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PROBABLE RIFT ORIGIN OF THE CANADA BASIN, ARCTIC OCEAN

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ABSTRACT

Formation of the Canada basin by post-Triassic rifting seems the most workable and logical hypothesis with information available. Speculated counterclockwise rotation of the Alaska-Chukchi continental edge best rationalizes the complex geology of northern Alaska, whereas a single continental block before the Jurassic makes the best palinspastic fit for Arctic America.

The Arctic Ocean is the focus of present-day spreading and probably was the focus of earlier stages of spreading in which spread of the Canada basin would be an initial stage. If the Atlantic formed by sea-floor spreading, spread of the Canada basin is probable because analogies between the Arctic and Atlantic edges indicate a common origin for the ocean basins.

Late Cretaceous and younger deflections of the Cordillera in the Arctic and diabasic emplacements in the northern Arctic Islands may reflect later stages of spreading. Pre-Mesozoic plate tectonism may be represented by the widespread Proterozoic diabasic emplacements in the Canadian Arctic and by the Franklinian-Innuitian tract where the volcanogenic rocks and deformation resulted not from a classical eugeosyncline-miogeosyncline couple but from the junction of a mid-Paleozoic continental edge and another plate on closure of a pre-Arctic Ocean.

INTRODUCTION

Unlike many of the other speculations in this session, the contention that the important Canada basin element of the Arctic formed by sea-floor spreading is not based on or constrained by a great amount of data. Instead, its bases are mainly onshore geology and common sense--the geology of Arctic North America seems fit best by the speculation that the edges of the basin rifted and rotated apart in the Mesozoic. This better fit became apparent in 1967, and indications supporting it have accumulated since then. The speculation is workable and, in one instance (Rickwood, 1970), has been applied to explain the entrapment of Prudhoe Bay oil.

The better paleogeographic fit between Arctic Alaska and Arctic Canada with Carey's (1958) sphenochasm restored was realized when preparing for the International Symposium on the Devonian System (1967). Devonian clastic wedges on the Amerasian continental edge and in the Canadian Arctic Archipelago seemed much more likely to have been shed off opposite flanks of a shared, linear uplift than off the southern flank of a 3,500-km-long semicircular uplift whose northern flank was an ocean deep.

Almost concurrently, Hamilton's (1967) conjecture that the Chukchi Shelf was drifting past the Siberian mainland as part of complex rifting in the Arctic introduced the possibility of plate tectonics in northern Alaska. The drift that he postulated could be accommodated in Alaska in the strong deflections--shortening--in the Cordilleran front. Prior counterclockwise rotation of a northern Alaska plate, out of the Canada basin, could have caused large-scale dislocations present in the Brooks Range fold belt (Tailleur and Snelson, 1968b).

Since 1968, suggestion of a two-stage spreading history for the rest of the Arctic Ocean has provided a sequence in which spread of the

Canada basin logically could be an initial, third stage. And mirror imagery between the Arctic and Atlantic coasts, across the North American craton, suggests a common origin for the continental edges and also suggests that the Canada basin formed by rifting and sea-floor spreading, assuming that the Atlantic has rifted and spread.

Finally, a trip through the North American Arctic in 1970 impressed me with the probability of a long history of plate tectonics in those provinces. The American Arctic may record spreading beginning in the late Precambrian, plate collision ending in the Devonian, and current plate motion beginning after the Triassic.

GENERAL SPECULATIONS

Three fundamental aspects of the Canada basin are equivocal or unknown: its nature, its age, and its origin.

The nature of the ocean deep--whether it is oceanic, continental, or hybrid--has not been determined. However, evidence (Churkin, 1969) in favor of oceanic crust is growing and supports the assumption that the Canada basin is a true but small ocean deep.

Less evidence for the age of the Canada basin than for its nature has been found. Assuming the deep is oceanic, an age older than Mesozoic would be unique because no present oceanic basin is known to be as old as the Paleozoic. An ancient ocean ringed by mid-Paleozoic orogenic belts, as advocated by Churkin (1969) until recently, creates the additional problem of incorporating into oceanic crust the considerable amount of continental material represented by the poleward flanks of the belts and the detritus shed from them. The possible Permo-Carboniferous spreading, and therefore oceanic crust of the same age, in the southern Canada basin suggested by Hall (1970) is unsupported by the nonorogenic sedimentary

records for that time interval in northern Alaska and the Arctic Archipelago. In comparison, the Jurassic to mid-Cretaceous age consequent upon the rifting and spreading speculated below seems reasonable.

The origin of the Canada basin also is entirely speculative. The rifting and spreading of the Canada basin briefly elaborated on in the following section seems the most workable of the several, sometimes mutually exclusive, hypotheses for the basin's genesis. It provides the energy, and the mechanism of underthrusting on a leading plate edge, to account for the gross dislocations in northern Alaska; having the Canada basin closed during the Late Devonian to Triassic interval provides a better fit between the geology and geologic relationships of the Chukchi Shelf-northern Alaska, Yukon Territory and the Arctic Islands.

