appears dominated by Ellesmerian (in the broad sense, including earlier, Acadian) northeastern trends. Certain structural zones, however, such as the older Boothia and Rens Fiord uplifts and those of the central part of the Sverdrup Basin are marked by trends that lie across the regional (northeast) pattern.

The principal or dominating structural features are described first in the following paragraphs in order to establish clearly the regional structural framework. Older and younger features are discussed later, rather than in chronological order (see TRETTIN 1972, 1973; THORSTEINSSON 1974). As with the stratigraphic account, the following description of structural features will emphasize relationships evident between central and northern Ellesmere Island, where the most complete cross-section of the Franklinian basin is exposed.

THE PRINCIPAL STRUCTURES: ACADIAN–ELLESMERIAN

The dominating Ellesmerian structures, with their sharply sigmoidal pattern, conform closely to the sedimentary depositional trends of the Franklinian Geosyncline. Thus, the structures trend southwest in the north, then swing southward, then westward. The structural style of features of Ellesmerian age varies from northwest to southeast, across the orogen as exposed on northern Ellesmere Island. The change in structural style may be due in part to differing position within the Ellesmerian orogen but undoubtedly also relates to differences in competence among sedimentary facies (see TRETTIN 1972, p. 129). Axial planes of folds in the axial region are generally steep, dipping northwest, although some dip towards the craton (CHRISTIE 1964; TRETTIN 1971). Low angle thrust faults are not a conspicuous feature; where these are present, they appear mainly to be of Tertiary (Eurekan) age, although some may be reactivated older faults. Some thrusts in northern Ellesmere Island are directed to the northwest. (The major, northwest-dipping Lake Hazen Fault Zone only is shown in Fig. 3b). Concentric, faulted folds prevail in the northwestern, volcanic eugeosynclinal region, where massive carbonate and volcanic units are present. However, the structural pattern in this region is complicated by metamorphic complexes and anomalous structural trends of uncertain origin. Isoclinal folds – that is, complex, tight folds with near-parallel limbs – prevail in the axial, flysch belt. Both normal and reverse faults are present in the axial region (TRETTIN 1971, 1972).

Folds are systematically spaced and concentric in the foreland fold belt to the southeast, with intensity of folding decreasing toward the craton. From the evident concentric limbs and flexural slip it appears that the folding extends to limited depths and must be of a décollement type, presumably having slipped on one or more of the thick and widespread lower Paleozoic evaporite deposits of the southwestern region, and on deeper, unknown surfaces in the northeastern region (TRETTIN 1972).

Regional metamorphism to low grades is characteristic of the northern regions, and the degree of alteration decreases southeastward from the north coast of Ellesmere Island. Greenschist and amphibolite facies are developed extensively in the metamorphic belt; metamorphism can be described as Barrovian in type, and there is evidence of widespread cataclasis and retrograde metamorphism. Metamorphism on a regional scale has occurred at different times and different places, however, so that the various metamorphic terrains do not form a single entity (FRISCH 1974).

OLDER STRUCTURAL ZONES

A zone of older folded and metamorphosed rocks of the north-coastal region of Ellesmere Island is broadly concordant with Ellesmerian structures. The Boothia and Rens Fiord Uplifts, on the other hand, are transected by the younger trends.

The northernmost, coastal exposures of the metamorphic terrain are amphibolite-facies granitoid gneisses and amphibolite, and extensive areas of greenschist facies rocks lie inland (see FRISCH 1974). Metamorphic grade thus appears to increase northward. However, cataclasis and retrograde metamorphism are widespread, and certain gneisses are overlain with sharp contact, in domal structures, by altered sedimentary rocks of distinctly lower metamorphic grade. The metamorphic rocks thus apparently form a complex. The southern limit of the main Precambrian orogeny is as yet uncertain because of difficulty distinguishing older from younger structures.

Foliation and banded structures, and the boundaries of metamorphic facies, trend mainly west and southwest, thus conforming approximately to the regional pattern.

The gneisses and schists, from the presence of repetitive layering and from their chemistry, are probably derived from volcanic and/or sedimentary rocks in part. From the ratio of strontium isotopes, a crustal rather than a mantle origin is suggested by SINHA and FRISCH (1975) for gneisses that may have been intrusive, granitic rocks. It is now clear from isotopic age determinations (minimum 742 ± 12 m.y., noted earlier) that these rocks, and an early orogeny that raised their metamorphic grade to the amphibolite facies, are older than the lower Paleozoic sediments of the Franklinian geosynclinal sequence. Steep attitudes of the gneissic structures presumably are due to the early orogeny, structural features of which are otherwise difficult to distinguish from those of later periods of deformation.

The gneisses, schists, and phyllites thus form the infrastructure of the Pearya Geanticline (see TRETTIN 1972, p. 125): although older than the Paleozoic part of the geosynclinal sequence, as just noted, they still may be equivalent to the oldest known Franklinian strata, or to conformably or disconformably underlying, non-metamorphosed strata not yet recognized.

The north-trending Boothia-Cornwallis structural belt lies nearly at right angles to the later, transecting Acadian-Ellesmerian structures. The Cornwallis Fold Belt is interpreted as a broad anticlinorium that overlies the Boothia

Uplift; the fold belt flanks the exposed core of the uplift in the Central Stable Region and continues northward beyond it, into the geosynclinal region. The north-trending structures in the geosyncline thus probably formed in response to vertical movements in the basement. The trends of high-angle reverse faults, probable horst-and-graben structures and related folds, mainly of Late Silurian–Early Devonian age, are about parallel to the gneissic structures of the Precambrian core over much of the length of the uplift (KERR 1974, 1977).

Northwesterly-trending structures are present in the Ordovician or older core of the Rens Fiord Uplift. These trends differ from the predominantly southwestward trends of northwestern Ellesmere Island. Dips are steeper and structure more complex in the core of the uplift, but the structures are difficult to distinguish in detail from later, Ellesmerian structures. From stratigraphic evidence (noted earlier), the complex structures in the older rocks are attributed to Late Silurian–Early Devonian deformation (TRETTIN 1969a, 1972).

YOUNGER STRUCTURES

A few folds and faults of Early Permian age have been identified at scattered localities from Ellesmere Island to Yukon; these structures represent the Melvillian Disturbance (see TRETTIN 1972, p. 132). Such structures in the Arctic Islands are superimposed on the earlier, Ellesmerian trends, so their true extent and origin are uncertain.

The large, successor sedimentary basin, the Sverdrup Basin,[1] with its partly conforming structural pattern, is an intriguing feature of the Innuitian Orogen. The overall conformity of structural trends of different ages naturally leads to speculation that major structures in the Sverdrup Basin reflect underlying features, in spite of the considerable, blanketing thickness of rock in the younger basin.

The Eurekan Orogeny (see THORSTEINSSON and TOZER 1970, p. 585) ended sedimentation in the Sverdrup Basin and imprinted a widely spread pattern of folds and faults on the Innuitian Orogen in latest Cretaceous to mid-Tertiary time. Eurekan structures include a wide variety of folds, thrust faults, and normal faults. Tectonism was most intense on Ellesmere and Axel Heiberg Islands. In the western islands, in contrast, folds are of low amplitude. Eurekan and the older, Ellesmerian structures are concordant; however, Eurekan folds and thrust faults extend into miogeosynclinal parts of the Franklinian Geosyncline that had not been affected by the Ellesmerian Orogeny.

Thrust faults of probable Tertiary age trend mainly northeast, with motion directed southeastward; some of these faults occur on the southeast sides of tectonically high, mountainous areas and apparently bound major uplifts. Northwesterly-directed thrust faults, normal faults, and elongate grabens also are present. Some of the faults probably represent rejuvenation of motion along Ellesmerian structural trends.

[1] General accounts of the Sverdrup Basin have been written by THORSTEINSSON and TOZER (1970), PLAUCHUT (1971, 1973), and NASSICHUK (1972).

A REVIEW OF SOME TECTONIC FEATURES OF THE INNUITIAN REGION

Certain tectonic features and events of the Canadian portion of the Innuitian region, although of uncertain origin, appear potentially significant in achieving an understanding of the tectonics of the region. Among these are: coincidence of basinal axes of different periods; parallelism of structural trends of different ages; the sharply sigmoidal form of the fold region; and transection of the orogen by a fracture zone of a wide range of ages.

The Franklinian Geosyncline now is structurally complex and deeply eroded. In contrast, the successor, Sverdrup Basin is relatively simple. But the two basins have some features in common: near coincidence of depositional axes, and comparable depth of sedimentary fill (see Fig. 3b; Table 1).

The Sverdrup Basin, although evidently at no time larger than the Franklinian Geosyncline, may have been nearly co-extensive and contained an almost equal thickness of sediments. Estimates of maximum thickness for the Sverdrup Basin range from about 10 000 m to 14 000 m; for the Franklinian Geosyncline, 9000 m to 15 000 m. Such repetition of episodes of downsinking and accumulation of major volumes of sediment in one linear belt may have been due to repeated operation of a single mechanism. A thinned crust beneath the axis of the Sverdrup Basin is inferred from gravity data (SANDER and OVERTON 1965), and speculation based on the magnetic pattern of the Sverdrup Basin questions whether a Precambrian basement is present beneath the basin, or whether the basement is of a different character (RIDDIHOUGH et al. 1973). A geotectonic model that allowed repeated thinning of the crust would be favoured for the Innuitian region.

Table 1.

Some recent estimates of total thickness and volume of sediments in Sverdrup and Franklin basins.

	Sverdrup Basin	Franklinian Geosyncline
THORSTEINSSON 1974	12,000 m (40,000 ft)	15,000 m (50,000 ft) Late Precambrian to Late Devonian
DRUMMOND 1973, p. 450	12,000–14,000 m (40–45,000 ft)	14,000 m (45,000 ft)
	1,500,000 km³ (350,000 mi³)	1,100,000 km³ (273,000 mi³)* * Cambrian to Devonian of the "Franklinian Fold Belt"; volume underlying Sverdrup Basin and northern Ellesmere I. eugeosynclinal belt not included.
THORSTEINSSON and TOZER 1970	10,000 m (35,000 ft)	12,000 m (40,000 ft)
	600,000 km³ (150,000 mi³)	Cambrian to Devonian

Thinning of the crust and subsidence of the axial region of a basin are not provided for specifically in the recently developed theory of plate tectonics although subsidence of a *continental shelf* does figure in the formation of a "flysch-molasse basin accumulating continent-ward directed sediments" (see DEWEY and BIRD 1970a; 1970b, p. 2639, Fig. 10C). However, this does not appear to be a good description of the Sverdrup Basin.

The Sverdrup Basin may be an unusually well-developed, fault-bounded trough, perhaps owing its size and depth to massive reduction of the root zone of the Franklinian Orogen by convection in the mantle (see LAMBERT 1973, Fig. 5). MCCROSSAN and PORTER (1973, p. 618, 668–673) have classified the Sverdrup Basin as a "rift basin" from its trough-like form, thick sedimentary fill, and extremely abrupt thickening from the edges to the basin centre. Alternatively, the Sverdrup Basin might be related to a "new" continental edge, a result of rifting that preceded it, and its coincidence with the Franklinian Geosyncline may be more or less fortuitous. This possibility is discussed in a later section of this paper.

Structural trends of different ages are markedly parallel in many parts of the Innuitian region. For example, folds in the eastern margin of the Ellesmerian fold belt parallel gneissic trends in the adjacent Canadian Shield. Similarly, Eurekan trends in the eastern part of the Sverdrup Basin lie parallel with those in the adjacent Ellesmerian Orogen, and approximately conform to the trend of otherwise transecting structural zones such as the Boothia Uplift. This uplift, in turn, follows trends in its gneissic core, at least in its northern and greater part.