GEOLOGIC FIT

The generalized tectonics of the Brooks Range can be related to northern Alaska's counterclockwise rotation out of the Canada basin (see figures 1a, b). The map units are generalizations of different Devonian to Cretaceous facies and stratigraphic successions described elsewhere (Tailleur and others, 1966; Tailleur and Snelson, 1968a; Snelson and Tailleur, 1968; Martin, 1970). Superposed, thrust-together sequences are fairly well defined in the western Brooks Range but are partially inferred in the east. Contrasts in facies are marked--for instance, Devonian carbonate beds in map unit III versus Devonian clastic beds in unit II, prominent Jurassic ophiolites in unit III opposed to minor mafic rocks in the other units; earliest Cretaceous wacke in unit III, earliest Cretaceous condensed shale and coquina in unit II, and earliest Cretaceous basinal shale in unit I. Although the units have been thrust together, as shown in figure 1a, they were deposited in regions that originally were widely separated, as shown in figure 1b.

The Brooks Range orogen in northern Alaska (fig. 1a) was constructed from an old sedimentary basin. Stable sedimentation offshore in this Arctic Alaska basin (see Tailleur and Brosgé, 1970; Brosgé and Tailleur, 1970) was first interrupted by the intrusion of shallow diabase sills in unit II at the beginning of the Jurassic. Ultramafic complexes were emplaced in what seems to have been ocean-deep conditions imposed on a former continental slope in unit III during the Middle Jurassic. In the earliest Cretaceous, a foredeep coupled with a volcanic provenance on the south formed in unit III. The large-scale flat thrusts, which foreshortened the orogenic welt in excess of 200 km (150 mi), formed in Aptian and Albian time. They preceded and accompanied uplift of an ancestral Brooks Range geanticline and depression of flanking flysch-troughs. Deformation continued in subsequent episodes--and perhaps is still active to some extent--but mid-Cretaceous and later sedimentation into successor basins on either flank of the present Brooks Range geanticline was postorogenic in character.

At least two conditions in the Brooks Range orogenic history appear to be missing from the history of the foreland belt of the Cordillera to the south: foreshortening of about 50 percent during the middle, perhaps culmination, of the orogeny; and intrusion and extrusion of abundant mafic igneous rocks near the beginning.

The concept of sea-floor spreading and plate tectonics is invaluable to interpretation of these conditions that are unique to the Arctic segment of the Cordilleran foreland belt: it provides in my opinion the only credible energy source and mechanism for the gross dislocations in the Brooks Range; it is compatible with the development of a continent-ocean

boundary on a continental plate.

Accounting for the stacked-up thrust sheets by northward gravitational sliding seems impossible, if for no other reason than that there is no known paleo-uplift to the south from which the sheets could slide. Northward compressional overthrusting is no better an explanation; it seems precluded by the inherent weakness of sheets thousands of square kilometers in extent but generally less than 2 km thick.

A southward-drifting continental plate, on the other hand, seems capable of thrusting the sheets successively under one another. The energy available certainly would be sufficient. Thin sheets of the earth's skin need not have been very strong for the upper ones to have remained in place while the lower ones were carried under by the moving crustal plate. Thus, the stacked-up thrust sheets in the Brooks Range could have been produced by underthrusting as the northern Alaska plate drifted southward, rotating counterclockwise out of the Canada basin.

The Jurassic igneous activity far offshore in the Arctic Alaska sedimentary basin may be evidence of a spreading Canada basin. The igneous rocks, particularly 160-m.y.-old mafic-ultramafic complexes along the south palinspastic limit of the basin (fig. 1b), appear to be ophiolitic. In the concept of plate tectonics, these ophiolites mark the boundary or leading edge of an active plate. Plate-edge conditions along the south side of the Brooks Range are also indicated by glaucophane there. Thus, northern Alaska may have had a leading edge to the south, another indication of rotation out of the Canada basin.

Figure 2 demonstrates the paleogeographic fit, assuming that the Canada basin was not open before the Jurassic. Sedimentation in the Arctic would have been an extension of Cordilleran sedimentation in the south (fig. 2b). "Barrovia," the provenance for the old Arctic Alaska sedimentary basin (Tailleur and Brosgé, 1970) and named for Pt. Barrow, and "Innuitia," the tectonic land that lay off the Archipelago (fig. 2a), would have formed a single, linear positive element. Such a reconstruction is particularly attractive for the Late Devonian, when postorogenic clastic wedges were shed off both flanks and probably off the end of the Innuitian orogen while carbonate sediments were deposited farther offshore (fig. 2b). Another attractive feature is the more or less colinear placement of the Devonian to Jurassic paleoenvironments in northern Alaska and the Yukon. The Devonian, Mississippian, Permian, and Triassic Systems at the intersection of the Yukon River and the International Boundary, in northern Alaska, and on Wrangel Island are all so similar that deposition in the same, continuous environments seems required. At present, these environments trace concentrically around a 90° bend going into Alaska (fig. 2a); the essentially linear traces subparallel to reconstructed Innuitia in figure 2b seem much more natural.

ANALOGIC FIT

Figure 3 shows analogies between the Canada and Atlantic basins which suggest they had a common origin.

Basically, the Arctic seems to be the mirror image of the Atlantic seaboard across the craton or continental nucleus. Probably the most important element of similarity is the tectonic land seaward of Devonian clastic wedges in the Canadian Archipelago and along the Atlantic. Similar Devonian wedges and seaward provenances in Wrangel Island and northern Alaska seem analogous to Devonian conditions in Europe. The vertical tectonics that probably controlled the Arctic Sverdrup basin in late Paleozoic and Triassic times mirror the vertical, extensional tectonics and

sedimentation along the Atlantic coast during the same time. The 200-m.y.-old sills in northern Alaska may be synchronous with the Palisades sill and other mafic rocks on the east coast, and possibly on the African coast. In Mesozoic time, provincial sediment-transport directions were reversed in northern Alaska, the northwest flank of the Sverdrup basin, and the Appalachians so that detritus was carried toward the present oceans; continental shelf deposition continued thereafter. A gravity high exists along the continental slopes of the Canada basin and a gravity high occurs along the Atlantic coast. The mirror imagery persists to the present in the filling of the Canada basin from the continent in much the same way that the Gulf of Mexico is being filled.

If it is acceptable to reconstruct the pre-Jurassic Atlantic as in figure 3b--with Devonian clastic wedges shedding from a single fold belt that subsequently rifted--there should be little difficulty in accepting the analogous reconstruction of the Arctic that is shown.

Furthermore, the reconstruction results in analogies far to the south in the Cordillera. As shown in figure 3b, the Innuitian orogen would have been the counterpart of the Antler tectonic element. The restored front of the foreland belt along the craton is far enough to the east that all the present foreshortening in the belt can be accounted for, as in northern Alaska, by drift of the "stable" plate.

FIT WITH ARCTIC SPREADING

The foregoing arguments for spread of the Canada basin are by no means conclusive; they would have little value if spreading of the Canada basin did not fit into the framework of the Arctic Ocean. Logic suggests, though, that spread of the basin could have been the initial stage of sea-floor spreading in the Arctic as in figure 4.

Spreading, currently focused along the Gakkel Ridge, appears to have shifted in the mid-Tertiary from a focus along the Alpha Rise (Vogt and Ostenso, 1970; Hall, 1970). Thus, spreading in the Arctic seems to show one shift in focus with time. A prior shift to the Alpha Ridge from a focus along the spreading axis in the Canada basin (fig. 4)--from which the Chukchi shelf-northern Alaska plate and the Archipelago plate rotated apart during Jurassic to mid-Cretaceous time--seems likely. A reconstruction involving three foci of spreading works out fairly well, as shown in figure 3b. I am satisfied for the present that Atlantic rifting and spreading were focused in the Canada basin during the Jurassic and Cretaceous, on the Alpha Ridge during the Cretaceous and Tertiary, and on the Gakkel Ridge subsequently.

SUMMARY

I have given a brief description of the circumstantial and intuitive evidence that spreading is the most workable explanation for the Canada basin: spreading best accounts for the tectonics of the Brooks Range; palinspastics of spreading make the best paleogeographic fit within the Amerasian Arctic and between it and the Cordillera to the south; analogies between the Canada and Atlantic basins suggest that they formed in the same manner; and the Canada basin is the logical first (Jurassic to Cretaceous) focus of spreading. The test of this hypothesis should be whether the Canada basin shows the magnetic print of a spreading ridge, whether the continental crust traces to edges under the shelf deposits, or whether a JOIDES hole through the icepack bottoms in Jurassic or Cretaceous mafic rocks. The questions are more than academic, of course, because the petroleum potential of the vast continental shelf northwest of Alaska may depend on the origin of the Canada basin.

OTHER ARCTIC SPREADING

If the Canada basin originated by sea-floor spreading, the Amerasian Arctic may record several other episodes of spreading.

Strong deflections can be seen in the trace of the front of the Cordillera in the Arctic and along its eastward continuation (fig. 5a)--the Chukchi syntaxis between Siberia and Alaska, and the syntaxial pair near the boundary between Alaska and Canada--that may be due to lateral foreshortening in response to the southeastward drift of the Siberian-Chukchi shelf. The Arctic plate would be decoupled from the crustal plate to the south along the Kaltag-Porcupine and Tintina elements. Motion should not have begun before the latest Cretaceous, and the right-handed separation is continuing on the Kaltag fault segment (Patton and Hoare, 1968). This motion would explain the discordant folds in the Chukchi Sea (Grantz and others, 1970) and the tectonics in northwestern Canada (Cook, this Symposium).

Another possible record of late sea-floor spreading is in the high Arctic Archipelago. Tertiary deformation there is of mountain-building magnitude. This orogeny, together with the abundant mid-Cretaceous mafic intrusive rocks in the region, suggest that the tectonics are related to a shifting plate edge.

A continental edge or some other plate-tectonic element may also account for the volumes of late Precambrian mafic and ultramafic rocks on the Canadian shield. Although the setting of these rocks seems unusually atectonic, mafic igneous activity is so conceptually coupled to current sea-floor spreading that some such association appears likely in Precambrian time as well.

The final suggested spreading requires substantial change in interpretation of the Paleozoic Franklinian geosyncline in the Archipelago (fig. 5b). It would not be a classical eugeosyncline-miogeosyncline pair. Instead, the miogeosynclinal deposits would be merely continental shelf accumulations or buildups into a pre-Arctic Ocean. The eugeosynclinal rocks and subsequent deformation would have resulted from the collision of two continental plates on closing of the pre-Arctic Ocean during middle Paleozoic time. A similar closing of a pre-Atlantic Ocean has been suggested by Wilson (1966) and others. As a matter of fact, Wilson (1968, p. 314) has wondered whether the Arctic Islands represented closure of a former ocean in the Arctic. Besides following the new reasoning that the eu-, miogeosynclinal concept may be generally invalid, this suggestion explains why basement rocks east and west of the McKenzie Delta are different and why no Archaeozoic, crystalline basement has been found in northern Alaska: The Devonian or older Neruokpuk Formation and other sub-Mississippian basement rocks of the western American Arctic were originally part of another continent. Perhaps the suture between two old continental plates will eventually be traced through its distortions in Alaska to join the collision zone between continental plates that may exist near the Pacific coast to the south.