It is possible that the prominant Boothia structure, which is clearly an expression of a basement feature, extends beneath the Sverdrup Basin, and one might suppose (as KERR 1977 does – noted earlier) that basement structures have influenced or controlled structural trends in the successively younger basins. TRETTIN (1972), p. 165) describes as a "transverse ridge" four or more en echelon uplifts, including the Boothia Uplift, of various ages that cut across the depositional axes of the Franklinian and Sverdrup sedimentary basins. These are taken (op. cit., p. 127) to be expressions, possibly, of a region of basement-controlled, Siluro-Devonian block faulting.

Can older structural trends reappear through a blanket of sediment at least 10 km thick? The northern part of the Canadian Shield is characteristically heterogenous and variable in structural grain, and the large, linear sedimentary depressions (both Franklinian and Sverdrup) apparently cross the basement structures, little affected by them. The parallelism may be more apparent than real: trends perhaps conform only at basin-edges, where the younger cover is thin, or a degree of convergence may result from, say, a sharp flexing of the regional structure.

A notable feature of the sharply flexed, southeastern boundary of the Franklinian sigmoidal form is the absence of late Precambrian sediments along the margin of the Franklinian sedimentary basin. Some 3000 m of late Precambrian sedimentary rocks are exposed in northern east-coastal Ellesmere Island, and late Precambrian rocks also underlie early Paleozoic beds on northern Victoria Island, in the platform region. (The western extension of the pre-Paleozoic Franklinian basin edge is hidden beneath a Paleozoic cover). Between Bache Peninsula and the Boothia region, however, the Precambrian gneisses of the Canadian Shield are overlain directly by Cambrian beds. This absence of late Precambrian beds could be due to non-deposition – that is, simple onlap of the basal Paleozoic beds onto the crystalline shield; or, it could result from uplift and erosion of older beds in latest Precambrian – earliest Paleozoic time. In either case, the absence of the late Precambrian beds may signify an early expression of tectonic activity possibly relating to the "sigmoid". It can be observed that the flexure is directed like a broad arrow down Baffin Bay. Or, put another way: the coincident, southeast-trending embayments of the Franklinian and Sverdrup basins are aligned with the very large scale Baffin Bay-Labrador Sea embayment. The lower Paleozoic rocks of the Innuitian "embayment" region are of platform- and limited-circulation basinal type (carbonate and evaporite). Deeper basinal facies of the Sverdrup Basin, however, are known to extend far to the southeast, into the "flexure" of the sigmoid (W. W. Nassichuk pers. comm.). From the alignment of the Innuitian Paleozoic and Mesozoic embayments with Baffin Bay it seems possible that the latter feature may have been tectonically low at those times and that Paleozoic and Mesozoic sedimentary rocks may be found there. This possibility was suggested earlier by Fahrig, Irving, and Jackson (1971, 1973), who reasoned that a northwest-trending, late Precambrian dike swarm of Baffin Island is evidence of crustal tension of that age.

It appears, indeed, from geophysical data and dredging samples recently obtained, that remnants of a sedimentary basin, or a series of basins, of Mesozoic and possibly Paleozoic age may occur along the continental shelves of Baffin Bay, Davis Strait, and Labrador Sea (Johnson et al. 1975; Grant 1975; and see Fig. 2).

Beh (1975) has proposed a sedimentary trough in Baffin Bay and Davis Strait that received sediments as early as Jurassic time, the age based on the probable time of rift-opening of the seaway. Vogt and Avery (1974) have speculated on a possible connection between the Alpha Ridge of the Arctic Ocean and the Labrador Sea basin, the ridge being perhaps a "fossil" mid-oceanic ridge. Such a connection would of course pass through the sigmoidal embayment; no field evidence is known, however, to indicate a spreading ridge at this locality, and this line of speculation apparently is unsupported.

The lack of evidence just noted could, however, be ascribed to *incipient* development of a spreading centre or ridge in late Proterozoic time; thus, a domed or uplifted zone might explain the absence, either through non-deposition or erosion, of late Precambrian beds in the "flexure" region of the Innuitian sigmoid. Such an early tendency to ocean spreading in Baffin Bay, if it occurred, presumably was transformed to early transcurrent faults along Nares or Parry Channels.

The youngest major structural features expressing orogenic processes in the archipelago are the rifts, evidently of late Mesozoic or Tertiary age, that now are followed by large seaways and channels. The two largest rifts, Parry Channel and Nares Strait (Fig. 3b), cut obliquely across the overall northeasterly Innuitian trend.

Parry Channel, comprising Lancaster Sound, Barrow Strait, Viscount Melville Sound, and M'Clure Strait, nearly follows the 74th parallel of latitude. From geomorphological and geophysical data it appears that the feature is graben (M'Clure Strait) and graben or half-graben (Lancaster Sound) in form (Gregory, Bower, and Morley 1961, p. 24; Barrett 1966; Daae and Rutgers 1975; M. J. Keen et al. 1972). A northwestward extension of this rift feature appears to transect Ellesmerian trends, and certainly transects – at right angles – the southwestward extension of the Hazen Trough suggested by Miall (1976, p. 51, Fig. 11). The relationships here, however, are obscured by young deposits of the Arctic Coastal Plain and by widespread inundation by sea water. Few geophysical or subsurface data are yet available; so that much remains speculative.

Nares Strait, comprising Kane Basin, Kennedy Channel, and connecting straits to north and south, trends north-northeastward from the head of Baffin Bay, and on a recent bathymetric chart (Heezen and Tharp 1975) the lineament can be seen to extend northeastward along the eastern margin of Lincoln Sea. The Nares Strait lineament will cross the termination of the Lomonosov Ridge if that ridge terminates against Greenland as shown on the recent chart.[1] Northeastward, north of Peary Land, the lineament is represented by the western edge of the Morris Jesup Plateau. A distinct magnetic "low" follows the western side of Nares Strait but is broken by a "high" near latitude 79°30′ N. The "high" crosses the lineament, seemingly unaffected by it (Riddihough et al. 1973).

The Nares Strait lineament is relatively straight and narrow; this is the Wegener Fault of Wilson (1963). The lineament probably does mark a zone of transcurrent movement, but the net amount of translation that has occurred is unknown. Major stratigraphic features such as the margins of the Franklinian Geosyncline and the Thule Basin appear very little, if at all displaced (Kerr 1967a; Christie and Dawes in prep.), but uncertainty arises due to the acute angle (about 25°) at which the lineament crosses stratigraphic and structural trends: possible offset trends are accommodated easily in mapping. Both horizontal and vertical components of displacement on coastal faults along the northern part of the lineament were recognized in the field (Christie 1964, 1974), but no evidence was found suggesting horizontal displacement of more than a few kilometres. The continuity across Nares Strait of the magnetic "high" mentioned above also argues against significant horizontal displacement, as Riddihough et al. (1973) have noted.

The Nares Strait lineament, a younger, major structure of the Innuitian Orogenic system, is of interest in the present context if, as is the case for other structural features discussed previously, it was a locus of repeated tectonic

[1] The new chart, unlike earlier ones, shows the Lomonosov Ridge approaching western Peary Land, Greenland, as a straight and prominent, rising topographic ridge. The bathymetry of this region, however, is based on sparse data and may not be reliable (E. F. Roots pers. com.).

activity. The Nares Strait lineament must, in fact, be an older and more complex structure than first appearances might suggest; it forms, at least, a dividing line between contrasting structural regions that record differing patterns of mid-Paleozoic tectonic events: tectonic transport in folds and faults is dominantly southward west of the strait, and northward to the east (see KERR 1967a; DAWES 1973). This dividing line is inferred to have existed as some linear structural feature, probably a compressional fault zone with incipient strike-slip movement, during an earlier, presumably mainly Ellesmerian period of compression. The history of Nares Strait thus appears to be a long and complicated one. (For a review of the difficulties in comparing the geology on either side of the strait and of the restraints on overall movement see DAWES 1973, p. 938–939.) A line of fracture cutting diagonally across a major orogenic zone and expressed at more than one time suggests a deep-seated feature.

Little agreement has been reached on the positions and history of Greenland in the spreading opening of the North Atlantic Ocean, and some proposed positions cannot be reconciled with landward geology. Possibly, movement in both directions has taken place along the Nares lineament; that is, the lineament may be a zone of both sinistral and dextral transcurrent "adjustment" between Greenland and North America, and the net movement may thus be incidental rather than a measure of the importance of the zone.

Tectonic development of Svalbard and the Innuitian region

Both Svalbard and the Innuitian region lie at the edges of large continental masses: Svalbard at the northwestern "corner" of the Barents Shelf, and the Innuitian region along the northern edge of the North American craton. Modern theories of ocean-floor spreading invite hypothetical reassembly of earlier or supposed "supercontinents"; this exercise requires a review of the essential geological features of two regions that may have been juxtaposed.

Some possible tectonic settings of Svalbard and the Innuitian region will first be examined. Following this, the geology of the two regions will be viewed with the aim of determining connections that may have existed in the past.

TECTONIC MODELS TO ACCOUNT FOR THE ARCTIC OCEAN BASINS AND THE GEOLOGY OF SVALBARD

The Arctic Ocean Basin is small among ocean basins, and surrounded by continents. Various physical features are present, some of which clearly indicate rifting and sea-floor spreading whereas others are of less certain origin. Contrasting hypotheses have been formulated to account for the basin, and these have been described and appraised by CHURKIN (1973) and by CLARKE (1975), among others (see VOGT and AVERY 1974, p. 84).

The Arctic Ocean Basin is divided into two major regions separated by the Lomonosov Ridge: the Eurasian Basin off the Barents and Kara Shelves, and the Amerasian Basin off Canada and Siberia (see Fig. 2). The Eurasian Basin is elongate and marked by a median ridge, the Nansen Cordillera (or Gakkel Ridge); the Lomonosov Ridge and the opposing continental edge appear to form a good geometric fit. The Amerasian Basin is roughly triangular, with a straight margin along the Canadian Arctic Islands and an irregular one on the Siberian side. The irregular Alpha Ridge (comprising the Mendeleyev Ridge and the Alpha Cordillera) divides the Amerasian Basin asymmetrically with the large and deep Canada Basin lying north of Alaska.

An early concept of subsidence of a continental crust (that of SHATSKY and others, 1935 and later; see CHURKIN 1973) to explain the Arctic Ocean basins has given way to hypotheses applying one concept or another of rifting of continental masses or of geosynclinal development and continent-margin tectonics around a very ancient or "proto-" Arctic Ocean basin.

An orocline-and-rift theory proposed by CAREY (1955) interpreted the oroclinal bend of southern Alaska as complementary to a wedge-shaped opening of the Arctic basin. In a sea-floor spreading theory (VOGT and OSTENSO 1970), the Alpha Ridge is interpreted as a "fossil" spreading centre and the Nansen Cordillera as an active extension of the mid-Atlantic Ridge. Different geometric schemes have been incorporated with the seafloor-spreading concept to provide variations on the theory; e.g. early spreading at right angles to the present basin margins (TAILLEUR 1973) to account for the deep part of the Canada Basin north of Alaska; and Paleozoic collision of a "Kolymski Block" (of eastern Siberia) with North America and subsequent backward drift in Mesozoic time to open the Amerasian Basin (HERRON et al. 1974).

The existence of a Proto-Amerasian Basin in early Paleozoic or even Precambrian time was postulated by CHURKIN (1973), who showed that a series of continent-margin geosynclines may have existed in early Paleozoic time around the circumference of a Proto-Canada Basin. OSTENSO and WOLD (1973) also proposed a primeval sea, the "Hyperborean Sea", to account for the Amerasian Basin, in this scheme an ocean area remaining throughout the collision of three continental plates: the North American, Russian[1], and Siberian platforms. In all variations of the sea-floor spreading theory, the Eurasian Basin is accounted for by the splitting away of a continental sliver (the Lomonosov Ridge) during Cenozoic time, so that the eastern Arctic Ocean (as viewed from Canada) is, in origin, a northward extension of the North Atlantic Ocean and Svalbard has been removed from a position north of Ellesmere Island or Greenland.

Svalbard, in a pre-drift position north of Greenland, lies close to the junction of East Greenland (Caledonian) and Innuitian (Ellesmerian) structural trends. In its geology, too, Svalbard may reflect the tectonic history of both structural regions (see Fig. 5). The age of the main orogeny, Caledonian, suggests a close relationship with the folded East Greenland geosyncline, whereas the structural trends (in the reconstructed position) conform most closely to Ellesmerian trends. Svalbard evidently lies near a major junction of continental masses, and near the centre of a possible former "supercontinent"; the relationships, therefore, between structures of Svalbard and those of formerly surrounding regions may be critical to an understanding of the tectonic history of the polar regions.

A model proposed by HARLAND (1965, 1966, 1975b) begins with an essentially Caledonian Svalbard (that is, relating to the East Greenland geosyncline)

[1] Eurasian platform in the present discussion (see Fig. 2b).

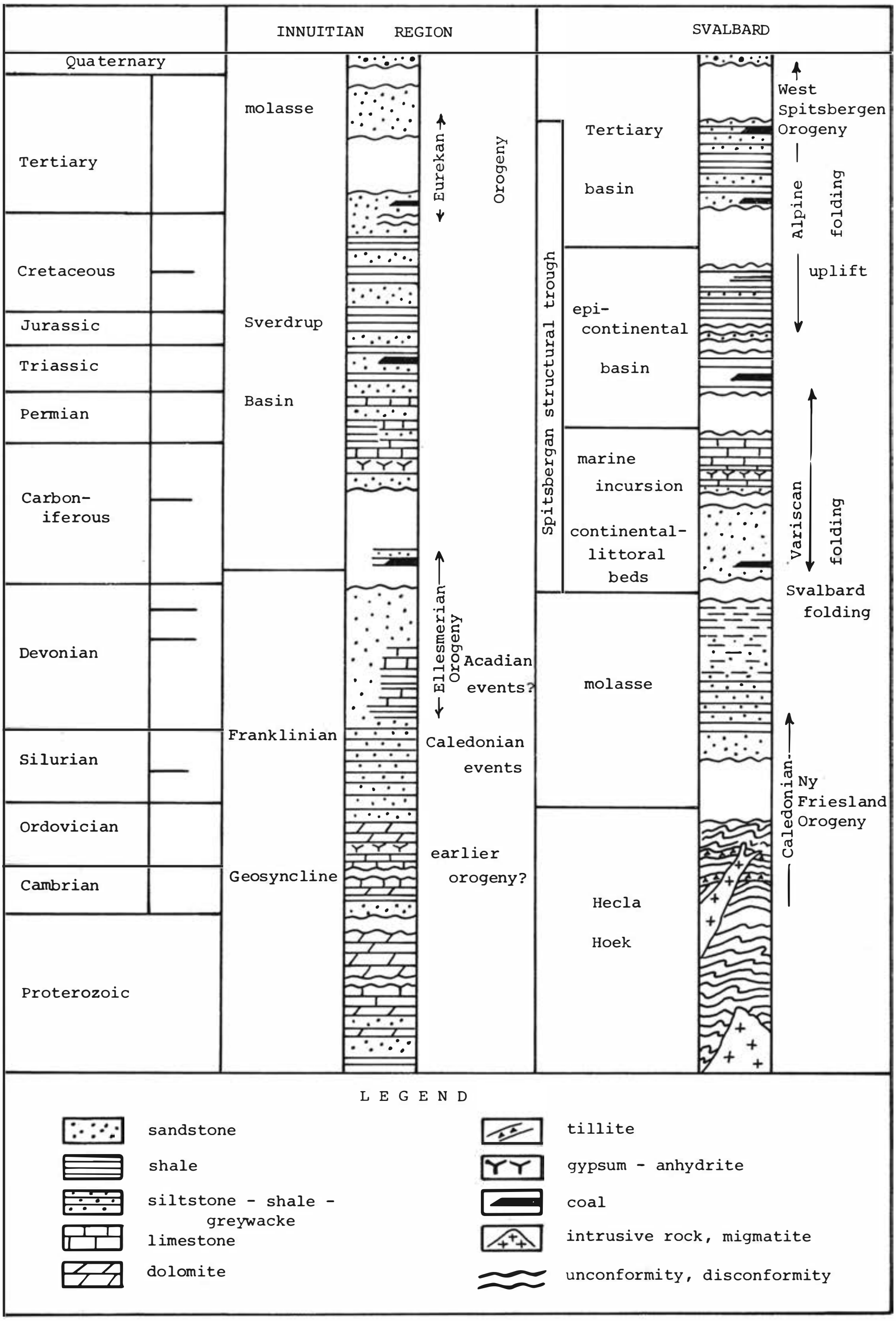

Fig. 5. *Comparative columnar sections, Innuitian region and Svalbard (Svalbard from* ORVIN *1940, Pl. IV).*

then, through Late Devonian sinistral plate motions, juxtaposes Svalbard and northeast Greenland. The Billefjorden Fault Zone, a major fault zone separating eastern and western Svalbard, is proposed to mark a line of substantial transcurrent displacement such that western Svalbard derived from a position adjacent to Peary Land while eastern Svalbard was related to central east Greenland. Svalbard and Peary Land then separated in late Phanerozoic time by dextral transcurrent movement along the de Geer line.

This scheme, however, requires substantial changes in directions and styles of motion (and tectonic processes?) along rather closely related lines of sheer (e.g. HARLAND 1966, Fig. 4, 6).

The model proposed in this paper, though in some ways no simpler, also may accommodate the data (see Fig. 6): in this case, the Svalbard and Franklinian geosynclines are presumed to have been a "pair", divided during certain periods by an intermittently positive tectonic welt, the Pearya geanticline of TRETTIN (1972, 1973). The paired geosynclines were thus separate but related. A geological history for the combined region will be proposed after a review of certain geological features.

The geology of Svalbard and the Innuitan region

An overview of the geology of the Innuitian region and Svalbard discloses both marked similarities and substantial differences. Some sedimentary and tectonic features are compared in Table 2. It seems clear (Table 2; Fig. 5) that the tectonic histories of the two regions can be divided into two main periods: an earlier, pre-Late Devonian period during which the histories differ, and a later, post-Devonian period during which the sedimentary and tectonic styles become distinctly similar. From late Precambrian time, when the known sedimentary record begins, to early Devonian time, the tectonic histories of the two regions appear to have little in common. A convergence in styles began during the Devonian; then, in early Tertiary time, certain differences reappear. These features have been recognized, and certain tectonic reconstructions are based on them (see HARLAND 1965, 1969a, 1969b, 1975b; HARLAND and GAYER 1972).

PRE-CARBONIFEROUS TIME

Some sedimentary-tectonic features of the two regions for this period appear, at first glance, to be rather similar: thicknesses of 15 and 19.8 km, respectively, of geosynclinal sediments pre-dating the main closing orogenies, or 15 and 28.8 km, respectively, of geosynclinal and molassic sediments before Carboniferous time (see Table 2a; Fig. 5). A major break in sedimentation took place in both regions by early Carboniferous time. However, although the complex geology of Svalbard is not yet explored thoroughly, it is evident that differences of a major order exist; the two geosynclines, while possibly connected by seaways, were nevertheless of different sedimentary-tectonic regions. Dissimilarities in sedimentary style appear when the sedimentary columns of the two late Precambrian–early Paleozoic geosynclines are compared: only

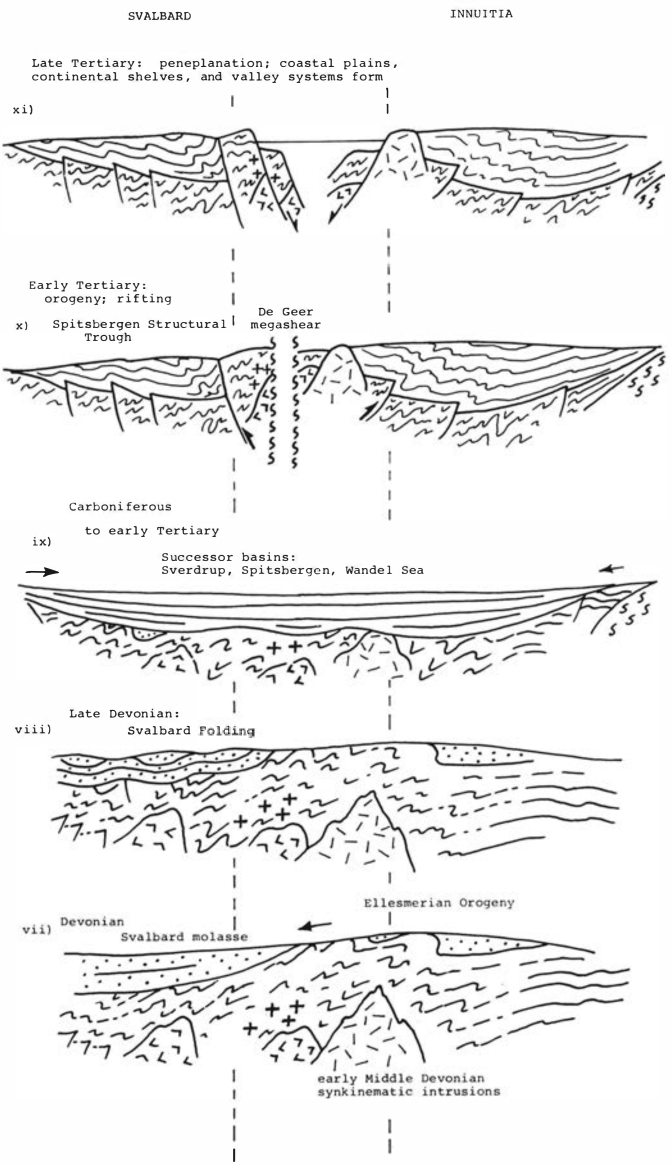

Fig. 6. *Diagrammatic representation of possible stages in the development of Svalbard and Innuitian geosynclines. Arrows indicate directions of sedimentary transport.*

1.7 km of late Precambrian beds are known in the Franklinian basin, whereas 18.6 km have been measured in Svalbard (see Table 2b; Lower and Middle Hecla Hoek). The proportions are reversed in early Paleozoic time: 8.3 km for Cambrian to Devonian time in Canada vs 1.2 km for Cambrian through Ordovician time (Upper Hecla Hoek) in Svalbard, with most of Silurian time not represented in Svalbard due to elevation of the region during the Caledonian orogeny.

A detailed comparison of sedimentary characteristics (Table 2b) might be interesting, but probably is not justified until more certain or complete

Fig. 6 cont.