These last observations are permissive only, but they serve as interesting, perhaps profitable, alternate bases for speculation.

CONCLUSION

Whether the principles of plate tectonics and sea-floor spreading are valid or not, the possible movements focus in the Arctic so that global treatment of the concepts, such as reproduced in figure 6, will be incomplete without considering the Arctic. Although the existence of some sort of "sinus borealis" in Pangaea cannot be disproved, for example, none existed

between Siberia and Alaska. Plate tectonicists, particularly oceanographers, must raise their perspectives above the Arctic Circle and also take into account what is known about Arctic geology.

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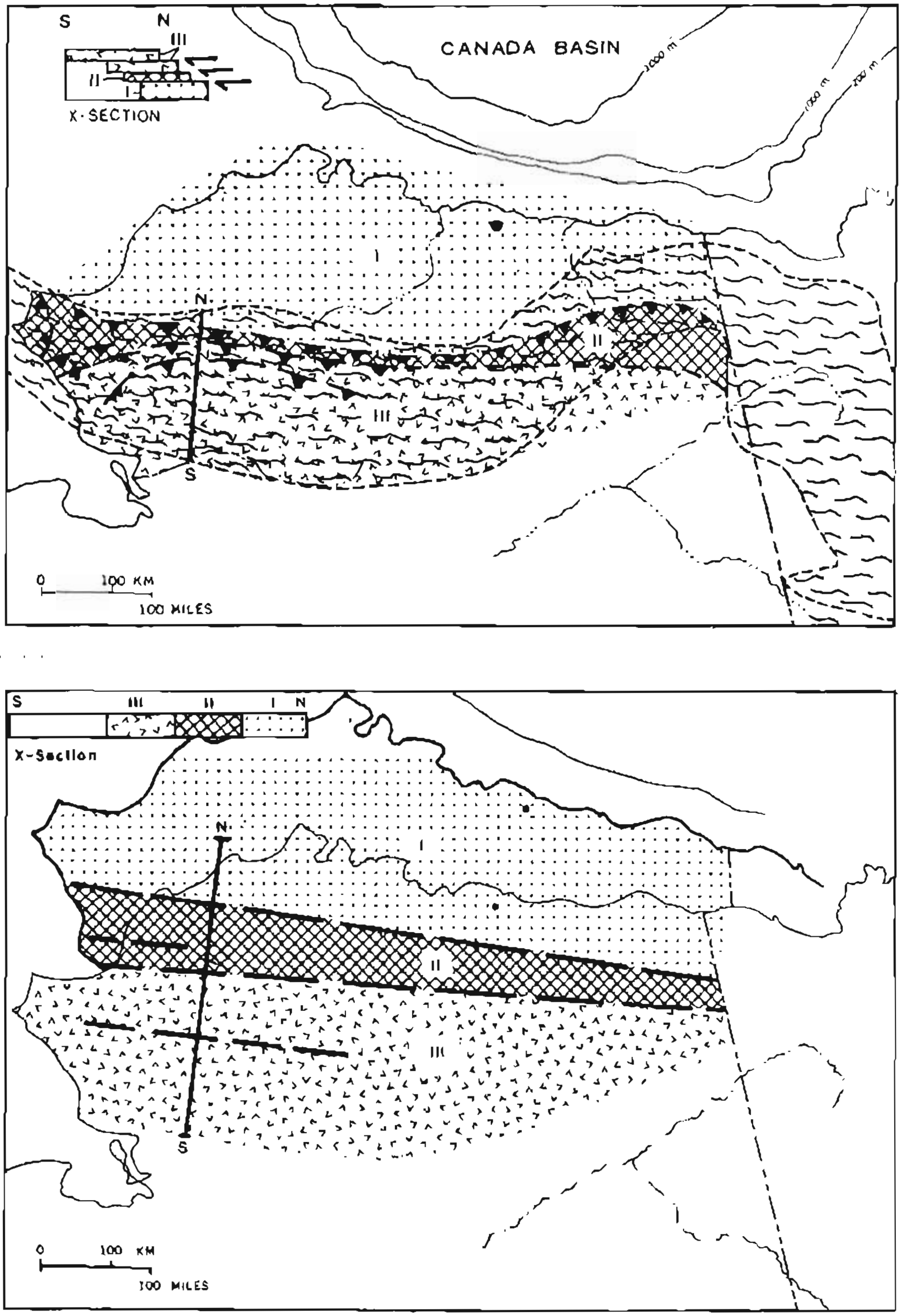


Figure 1.--Diagrammatic relations of large-scale thrusting and counterclockwise rotation in Arctic Alaska. a. Generalized map and section of thrusts and map units. The Brooks Range orogen and its eastward continuation shown by wavy pattern. b. Minimum extent of units before underthrusting.

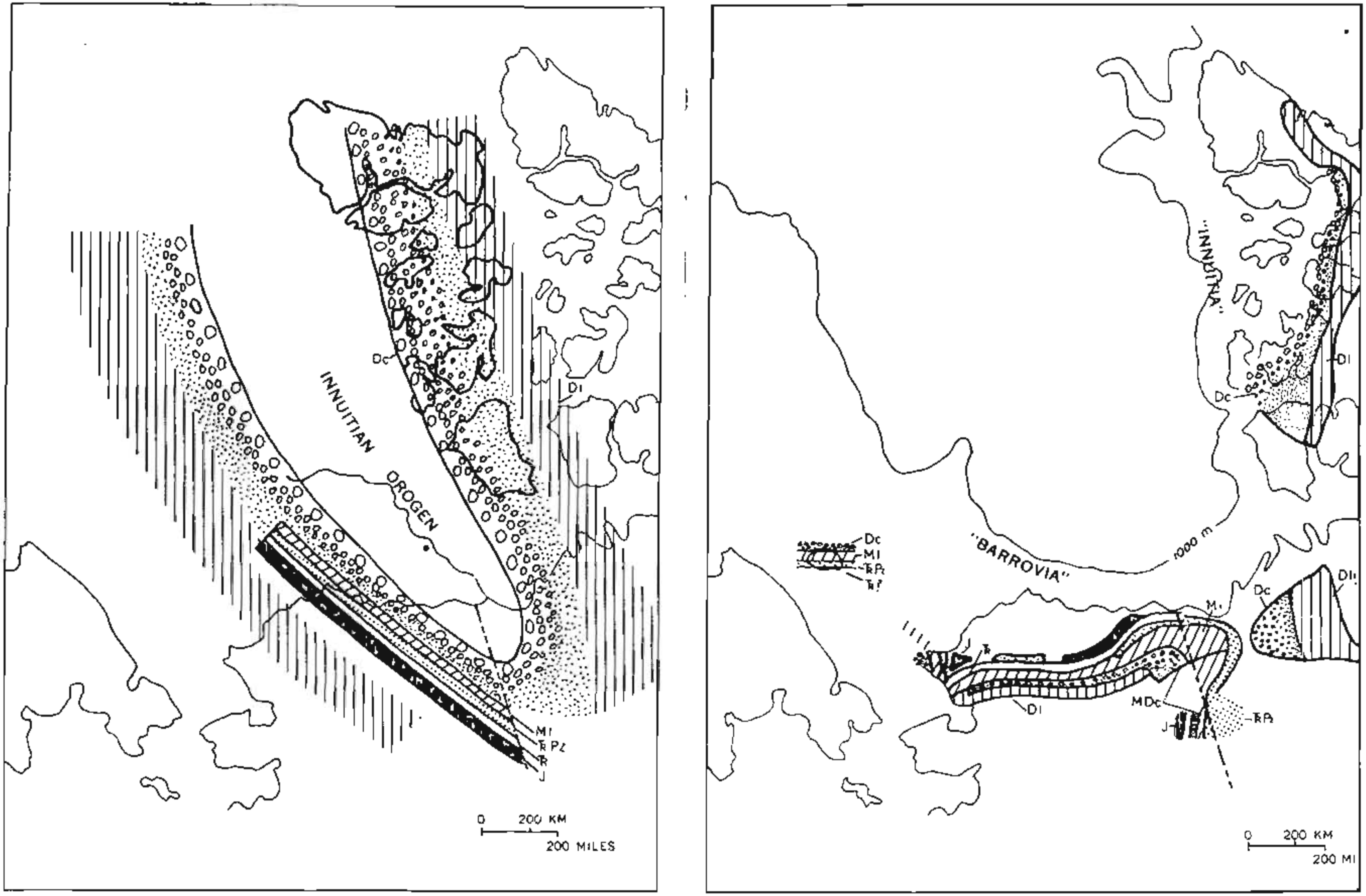


Figure 2.--Sketch maps of Amerasian Arctic showing: a. Present occurrences of coeval and lithogenetically similar rocks and their inferred provenances "Barrovia" and "Innuitia." b. Palinspastic geology and geography based on assumption that Canada Basin was not open before Jurassic. (Dl - Devonian carbonate deposits; (M) Dc (Mississippian) and/or Devonian clastic deposits; Ml - Mississippian carbonate deposits; TRPz - Triassic to latest Paleozoic nearshore deposits; TR - Late Triassic condensed deposits; TR? - Late Triassic nearshore? deposits; and J - Jurassic distal deposits).