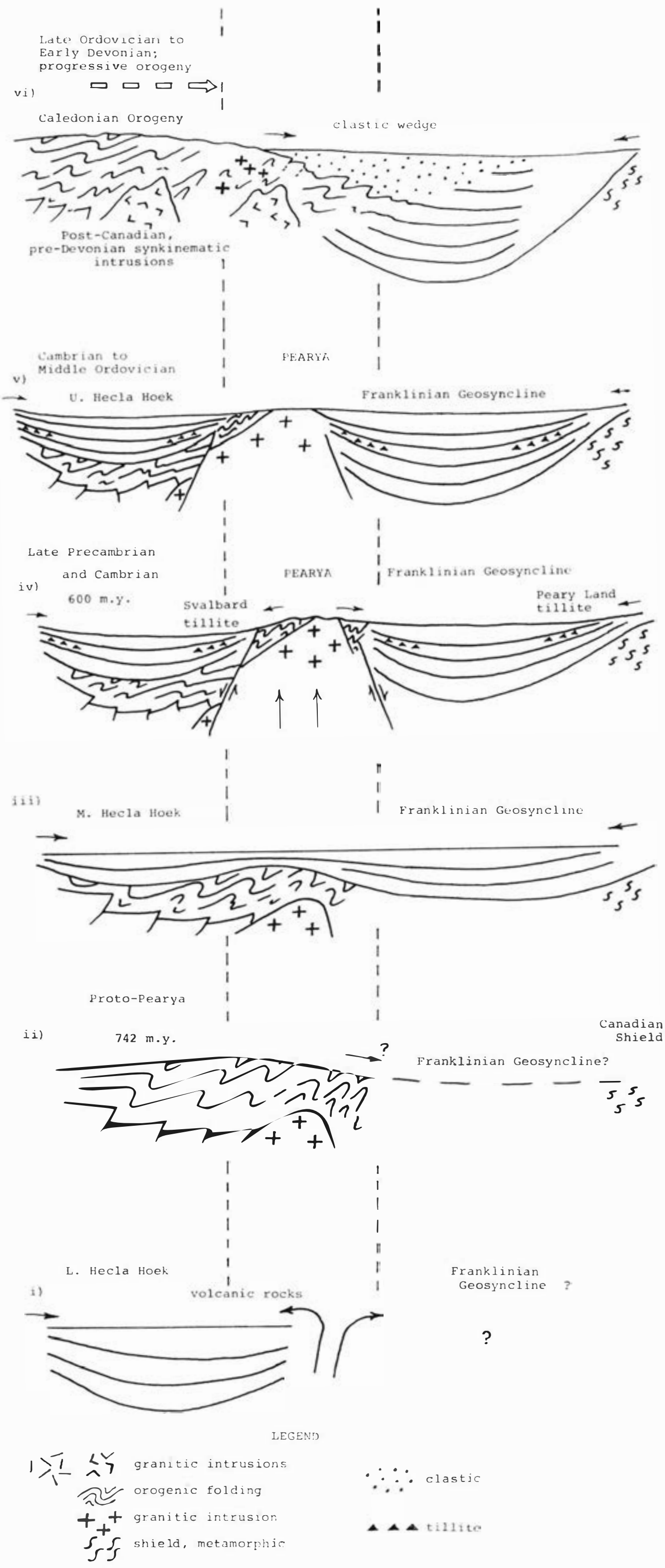
Late Ordovician to
Early Devonian;
progressive orogeny
vi)
Caledonian Orogeny
clastic wedge
Post-Canadian,
pre-Devonian synkinematic
intrusions
Cambrian to
Middle Ordovician
v)
PEARYA
U. Hecla Hoek
Franklinian Geosyncline
Late Precambrian
and Cambrian
iv)
600 m.y.
PEARYA
Franklinian Geosyncline
Svalbard
tillite
Peary Land
tillite
iii)
M. Hecla Hoek
Franklinian Geosyncline
Proto-Pearya
ii)
742 m.y.
Canadian
Shield
?
Franklinian Geosyncline?
L. Hecla Hoek
i)
volcanic rocks
Franklinian
Geosyncline ?
?
LEGEND
granitic intrusions
orogenic folding
granitic intrusion
shield, metamorphic
clastic
tillite

Table 2.

Sedimentary and tectonic features of the Innuitian region and of Svalbard compared. Superscript numbers refer to authors listed in table below. K-Ar, Rb-Sr: isotopic age determinations in millions of years (m.y.). ">" signifies "greater than".

	Innuitian Region		Svalbard	
a) Thickness and ages of sediments	Arctic Coastal Plain and late Cenozoic basins	2.5 km?	Paleocene-Eocene	1.5 km (up to 3.5 km)[25]
			L. Carb.–L. Cret.	4 km
	Sverdrup Basin (L. Carb.-Eocene)	12 km	Old Red ss (L. & M. Dev.)	9 km
	Franklinian: (late Prot.-Dev.)	15 km	Hecla Hoek (late Precambrian-M. Ord.)	20 km
	refs: 1,3		refs: 2,9	
b) General lithology Thicknesses are maxima; many units range from zero thickness	Arctic Coastal Plain and late Cenozoic basins: sand, gravel, silt, wood, peat refs: 3,6	0.1–3 km?	Continental basin Paleocene-Eocene: sandstone, shale, coal refs: 8,9	2 km (3 km[21])
	Sverdrup Basin Early Cenozoic conglomerate, sandstone, shale, coal	3 km	Epicontinental basin L. Trias.-L. Cret. shale, sandstone, limy sandstone, limestone, coal, conglomerate refs: 8,9	2.8 km (2.4 km[24])
	Triassic -Cret. sandstone, siltstone, shale, basalt	7.6 km	Continental beds and marine incursion M. Carb.-L. Perm. limestone, sandstone, conglomerate refs 8,9	0.7 km
	U. Perm. sandstone, chert, limestone	0.8 km		
	U. Carb.-L. Perm. conglomerate, sandstone, shale, limestone, evaporites	2 km	L. Carb. sandstone	1.2 km
	L. Carbonif. siltstone, sandstone, coal	0.3 km	Molasse (Old Red) Middle Dev. shale	2 km
	refs: 1,3,6,7		Late L. Dev. sandstone, shale	5 km

Table 2 cont.

	Innuitian Region	Svalbard
	Franklinian M. & Late Dev. sandstone, siltstone, limestone, shale 5 km Camb.-Early Dev. limestone, dolomite, shale, siltstone, sand- stone, greywacke, chert, conglomerate 8.3 km Late Prot. sandstone, dolomite, shale, limestone 1.7 km refs: 5,6,7	Downton-Ditton sandstone, conglomerate, siltstone 2 km refs: 8,9 Hecla Hoek U, carbonates Camb.-Ord. 1.2 km M, tillites, carbonates, greywacke, quartzite 7.1 km L, meta-volc., acidic & basic; quartzite, marble, meta-tilloid 11.5 km ref: 4
c) Provenance of sediments		
late Cenozoic	(Beaufort Fmn)[14] SE, E	
Oligocene-Miocene?		W (S)[21]
Eocene		
early Cenozoic	"local"[14]	E (N)[21]
Paleocene	(L. Cret. Isachsen Fmn: S[23])	E (N), NE (NW)[21,27]
Mesozoic	E, S (except certain Lower Triassic to Jurassic rocks: N, NW[14]) Triass-Jur.: S, E[16]	Jur.-Cret.: S?, SE? (E?)[8] N (W)[17] FREBOLD in 8 Mes.: W (S) Mes.-Tert. W (S)[19,8]
Permian, Carboniferous	in NW: NW[1,3] in SE: SE ("local")[1] "no source to N"[16]	
Devonian	W, NW[6] E, NE[22]	W (S)[17], E? (N?)[17] S (E)[2]
Late Silurian Early Devonian		W (S)[8]

Table 2 cont.

	Innuitian Region	Svalbard
Ordovician–Silurian	flysch: NW[15]	
Cambrian	NW[15]	
late Precambrian	SE margin: SE[5]	Hecla Hoek: "possibly a flanking . . . volcanic ridge": W (S) ref: 17

( ) – direction adjusted 90° to conform with meridian of northern Ellesmere Island – Peary Land.

	Innuitian Region	Svalbard
d) Tillite and "tilloid"	absent or not recognized	(c) In Polarisbreen Formation, ca. 800 m below L. Cambrian fossil horizon; late Precambrian (Vendian). (b) = Varangian tillite (15 km separate tillites) (a) meta-tilloid (tillite?) in Rittervatnet Fmn.; earlier late Precambrian. ref: 8,9
e) Main orogenies and peak metamorphism		Alpine ("West Spitsbergen"[20] Orogeny) E-W (N-S) compression; overthrusting, folding
	Eurekan (mid-Eocene to Oligocene)[14,28]	to E, NE (N, NW)[8] Miocene? post-Paleocene or -Eocene[9]
		Subhercynian or[8] Laramian? uplift;
	Ellesmerian (post-Famennian, pre-Viséan)[6] K-Ar determinations inconsistent[3]	Late Cretaceous
		Svalbardian Folding (Late Devonian)[8]
		Caledonian[8] (Ny Friesland Orogeny)[9] (Silurian[8]; post-Canadian, pre-Downtonian[9]) K-Ar } 430–420 my[12] Rb-Sr } 390–380 my
		? Pre-Caledonian event: ? early Cambrian or late Precambrian[9,12] K-Ar 600 my[12]

Table 2 cont.

	Innuitian Region	Svalbard
	Late Precambrian	
	Rb-Sr 742 my[11]	
f) Volcanic rocks	Basalt flows:	"Tuff-conglomerate":
	Upper Cretaceous[6];	Paleocene-Eocene[21]
	mid-Lower Cretaceous[6];	mid-Lower Cretaceous[8]
	lower Lower Cretaceous[6]	Barremian (?) volcanism[26] (mid-L. Cret.)
and/or	Bentonitic and tuffaceous layers: U. Cretaceous[29]	Diabase dikes:
	Diabase dikes: Mid-Cretaceous:	Berriasian (?) sills[26] (early L. Cret.)
		Early to Late Cretaceous?[8]
	K-Ar 102–110 m.y.[3]	mid-Cretaceous (100 m.y.)[25]
late, basic intrusions		Mid-Mesozoic: K-Ar ca 150 m.y.[12]
(diabase, dolerite, gabbro)		(Probably late Jurassic or early Cretaceous, from agreement between radio-metric and structural-stratigraphic data)[12]
		Distributed along S, SE (E, NE) trending fracture lines?[8]
	Post-Ellesmerian (early to mid-Mississippian?; trends NE, E)[3]	
		Caledonian (Silurian)[8]
		2 generations of metamorphosed dolerites in Hecla Hoek succession[10]
g) Lamprophyre dykes		K-Ar 309 m.y.[12]
h) Post-tectonic intrusions	Late Middle to Late Devonian? K-Ar 360±25 m.y.[3]	Silurian-Devonian boundary, Lower Devonian
(granite)		K-Ar, Rb-Sr: 400±20 m.y. or? slightly younger[12]
i) Synkinematic intrusions	Early to Middle Devonian[3,13]	

Table 2 cont.

	Innuitian Region	Svalbard
(granite, migmatite)	K-Ar 376±16 to 390±18 m.y.[13]	Post-Canadian, pre-Devonian K-Ar, Rb-Sr } ca 450–400 m.y.[12]
j) Basement	Northern boundary: gneiss>742±12 m.y. predates overlying metasediments and may be basement[11] Southern boundary: Aphebian, Canadian Shield (K-Ar ca 1735 m.y.)[18]	Existance of exposed basement doubted, or contentious[10]; 'Archean' not known.

Source references for comparative table

1. THORSTEINSSON 1974.
2. HARLAND 1969a.
3. TTETTIN 1972.
4. HARLAND and GAYER 1972.
5. KERR 1967b.
6. THORSTEINSSON **In**: THORSTEINSSON and TOZER 1970.
7. DRUMMOND 1973.
8. ORVIN 1940.
9. HARLAND 1961.
10. HARLAND, WALLIS, and GAYER 1966.
11. SINHA and FRISCH 1975.
12. GAYER et al. 1966.
13. FRISCH 1974.
14. TOZER **In**: THORSTEINSSON and TOZER 1970.
15. TRETTIN 1971.
16. MENELEY et al. 1975.
17. HARLAND 1959.
18. STOCKWELL 1970.
19. DE GEER 1919.
20. HARLAND 1969b.
21. KELLOGG 1975.
22. EMBRY 1976.
23. ROY 1974.
24. PARKER 1967.
25. LIVŠIC 1974.
26. HARLAND 1973.
27. BIRKENMAJER 1972.
28. BALKWILL, BUSTIN, HOPKINS Jr. 1975.
29. MIALL 1975.

knowledge of the facies distribution in the two geosynclines is available. On the other hand, certain distinctive rocks such as tillite (see Table 2d) or gypsum-anhydrite would be most useful if they could be identified in the two areas. Tillite has not been recognized in the Canadian islands, however (although it occurs in Peary Land, northern Greenland – see DAWES and SOPER 1973, p. 121), nor evaporites in early Svalbard rocks.

Major orogenic events in adjacent regions should be reflected in the stratigraphic record of each region. On this basis, it appears that Svalbard and the Innuitian Region were not contiguous (Fig. 5; Table 2e): except for the Svalbard episode of folding, orogenies in the two regions have been consistently out of phase since late Precambrian time. The Svalbard folding does coincide with part of the Ellesmerian Orogeny and these tectonic events in each area ushered in similar periods of mixed marine and continental basinal deposition (see Fig. 5).

The emplacement of intrusions (diabase, gabbro, granite, etc.) similarly might coincide in time in related regions, although it can be argued that because intrusions are known to vary in time of emplacement they are not a reliable criterion. In any event, the apparent ages of syntectonic and post-tectonic intrusions (Table 2h, i) suggest lack of contemporaneity, although limits of analytical error for certain ages allow slight overlaps. Late basic intrusions (diabase, gabbro), however, appear to have been contemporaneous (Table 2f), although the dates of the intrusive events in Svalbard are uncertain.

Basement rocks are recognized or suspected in both flanks of the Franklinian Geosyncline, but the existence of an exposed basement in Svalbard is questioned (Table 2j) so that comparison of such ancient terrains is not yet possible.

CARBONIFEROUS AND LATER TIME

Uplift and erosion took place in latest Devonian time both in the Innuitian region and in Svalbard. In both regions, this was followed by accumulation of continental-littoral sediments and by a marine incursion in Carboniferous time. Basal clastic rocks in each basin are succeeded by mixed sandstone, limestone, and evaporite beds, then by thick shale-sandstone sequences with some coal. Thus, the sedimentary columns are broadly similar although the upper parts differ in details of continuity and in thickness (see Table 2a, b). Particularly notable are similarities in the Lower and Upper Carboniferous successions; indeed, certain units in the two areas have been described as almost identical on a bed-by-bed basis in terms of lithology, age, and thickness (NASSICHUK 1975, p. 4). HARLAND (1965, 1969a, 1969b) and others (WILSON 1963) have proposed, on the basis of the evident similarities, juxtaposition of Svalbard and Ellesmere Island – northern Greenland in late Paleozoic and Mesozoic time.

Basalt flows, which can be contemporaries of basic intrusions, are present in the sedimentary column of the Sverdrup Basin, where early Early, mid-Early, and early Late Cretaceous times are represented. In Svalbard, "tuff-conglomerate" is mentioned by ORVIN (1940) in beds of about mid-Early Cretaceous age.

Perhaps especially significant is a similarity in Mesozoic tectonic history in Svalbard and the Sverdrup Basin: in both areas, a Cretaceous period of basic intrusion and (?) volcanic effusion was associated with a widespread marine inundation, in effect a dramatic widening (spreading of the shorelines due to depression of the land) of the area of the Mesozoic basins (see Fig. 5, Table 2b, 2f). The crustal tension and regional downsinking represented by the rocks noted presumably have a common origin: the beginning of rifting that eventually separated the basinal regions.

TECTONIC CONNECTIONS BETWEEN SVALBARD AND INNUITIA

The remarkably close correspondence of Carboniferous and younger units in the two regions serves to emphasize the differences between older successions. The similarities of the stratigraphic sections of one geological period suggest a close linkage of the basins at that time; by the same token, the contrasting thicknesses and lithologies of the older periods suggest that the earlier geosynclines of the Innuitian and Svalbard regions occupied distinctly different sedimentary-tectonic sites.

The suggestion of close connection in later times but distinct separation in earlier times appears enigmatic. The enigma perhaps may be resolved, however, by supposing that the two geosynclines were a rudely matched "pair" of sedimentary basins separated by a geanticlinal ridge. Such a positive anticlinal belt may have been the "borderland" required by several authors for paleogeographical and sedimentological reasons; a northwestern, rising orogenic welt in the Innuitian region was named the "Pearya geanticline" by TRETTIN (1971) after SCHUCHERT's earlier (1923), hypothetical borderland, "Pearya" (see Fig. 4B, 6 iv, v).

A relatively positive orogenic welt lying between the Hecla Hoek and the Franklinian basins would have been a source of clastic sediments for both basins during certain times. Deduced directions of sources of sediments, as reported in the literature (see Table 2c) and noted below, tend to support such a supposition.

The comparison of source directions in the two regions is complicated by three main factors: a) the change in nominal azimuth direction when Svalbard is moved to the meridian position of northern Ellesmere Island (for example); b) uncertainty or disagreement among various authors in the interpretation of the direction of the paleo-sources; and c) uncertainty as to disposition of the two basins before drift and whether adjacent parts of the basins are being compared. The first factor is easily adjusted, while the second and third must await refinement or agreement among researchers.

The third factor is a critical one: Svalbard probably was adjacent to Peary Land and not to Ellesmere Island. This is apparent from the geometry of the landmasses (see Fig. 7) and from evidence of sedimentary provenance noted by KELLOGG (1975) (see Table 2c). The question then arises: how consistent is the geology along the axial direction of the Franklinian trough (that is, from northern Greenland to Canada)? In answer: there are structural differences, already noted; but the sedimentary trends do continue from Canada through Peary Land (from personal observation; and see KERR 1967a; DAWES 1973, 1976; DAWES and SOPER 1973). From the consistency and continuity of both sedimentary and structural trends in the northeastern part of the Franklinian–Ellesmerian region it appears that the hazards of speculation here are at worst no more severe than those typically weathered in such exercises.

The apparent relationships between basins of deposition and source areas of sediments are reviewed in the following paragraphs (see Table 2c). Note that directions for Svalbard are adjusted counterclockwise 90° to conform to the longitude of northern Ellesmere Island–Peary Land region; thus, a "westerly source" reported in the literature is stated here as *southerly*.

i) In late Precambrian time, a source of sediment lay to the south (for marginal deposits) in the Innuitian region, and to the south (for volcanic and clastic geosynclinal deposits) for Svalbard. These directions apply to different facies of the basins and fit the model proposed.

ii) In early Paleozoic (pre-Carboniferous) time, directions of transport evidently were opposed: that is, from the north or northwest for the Franklinian Geosyncline and from the south or east for the Hecla Hoek succession.[1]

iii) Sedimentation in Permian and Carboniferous time began in both regions in scattered, small basins. Source areas in the Innuitian region were to the northwest in the northwestern part (although this is uncertain) and to the southeast or "local" in the southeastern region. No reported directions have been found by the writer for Svalbard.

iv) Sediments were derived mainly from the south in Mesozoic time in Svalbard, with some from the west, and possibly from the east. In the Innuitian region, source directions to the east and south are reported, as are sources to the north and northwest for certain Lower Triassic and Jurassic rocks. H. R. BALKWILL (pers. comm.), however, considers that there were contributions of sediment from the northeast and west, and possibly from the northwest, throughout Mesozoic time in the Sverdrup Basin.

v) Sedimentary sources were clearly in the north or northwest in Svalbard in early Tertiary time. In the Innuitian region, source directions are often reported as "local" or "unknown". Recent studies by BALKWILL (pers. comm.), however, suggest that early Tertiary beds on western Ellesmere and eastern Axel Heiberg Islands had sources to the north and west.

If one assumes that the two regions were juxtaposed, a picture emerges of a linear Tertiary basin with sources in the north or northwest (including the Barents Shelf).

A new sedimentary cycle in Svalbard, however, beginning in late Eocene time, approximately, gives evidence of a southerly source, opposite to that of the underlying beds. This event can be taken to represent the main tectonic phase of Tertiary time for this region (see KELLOGG 1975).

Can these various directions of source or direction of transport of sediments be accommodated in a single tectonic model?

A TECTONIC MODEL FOR SVALBARD AND INNUITIA

The model proposed here, as already noted, assumes that the late Precambrian and early Paleozoic geosynclines of Svalbard and Innuitia were adjacent, or "paired", separated by an intermittently positive tectonic welt. A geological history based on such a supposition might be somewhat as outlined below (see Fig. 6). The relationships between the Svalbardian–Franklinian geosynclines and others, such as the nearby Caledonian geosyncline, will be taken into account in subsequent paragraphs.

i) Lower Hecla Hoek time: beds of Lower Hecla Hoek deposited, with the region of the present Barents Shelf providing most of the sediment; volcanic vents along the future Pearya orogenic welt may signify an island arc and are the earliest recorded indication of a major linear structural weakness; state of Franklinian Geosyncline uncertain (Fig. 6i).

[1] Sources to the east and northeast are proposed by EMBRY (1976) for Devonian rocks of the Franklinian Geosyncline, based on paleocurrent indicators and on the distribution of sedimentary facies. It is here considered that these paleocurrent directions must represent basin-longitudinal transport.

Was the Barents Shelf a shield area? Geophysical data show the crustal structure to be continental, with a heterogenous basement of folded structures of various ages (Ostenso 1974, p. 759). Tkachenko et al. (1973, p. 342) describe the "Barents stable region" as outcropping in Nordaustlandet (northeastern Svalbard), where a granite-gneiss complex is considered pre-Riphean (pre-latest Precambrian). Uncertainties exist, but the entire "Barents plate" is assumed, as a working hypothesis, to be pre-Baykalian (older than the latest Precambrian orogeny). For the purposes of this paper, the Barents plate is assumed to be an isolated Precambrian platform, or microcontinent.

ii) Proto-Pearya: rising isotherms (=orogeny) result in intrusion, deformation(?), and metamorphism of Lower Hecla Hoek succession; uplift to provide early source of detritus to nascent Franklinian Geosyncline. Radio isotope age, ca. 742 m.y. (Fig. 6ii).

iii) Middle Hecla Hoek time: middle part of the Hecla Hoek and lower part of the Franklinian sequence deposited; proto-Pearya perhaps subsides, and the shield areas of the North American and Barents plates provide detritus. (Fig. 6iii).

iv) Late Precambrian to Cambrian time: Pearya rises as an orogenic welt shedding debris to north and south, respectively to the Svalbardian and Franklinian basins. Continental glaciation in the (mountain?) regions of northern Greenland, Svalbard, and? Pearya results in deposition of tillite (now preserved in Svalbard and in southern Peary Land; see Table 2d; Fig. 6iv).

v) Cambrian to Middle Ordovician time: continuing subsidence of the Svalbardian and Franklinian geosynclines and accumulation of clastic and carbonate sediments and evaporitic deposits (Fig. 6v).

vi) Late Ordovician to Early Devonian time: orogeny begins, and advances from north to south; Caledonian orogeny begins in Svalbard, during which syntectonic intrusions (post-Canadian, pre-Devonian) are emplaced; uplift results in deposition of a clastic wedge southward into the Franklinian Geosyncline (Fig. 6vi).

vii) Devonian: continued orogenic activity; Ellesmerian orogeny results in deposition of molasse (Old Red) deposits in Svalbard from debris shed northward from a rising "Franklinia"; early–middle Devonian synkinematic intrusions emplaced in Franklinia. The recently identified Frasnian clastic beds of northern Ellesmere Island probably were continuous with the molassic beds of Svalbard (Fig. 5, 6vii).

viii) Late Devonian: Ellesmerian orogeny widens to fold Svalbard molasse slightly (=Svalbard Folding) (Fig. 6viii).

ix) Carboniferous to early Tertiary: regional downsinking along the axes of earlier geosynclines; eventual general down-sinking resulting in widespread onlap of Cretaceous sediments. *Either* several separate basins exist, somewhat as beads on a string, *or* a linear depression is formed to receive sediments of this period (see Fig. 6ix; Sverdrup–Wandel Sea–Spitsbergen basins). If the several Carboniferous and younger successor basins were connected (as seems likely), they nevertheless probably were divided by "sills" or "highs" such as that determined for the northwestern margin of the Sverdrup Basin (see Meneley et al. 1975). The "highs" are represented schematically by basinal highs in Fig. 6ix).