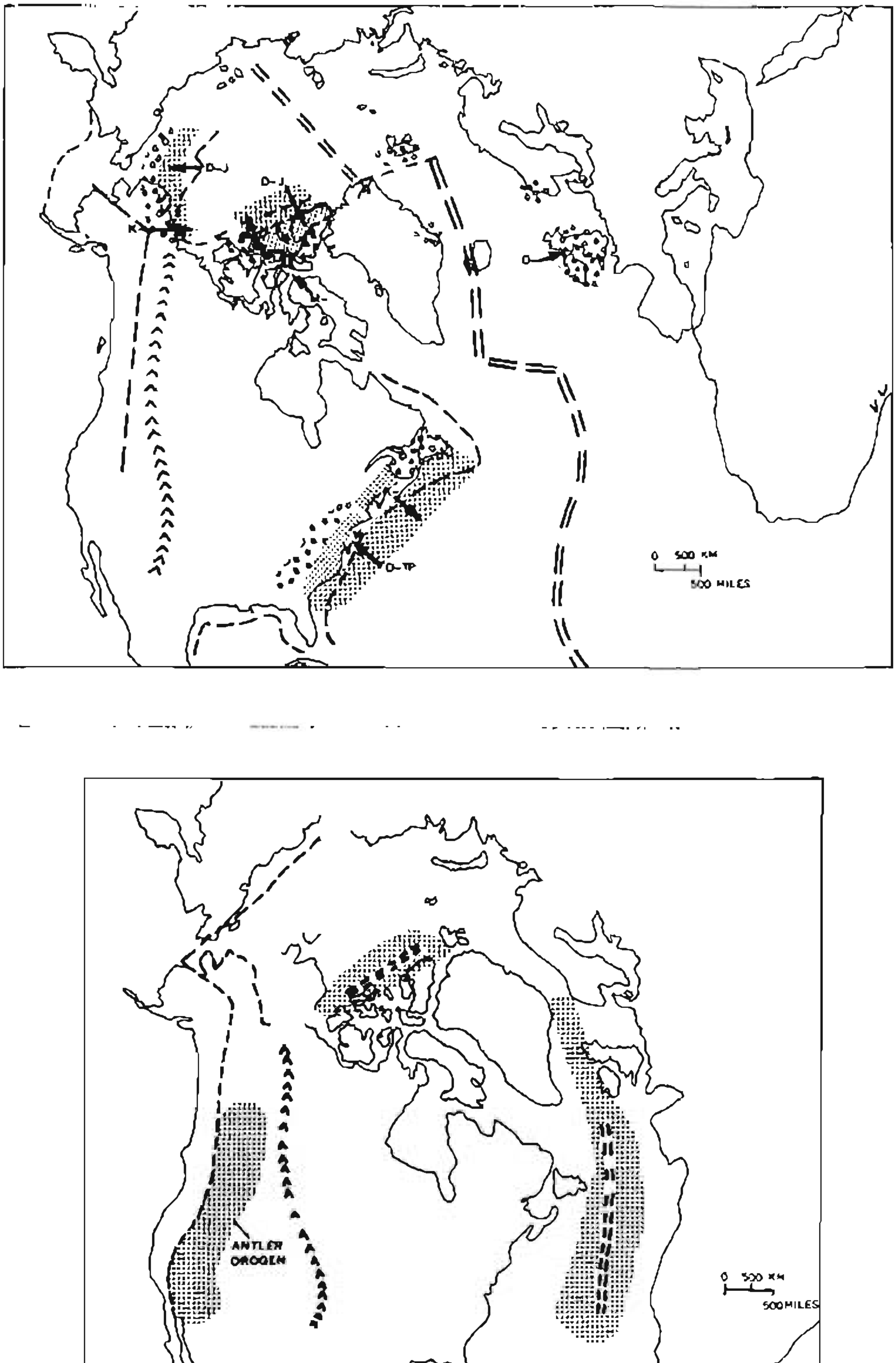


Figure 3.--Analogies between Canada and Atlantic basins that suggest a common origin of the two ocean deeps. (Computer-plotted projection centered in Hudson Bay). a. Present geography. Thick lines, Atlantic rift system and inferred transforms or sutures; dashed lines offshore, basin margins; inverted checks, Cordilleran front; circles and stippling, Devonian clastic wedges and offshore provenances; medium dots, late Paleozoic to Triassic basins; systemic symbols and arrows, age and direction of sediment transport. b. Pre-drift geography. Devonian orogens (stippled) and Arctic-basin margin are diagrammatic. Atlantic margin from Bullard and others (1965). Cordilleran front is palinspastic; Pacific margin is not.

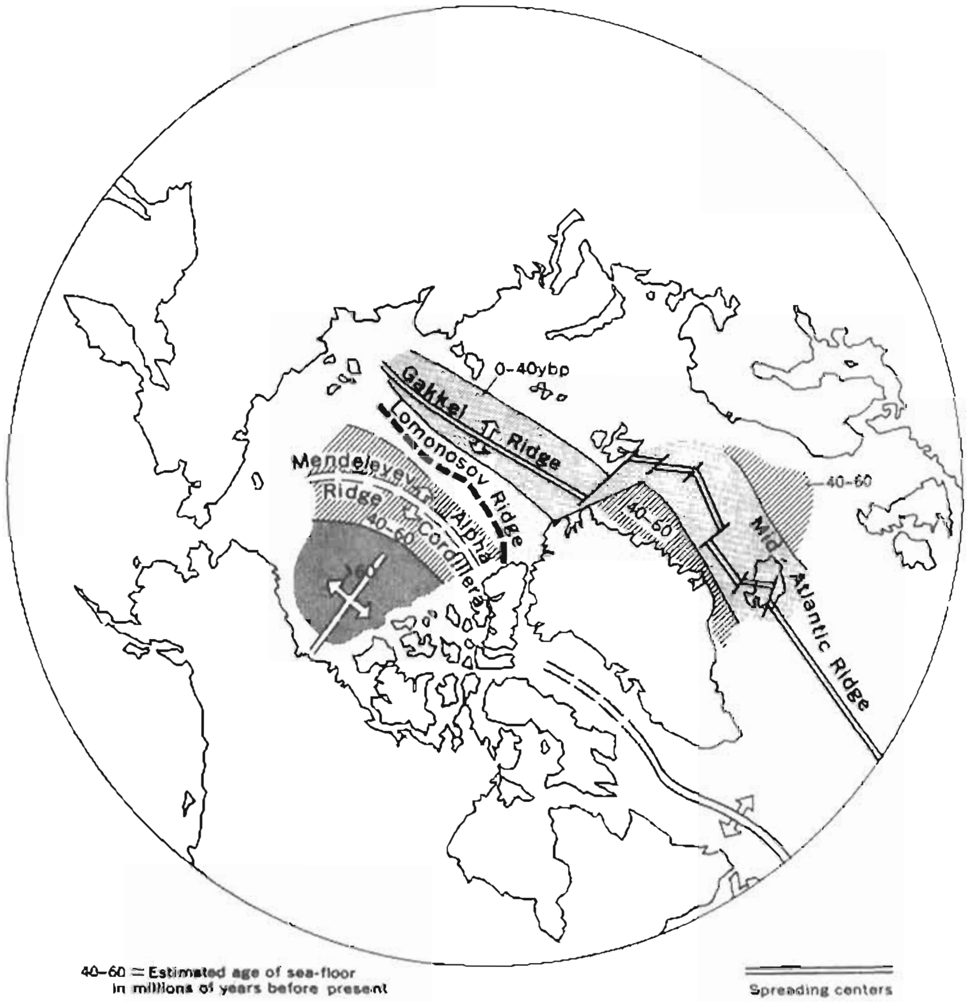
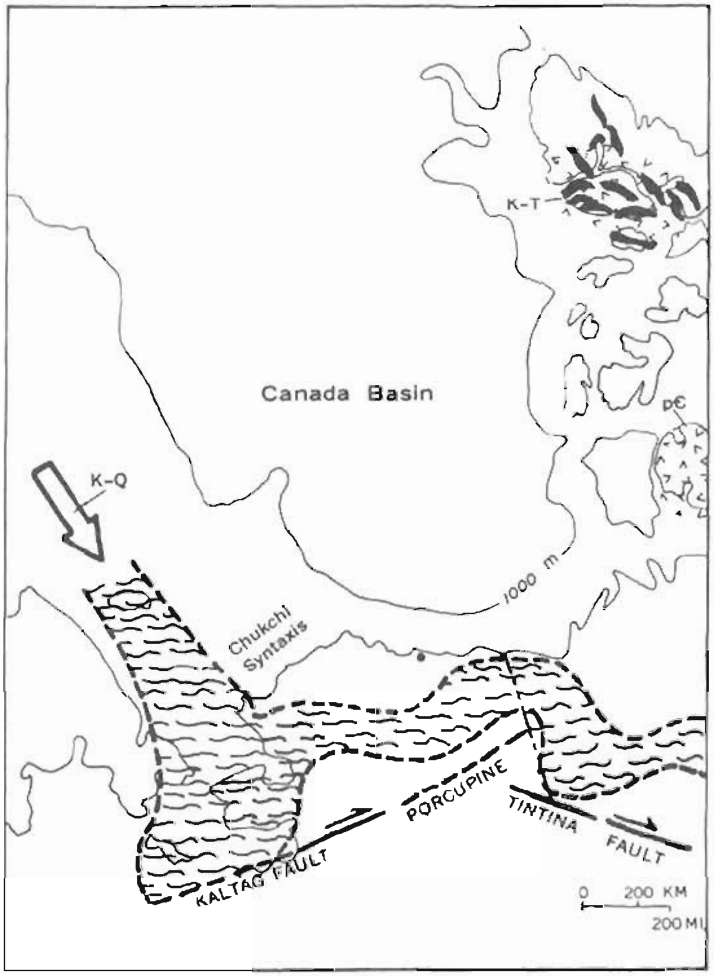


Figure 4.--Sea-floor spreading in Arctic, modified from Churkin (this Symposium). Current spreading from Gakkel Ridge presumably shifted from a focus along Alpha Ridge in Tertiary; logically, spread from Alpha axis could have shifted from focus (inferred) in Canada basin in Cretaceous.