The Carboniferous–Permian linear depression, it is suggested, crossed the Barents Shelf to the Urals–Moscow Basin–Donitz Basin of the U.S.S.R. (see DUTRO and SALDUKAS 1973, NALIVKIN 1973, p. 192). Former connection between these polar basins and the Atlantic (East Greenland–North Sea) linear Carboniferous to Cretaceous troughs is uncertain; perhaps they were not joined until a younger stage.

It is possible that the Canada Basin opened during an early (latest Paleozoic or early Mesozoic?) part of this stage (discussed in a later section). According to MENELEY et al. (1975), the northwestern margin of the Sverdrup Basin, earlier a platform region, in Triassic time was overwhelmed by clastic debris from the south. The termination of the "carbonate barrier" or platform stage of the northwestern margin may signify the birth of the Arctic Ocean in that region.

x) Early Tertiary: orogeny and rifting along the de Geer line. En echelon folds and strike-slip faults with compression to produce overthrusts; a "strike-slip orogenic belt" (as termed by LOWELL 1972) results (Fig. 6x). The resistant Pearya Complex is thrown up as horsts and in a later stage, when Greenland and Svalbard are separated, grabens form. The opening of the North Atlantic began in late Paleocene time (63 m.y. ago, according to PITMAN and TALWANI 1972); this marks the beginning of motion between the Eurasian and the Greenland–North American plates, and is about the time of the early phases of the Eurekan Orogeny in northern Ellesmere Island (see CHRISTIE 1976). The main phase of the Eurekan Orogeny took place somewhat later – usually described as mid-Cenozoic time (see THORSTEINSSON and TOZER 1970, p. 585); the model of PITMAN and TALWANI (1972, p. 638) suggests a "collision" between Svalbard and northern Greenland at around 47 m.y., or mid-Eocene time. Both pre-orogenic (as young as Paleocene) and syn-orogenic (late Eocene or Oligocene, or even Miocene?; see LIVŠIC 1974; HARLAND 1975a) clastic beds were deposited in Svalbard. Eocene beds in northern Ellesmere Island have been affected by thrust faults, and molassic beds at the top of the Tertiary section may be equivalents of the syn- and post-orogenic clastic beds of Svalbard (see CHRISTIE 1976).

The late Precambrian to mid-Paleozoic sequence of events listed above is proposed to provide a plausible or possible model for the Franklinian and Svalbard geosynclinal rocks. Subsequent events, such as the deposition of strikingly similar strata and fauna in the Carboniferous–Permian basins of the Arctic, are better documented. DUTRO and SALDUKAS (1973), for example, show by paleogeographic maps (for Early and Late Permian) that a linear sea joined the Sverdrup Basin and the "Perm Basin" (Urals–Moscow Basin–Donitz Basin) of western U.S.S.R. Similarly, VANN (1974, Fig. 2), in demonstrating a sophisticated "fit" of Greenland and western Europe, has shown that a linear Mesozoic basin may have extended northwest from the North Sea; such a basin would almost certainly be continuous with the Wandel Sea Basin (DAWES and SOPER 1973), probably as early as Carboniferous time.

Livšic (1974), however, concluded from a "block-faulting" model and sedimentological evidence that Svalbard was an archipelago in Paleogene time and that the Polar Tertiary sedimentary province comprised relatively small, separate, or "segmental" basins.

THE DE GEER LINE AND OTHER LINEAMENTS

The supposed dextral translatory movement of some 750 km along the major shear zone and transform fault, the de Geer Line (see Wegmann 1948, p. 21) is an important element in the proposed model for the Franklinian and Svalbard geosynclines. Is there direct evidence for such a major shear zone in Tertiary or earlier time? Such evidence might be geomorphological, geophysical (the line is submerged in ocean water), or sedimentological. If the shear zone extends onto continental areas, then major displacement of landward structures may be identifiable.

The chief geomorphological evidence for transcurrent movement is the large-scale lineament itself: the alignment of continental edges along a small circle of the globe (see Fig. 2). This feature was noticed by de Geer and named after him by Wegmann (1948).

The de Geer Line has long been considered a possible path of continental displacement, and Wegmann, in reconstructing pre-drift land masses, suggested a northern Greenland–northern Ellesmere source for the Tertiary sediments of Svalbard. De Geer's Line, on a globe or a polar projection, indeed conforms convincingly to the movements proposed. The line, at least in the Greenland Sea, is a dextral transform fault (Wilson 1965) rather than a simple transcurrent displacement, in terms of contemporary tectonic theory.

Geophysical data confirm the supposed transform fault: earthquakes have been reported along the fault but not along the physiographic extensions, the now quiescent traces of early breaks between continental masses (see Wilson, 1965, p. 344).

The sedimentological evidence for former juxtaposition of Svalbard and Peary–Grant Land has been reviewed in preceding paragraphs: a westerly (southerly, at the longitude of Peary and Grant Lands) source of sediments in Svalbard in late Eocene time is required from field evidence.

The conspicuous linear feature, Nares Strait, which cuts across the Innuitian region and is an important structural element, was described earlier. Displacement along this lineament of up to 150 km since early Tertiary time is required in certain reconstructions based on geophysical data: for example, that devised to accommodate an oceanic crust in northern Baffin Bay (C. E. Keen et al. 1972). From other geophysical evidence, however, one is cautioned against the assumption that oceanic crust floors certain parts of Baffin Bay; Davis Strait, an area particularly critical to "pre-drift" reconstructions, may be underlain to a considerable extent by continental crust (Grant 1975). As suggested earlier, the net movement along the Nares lineament may be small, and it is presumed, in the context of the model proposed in this paper, that the lineament is unimportant.

Two submarine plateaus, the Yermak, off Svalbard, and the Voring, off

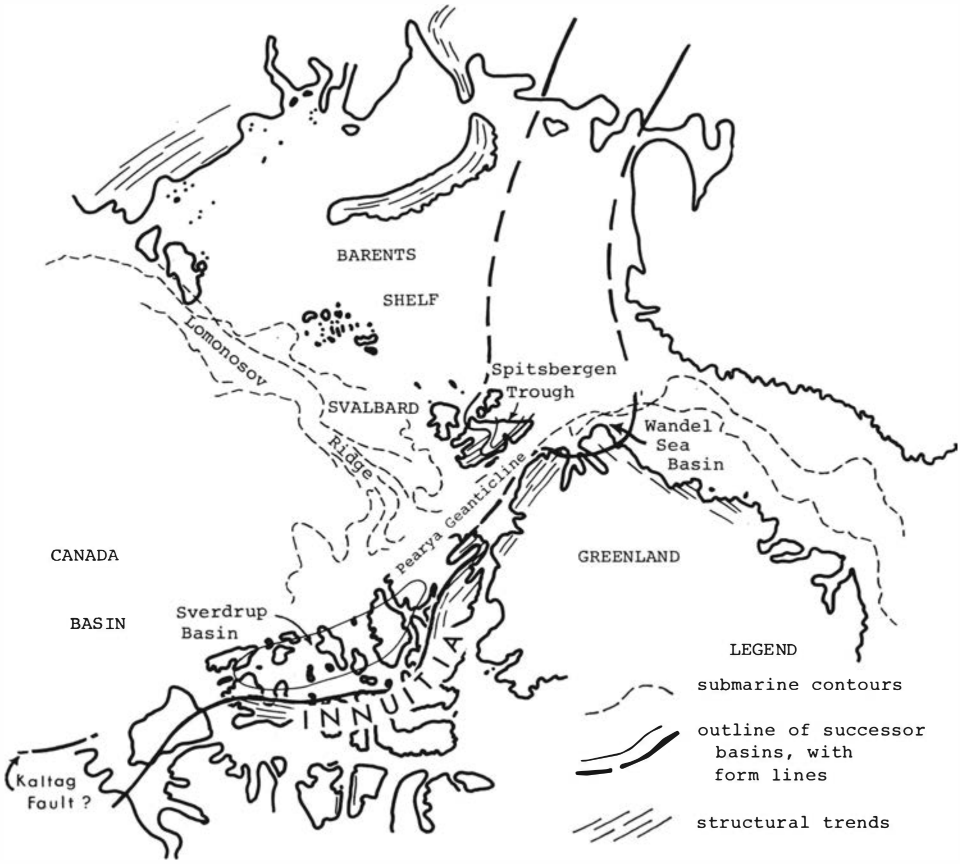

Fig. 7. *Possible pre-drift configuration, Innuitia and Svalbard.*

central Norway, were noted by Birkenmajer (1972, p. 214) as "not fitting the jigsaw puzzle" of continental drift and therefore as being, probably, of late Tertiary age. The close spatial relationship of both plateaus to fracture zones (transform faults) was taken to suggest a probable presence of volcanic rocks.

The Yermak Plateau appears to have a mirror partner on the other side of the Nansen Ridge (Fig. 2): the Morris Jesup Plateau off the north coast of Greenland (see Heezen and Tharp, 1975). The composition and structure of these plateaus are critical in an interpretation of the history of this part of the Eurasian Basin. For example, the presence of continental crust beneath the plateaus would be evidence that Greenland had, after all, moved northeastward along a Nares Strait transcurrent fault. More probable is the possibility that a superficial "pile" of material was deposited in Tertiary time, during or after partial opening of the Eurasian Basin; continued spreading of the sea floor could separate such a deposit into two "plateaus". The volcanic rocks of Kap Washington (northern Greenland) are probably Tertiary in age (from isotopic age determinations – approximately 35 m.y. indicated – and structural relationships) and certain geophysical data may indicate an offshore extent (Dawes and Soper 1971; Dawes 1973); such a suite of rocks may represent a young, oceanic volcanic pile. The site of the eruption may be related to the former junction of Nares Strait, the Arctic Mid-oceanic Ridge, and the Nansen Fracture Zone (of the de Geer Line). This supposed former junction would have been a "triple junction" of the FFR (Fault-Fault-Ridge) type (McKenzie and Morgan 1969). If such a junction existed, it evidently became unstable and movement ceased on the Nares transcurrent fault at an early stage. Both the petrographic character and the tectonic siting of the volcanic rocks of Kap Washington are similar to those of Iceland: basalt, andesite, rhyolite, and breccias at the junction of oceanic ridges or lineaments (see Dawes and Soper 1970; Einarsson 1973).

A possible westward extension of the de Geer lineament figures in tectonic models that provide for an "opening" of the Arctic Ocean basin, as does the relationship of the fold belts of northern Alaska and Yukon to the Cordilleran and Franklinian Geosynclines. Several hypotheses have been erected to explain the geometry of these regions; examples are: subsidence of a boreal landmass into the Arctic Ocean (Eardley); and rifting and rotation of Alaska away from the Canadian islands (Carey). Churkin (1969, 1972, 1975) showed that the Canada Basin may be an ancient ocean, rimmed from Greenland to eastern Siberia by an early Paleozoic geosynclinal belt. The Alpha–Mendeleyev Ridge as an inactive mid-ocean ridge was discussed by Hall (1970); three successive periods of arctic ocean-floor spreading, none older than Jurassic, were suggested by Tailleur (1973); and folding of the Franklinian Geosyncline in mid-Paleozoic time by collision of an Asian, "Kolymski plate" with the North American plate was proposed by Herron, Dewey, and Pitman (1974).