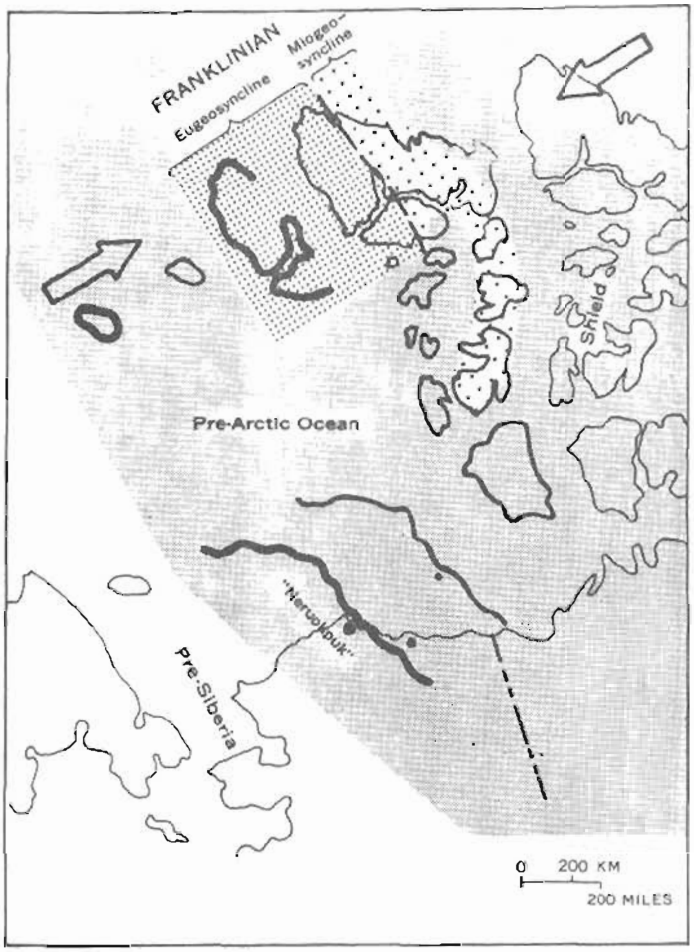


Figure 5.--Evidence of other drift in Amerasian Arctic. a. Deflections (shortening) in trace of fold belt and right-handed dislocations in response to Cretaceous to Holocene southeastward drift of Chukchi Shelf; Cretaceous mafic rocks (v) and Tertiary deformation (spindles) in high Arctic (Axel Heiberg and Ellesmere Islands); and late Precambrian mafic rocks (v) on edge of North American craton. b. Suggested Paleozoic plate-tectonism; Franklinian "miogeosyncline" on continental slope of North American craton; "Neruokpuk" sedimentary basin on pre-Siberian continent; and Franklinian "eugeosyncline" along plate junction in pre-Arctic Ocean.

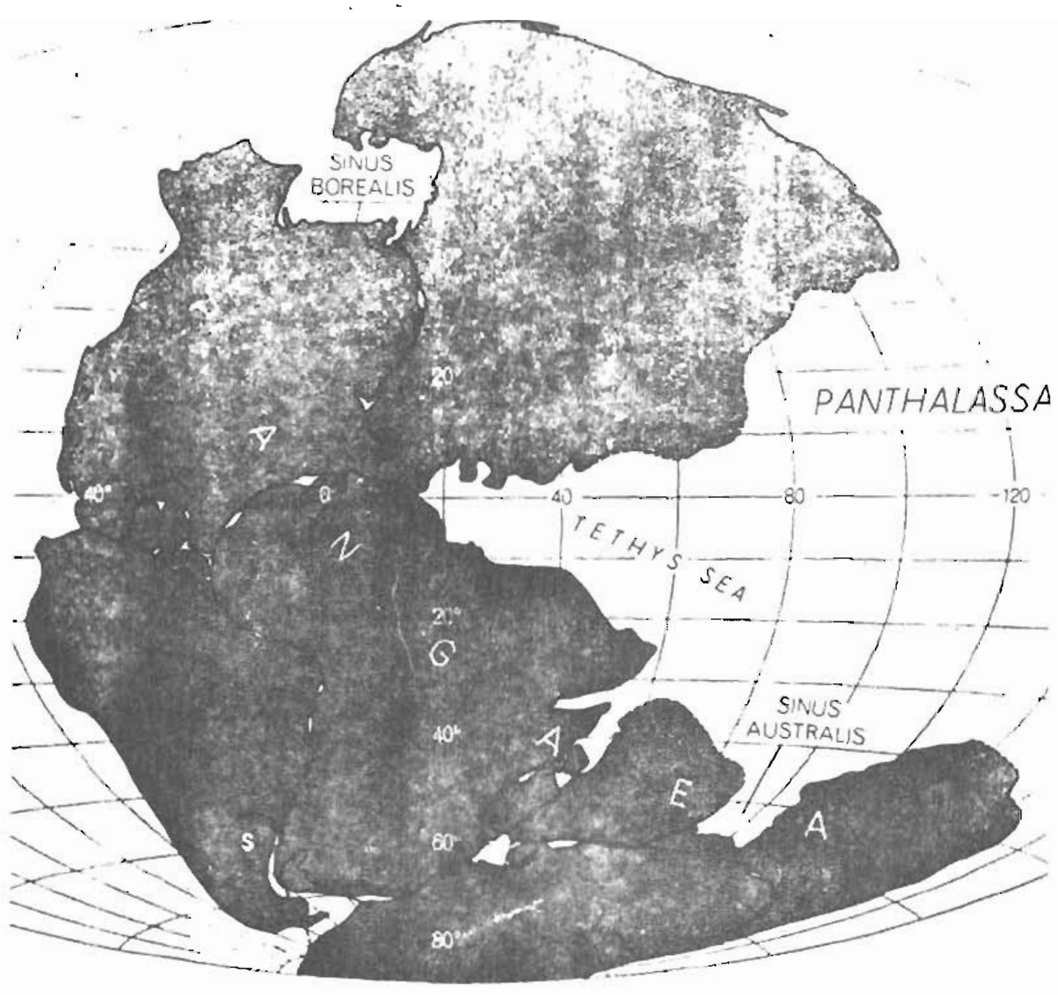


Figure 6.--Triassic Pangaea (Dietz and Holden, 1970; with permission of Scientific American)--an example of untenable reconstruction of the Arctic. At minimum, any "sinus borealis" would have been separated from Pacific basin by join between northern Alaska and easternmost Siberia in existence since late Paleozoic.