A possible westward extension of the de Geer lineament is the Kaltag Fault of northern Yukon and Alaska (Norris 1974). This major fault zone has been traced northweastward from Bering Sea to the Canadian border, where continuations of the fault, curving northward, have been mapped. A possible extension of the Kaltag Fault across the Beaufort Shelf to the southern edge of the Canada Basin (see Fig. 7) was suggested by Norris, who noted a marked kink in the Bouger anomaly field of the shelf. Norris suggested the Kaltag Fault may be a junction between continental plates: it cuts through the Cordilleran orogenic system from Bering to Beaufort Seas, it has a displacement measurable in several tens of kilometres, and its sense of movement is right-lateral and thus compatible with the supposed differential motion of the plates in Tertiary time. Large-scale motion on the fault, however, is supposed, from geometric data, to have ceased by the end of the Cretaceous; subsequent westward drift of the by-then fused North American plate was presumably accomplished through right-lateral movement along the de Geer fault. Northeastward extension of the Kaltag structure has been suggested on the basis of a belt of elliptical-shaped, strong, positive Bouger and free air anomalies that lies along the continental margin northwest of the Canadian islands. Trettin (1972, p. 151) noted that the belt continues, apparently uninterrupted, past the Nares Strait lineament. In a recent analysis, however, Sobczak (1975a; 1975b) suggested that most of the "elliptically-shaped, positive, free-air gravity anomalies" can be explained by assuming the presence of prograded wedges of

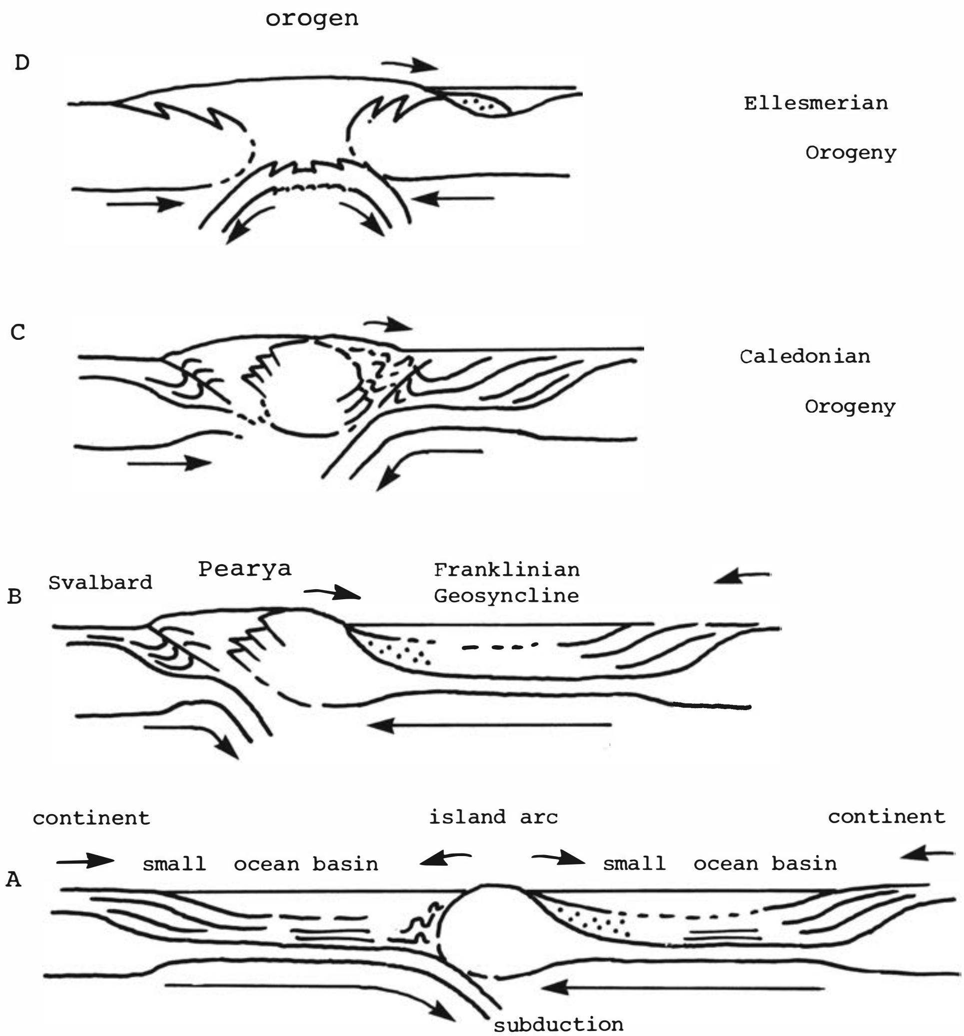

Fig. 8. *Diagrammatic representation of two small ocean basins flanking an island arc* (*Diagrammatic style after* DEWEY *and* BIRD *1970a, 1970b*). *Arrows indicate directions of sedimentary and tectonic transport.*

Tertiary and younger sediments acting as uncompensated loads on the crust at the continental margin. The edge of the continental crust becomes distinctly more abrupt in the new model, which is thus the more compatible with a faulting or rifting origin for the edge.

The Ellesmerian folds of the western Queen Elizabeth Islands are mainly buried near the continental margin, but from their limited western exposures (on Melville Island) they are west-trending and appear to be truncated by the continent-margin. Were northern Alaskan structures perhaps once continuous with those of the Canadian Islands? The early Paleozoic rocks of northern Alaska have long been compared with those of the Franklinian Geosyncline (MARTIN 1959; CHURKIN 1969, 1975) and interpreted as part of a circum-Canada Basin geosynclinal belt. An approximation of the Paleozoic position of northern Alaska might be obtained by northeastward translation and rotation of a "Bering Sea Plate" along some zone such as the Kaltag–de Geer lineament[1] to reverse sinistral movement that may have taken place in post-Ellesmerian (late Paleozoic or Mesozoic?) time (Fig. 9D, E, F). Such shearing would be an early stage of opening of the Arctic Ocean, with a probable spreading centre along the Alpha Ridge (see CHURKIN 1972; GALLAGHER 1973). Northwestward thickening of Carboniferous carbonate sediments over the northwestern, marginal rim of the Sverdrup Basin (MENELEY et al. 1975) may be evidence that a Canada Basin was present at that time.

THE GEOSYNCLINAL CONCEPT AND THE MODEL FOR SVALBARD–INNUITIA

The model here proposed for Svalbard and the Innuitian region is one in which paired geosynclinal belts are separated by a geanticlinal belt. At least substantial parts of the combined belts lay either within a continent (now broken up) or between two continental masses.

How well does the proposed model for Svalbard–Innuitia conform to the recently elaborated theory of plate tectonics (see DEWEY and BIRD 1970a; 1970b)? TRETTIN (1972, p. 165) has remarked on the general plausibility of the plate tectonic explanation for the Innuitian region, and VOGT and AVERY (1974, p. 109–112) have reviewed the possibilities and probabilities of various forms of plate-tectonic origin, in the light of available geophysical data, for the Canada Basin and the continental margins of the Arctic. TRETTIN noted that the early history of the mobile belt may be an example of plate tectonics in a "small ocean basin" (a term applied by DEWEY and BIRD to small oceanic areas lying between island arcs, between arcs and continents, or between two continents). Among the models figured by DEWEY and BIRD (1970a, p. 633), the "small ocean basin" lying between two continents appeals most to the present author for the Svalbard–Innuitia regions; the "paratectonic orogen" arising from this arrangement of tectonic features (op. cit., Figs. 4E, G) should have an inherent symmetry that conforms well to the model proposed in this paper. An improvement on this model might be that of an island arc lying between two continents. In this case (Fig. 8A, this paper), two small ocean basins flank the island arc. Orogenic deformation of one or the pair of geosynclines would occur when one of the continental masses collides with the arc (Fig. 8B); later, collision of the second continental mass with the older orogen would result in a second, or progressive orogeny (Fig. 8C). This model provides: a) an early tectonic welt; b) progressive orogeny; and c) symmetry in the resulting final, paratectonic orogen.

A yet more complex variation of small ocean basins might be suggested: that of two island arcs, eventually caught between approaching continents. Collision of the island arcs could result in the formation of an early orogenic welt (a proto-Pearya Geanticline) while the paired geosynclinal basins still existed,

[1] The identified movement on the Kaltag structure is right-lateral, as noted, opposite to that required by the proposed reconstruction of Figure 9. Left-lateral movement may have taken place at an earlier time, or along some similar but unrecognized zone.

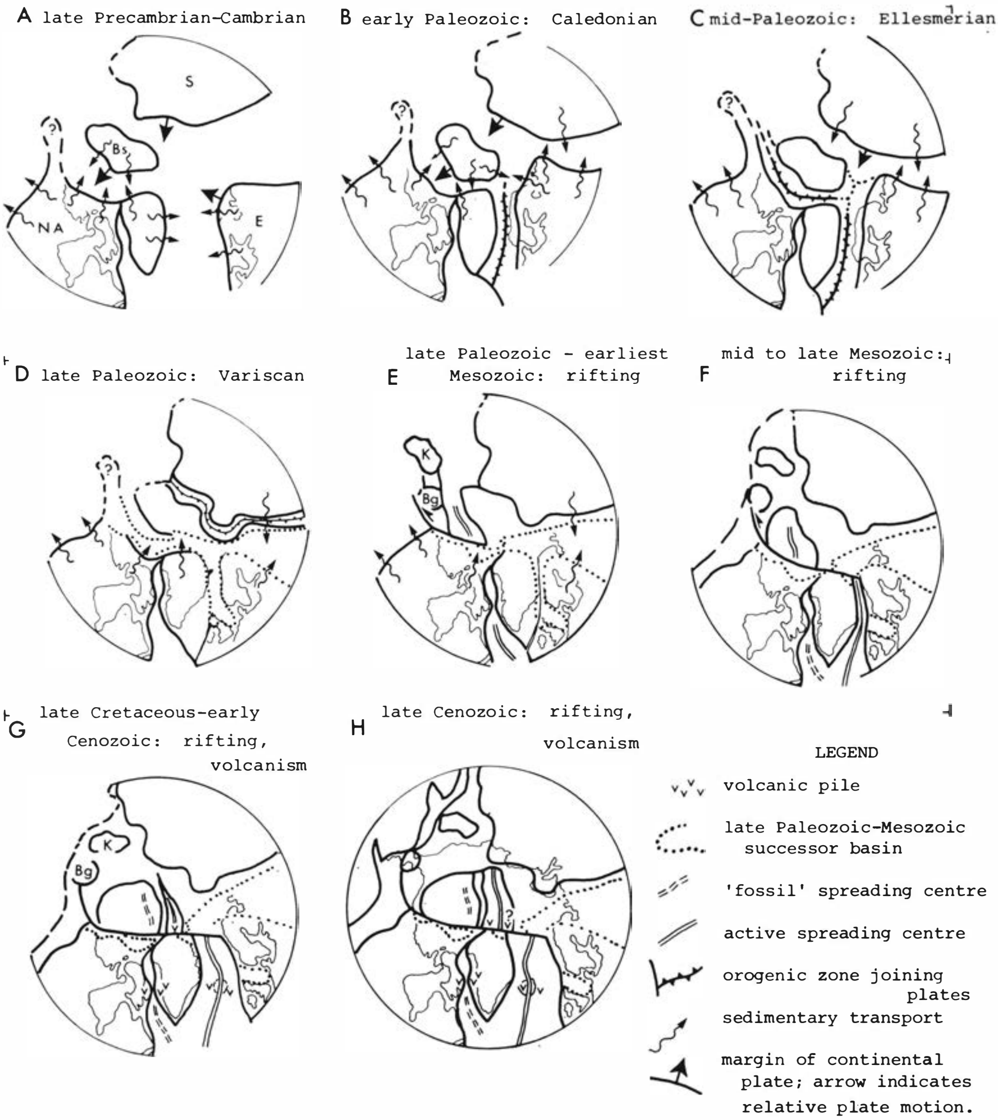

Fig. 9. *Stages in a hypothetical reconstruction of continents of the boreal region. For geographical nomenclature see Figure 2b. NA – North American platform; S – Siberian platform; E – Eurasian platform; Bs – Barents splinter; Bg – Bering splinter; K – Kolymski splinter.*

relatively undeformed, to receive sediments and volcanic rocks. Subsequent collapse of first one geosyncline, then the second of the pair, would result in the final, extensive, symmetric paratectonic orogen.

A review of the history of thought on geosynclines shows that both the concept of linear, geosynclinal belts separated by intermittently positive tectonic welts, and the concept of mobile belts between continental masses have recurred since about the turn of the century (see GLAESSNER and TEICHERT 1947). HAUG (in 1900), influenced by the tectonics of the Mediterranean area, defined geosynclines as mobile belts between rigid continental masses. HAUG evoked a "median geanticline" as a "tectonique embryonnaire", or earliest indication of crumpling of the geosyncline. Geanticlinal ridges (lying between "furrows" within the geosyncline) formed a prominent part of AUBOUIN's (1965) careful review of the concept of geosynclines. He also noted and figured some tectonic characteristics of the "complex geosynclines" that may develop when two continents with marginal geosynclines are sufficiently close: a "median zone" of eugeosynclinal ridges may form. This zone would contain the central massifs, or "zwischengebirge" earlier described by L. KOBER. The median zone of the geosynclinal complex, it was supposed, would be affected early by orogenesis, the orogenic activity "diverging" in both directions toward the miogeosynclinal and foreland regions. It was not considered that geanticlinal ridges are necessarily continuous in the median zone: where the ridges die out, then a median, eugeosynclinal furrow may remain. Such geosynclinal complexes, AUBOUIN stated, give rise to the "classic (mountain) chains of bilateral symmetry".

The model here proposed for the combined Franklinian Geosyncline–Pearya Geanticline–Hecla Hoek geosyncline contains features, including bilateral symmetry and a median geanticline (see Fig. 6v, vi, vii), that recall some of the ideas alluded to above. The Franklinian–Svalbard region was, according to this model, one of early continental collisions and of "Mediterranean" orogenic type.

The preferred models, described above, require small ocean basins between continents and rifting of the subsequent orogen. This scheme contrasts with the often-suggested model in which the Arctic Ocean (an ancient ocean) was rimmed by several subduction zones (e.g. HALL 1970, and see VOGT and AVERY 1974, p. 112). Rather, as with the present margins of Greenland, Norway, and the Barents Shelf, the existing borders of the Canada Basin are taken (after VOGT and AVERY, p. 112, and GALLAGHER 1973) to be rifted margins formed in the initial stages of sea-floor spreading at ancient times. The continent-margin from about northern Ellesmere Island east is matched by the western edge of the Barents Shelf (including Svalbard) (see Fig. 2), while that to the southwest is presumed to be represented by northern Alaska and the "Bering plate" (Bg in Fig. 9F).

The question remains of the relationship of the successor, Sverdrup Basin, with its large size and substantial depth apparently along the axis of the Franklinian Geosyncline. This basin and its extension or contemporary basins appear to conform to KAY's (1951) *epieugeosyncline* ("above" a eugeosyncline: elongate, relatively non-volcanic; sediments derived from the older, relatively immobile orthogeosynclinal belt). However, some aspects of the geometry and of the provenance of sediments of the Sverdrup Basin make it a partial misfit in this category: a large part of the sediments may have been derived from the craton, and the depth of fill is of an order equal to that of the earlier geosyncline. A *taphrogeosyncline* or rift-basin assignment was suggested by MCCROSSAN and PORTER (1973) on the basis of the deep fill and the very rapid basinward thickening at the margins. Although there are no identifiable major, basin-margin faults (that is, that could account for the basin's depth in a few simple steps), there are two lines of evidence that tend to confirm that faulting has played an important part in the development of the Sverdrup Basin: i) the northwestern "rim" of the Sverdrup Basin appears as a faulted or horst-form structural "high" in seismic sections of that part of the basin margin (see MENELEY et al. 1975); ii) early deposits of the Sverdrup Basin include substantial amounts of evaporite and marginal units of red-weathering, coarse, terrigenous clastic rocks; such a suite of rocks is generally taken to be characteristic of fault-bounded basins with restricted circulation. (Such a fault-origin for the entire series of successor basins, noted below, is not implied at this time, and no faulting is shown in Figure 6ix).

The Sverdrup Basin is a substantial and long-lived sedimentary basin that subsequently was more or less deformed by an important (the Eurekan) orogeny. In spite of the distinctive characteristics of great size and longevity, however, the Sverdrup Basin can be taken as a "successor basin" in the Innuitian orogenic system, and can be grouped with similar, if smaller, successor basins between Svalbard and Alaska: e.g. the Carboniferous to Tertiary basin of Svalbard (KELLOGG 1975), the Wandel Sea Basin of northern Greenland (DAWES 1973, p. 131), certain successor basins with "molassoid" successions in the Mackenzie region (YORATH and NORRIS 1975), and the Colville Geosyncline of northern Alaska (GRANTZ et al. 1975) (see Fig. 8D). These basins are perhaps best described merely as "post-orogenic basins" in the spirit of P. B. KING's simple terminology (KING 1959).

Certain distinctive tectonic characteristics of the basins here described as successor basins of the Innuitian region may be noted (see Fig. 3a, 3b): i) marked depocentres lie inside the continental margin; ii) a prominant basement high or arch lies near or along the continental margin (the arch, however, is covered by at least the younger beds of the basinal fill); iii) the detritus was mostly transported from the craton, evidently filling the basin and prograding across the continent-margin "high". Thus, the successor basins of the Innuitian region are tectonic depressions within the continent, and there is an apparent positive tendency along the continent-margins separating the successor basins from the adjacent ocean. The formation of the cratonic basins may be due to crustal distension. In tectonic position and relationships the successor basins are thus similar to the grabens, figured by DEWEY and BIRD (1970a, Fig. 1B, C), that lie within the newly-formed edge of a continent being separated by an expanding ocean. Faulting, however, apparently played a part only in the early stages in the case of the Sverdrup Basin, the trough perhaps having formed through faulting at depth, with "drape" or warping of beds taking place in the upper levels. Yet unexplained is the scale of the downsinking in the Sverdrup Basin – locally matching that of the earlier geosyncline (see Table 1). One can suppose that massive crustal thinning took place, although the mechanism for this (mantle convection?) is unknown.

Essentially this model for basins of "flyschoid and mollassoid" sediments along the northern continental rim was proposed, and tested against geophysical results, by YORATH and NORRIS (1975, Fig. 13). In their model, however, another series of (smaller) linear basins lies to seaward (but still landward of a continent-edge uplift) of the rim of the Sverdrup Basin. The northern rim of the Sverdrup Basin is considered by these authors to be a positive tectonic feature related to rifting along the northwestern edge of the Queen Elizabeth Islands. The rifting began perhaps as early as Triassic time. The foundering of the Sverdrup Basin is supposed to have followed a period of relatively slow subsidence in the Carboniferous, during which time subcrustal mantle transfer may have been initiated.

A tectonic history of the boreal continental margins as conceived in the preceding sections will be summarized below. Tectonic reconstructions to account for a history of northernmost North America and the Svalbard regions, however, inevitably necessitate suppositions for adjacent regions of the North Atlantic and Arctic oceans. These suppositions are stated below in order to complete a picture but, for economy of words, justification or support for all of them will not be attempted here.

i) A setting for late Precambrian time may have been as follows (see Fig. 9A): three large platform areas and several smaller continental "splinters" are separated by oceanic areas (the splinters perhaps derived from a preceding continental breakup); the fragments of continental material include the North American, Siberian, and Eurasian platforms and the Barents, Bering, and Kolymski splinters, or smaller plates. The proto-oceans between the fragments are presumed to have been shrinking, and the three platforms approaching one another. (The question of the time of separation of the subcontinent, Greenland, from the North American platform is not considered here and the Labrador Sea–Baffin Bay "opening" is left, unclosed, in the diagrams.)

ii) The Caledonian and the Franklinian geosynclines accumulate sediments from the continents and, as the continental platforms approach one another (Fig. 9B), sediments and volcanic material accumulate as proposed in the scheme of plate tectonics of Dewey and Bird 1970b). The Caledonian Orogeny represents the collision of the North American and Eurasian plates in early Paleozoic time. The fit of these plates follows that of Vann (1974), which is a modification of the earlier proposals of Bullard et al. (1965). Sedimentation continues in the Franklinian Geosyncline; however, earlier collisions of island arcs and continents had resulted in the rise of a proto-Pearya (see the tectonic model for Svalbard and Innuitia, described earlier). Caledonian structures evidently end at about the latitude of northern Norway and do not cross the Barents Shelf (Tkachenko 1973, p. 342), a contention supported by geophysical data (Vogt and Ostenso 1973). The Caledonian Geosyncline thus may terminate northward as a relatively neutral area in which sediments were deposited but little deformed by the continental collisions (Fig. 9B).

iii) Collision of the Barents plate and the North American platform (Fig. 9C) results in the Ellesmerian Orogeny and the close of sedimentation in the Franklinian Geosyncline. Svalbard now lies adjacent to northern Greenland.

iv) Collision of the Siberian platform with the agglomerated North American–Barents–Eurasian continental masses forms the Uralides (Fig. 9D) in late Paleozoic (Variscan) time (Hamilton 1970). The boreal successor basins (earlier described) form a linear belt.

v) Rifting in the Arctic Ocean region begins in latest Paleozoic or earliest Mesozoic time (Fig. 9E). Note that the Bering and Kolymski plates are assumed to have been part of the North American platform; their westward movement resulted in formation of a proto-Arctic Ocean (the Canada Basin).

vi) The North Atlantic Ocean opens in mid- to late Mesozoic time; the proto-Arctic Ocean is an enclosed sea, with the Kolymski plate colliding with the Siberian platform (Fig. 9F).

vii) Ocean-floor spreading continues into Cenozoic time with the splitting off of a continental sliver, the Lomonosov Ridge, and the opening of the neo-Arctic Ocean (Fig. 9G). Shearing, but with a compressive component, occurs along the de Geer Line transform fault. The compression is represented by the Eurekan and West Spitsbergen orogenies. Molassic sediments accumulate at the top of the succession in the Sverdrup Basin and the Spitsbergen Trough.

viii) The platforms assume about their present disposition by late Cenozoic time (Fig. 9H); the Franklinian–Hecla Hoek basins are now torn asunder and represented by rocks in Svalbard, the Queen Elizabeth Islands, and northern Alaska. The belt of successor basins similarly is dismembered and represented by scattered remnants between Alaska and western U.S.S.R.

Conclusions

The sedimentological and stratigraphic data of the Innuitian and Svalbard regions can be reconciled by a tectonic model in which paired, late Precambrian to early Paleozoic geosynclines are separated by an intermittent tectonic welt, the Pearya geanticline. Subsequent downsinking of the entire orogen may then have resulted in deposition of late Paleozoic to early Tertiary beds in a polar linear basin extending from Alaska to the Moscow Basin region of the U.S.S.R. Rifting and ocean-floor spreading in the Arctic Ocean (in late Paleozoic or early Mesozoic time) may have resulted in separation of the western extension of the Franklinian Geosyncline along the Kaltag Fault. Tertiary rifting and ocean-floor spreading in the North Atlantic and neo-Arctic Oceans appear to have separated the northern basins – now exposed on Svalbard – from those of northern Canada and Greenland. The de Geer Line then must be a major shear or transform fault.

Close similarity of the post-Carboniferous successions of the Innuitian and Svalbard regions, in this model, is explained by their being connected or continuous, while dissimilarity of stratigraphy but conforming structural trends of the pre-Carboniferous rocks are presumed to be due to separation of geosynclinal basins by an orogenic welt and by progressive orogeny, from north to south, in the combined sedimentary-tectonic region.

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