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Paleozoic Tectonic History of the Arctic Basin North of Alaska

The origin of the Canada Basin is interpreted from geologic and geophysical data.

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Hypotheses on the origin of the Arctic basin north of Alaska (the Canada Basin) that were made before geophysical data were available suggested that this depression developed by subsidence of a Precambrian shield (*1–4*). This view was based on the distribution of Precambrian shield areas around the Arctic Ocean, the broad continental shelves, the presence of only a thin platform of sedimentary rocks in the Soviet Arctic Islands, and the apparent trend of Paleozoic orogenic belts that project to, and perhaps under, the Arctic Ocean. By assuming that all of Alaska is part of the Cordilleran geosyncline and by drawing an analogy with more southerly parts of the geosyncline, Eardley (*2*) concluded that an ancient continental landmass (Arctica) bordered Alaska on the north in the area now occupied by the Arctic Ocean. The coarse clastic rocks in the Devonian and younger Paleozoic sections in the arctic regions of Alaska, Canada, and the U.S.S.R. required sediment sources north of any present-day landmass. These rocks were considered by many to be further evidence of the existence of this ancient landmass [the Barrow Platform of Payne and others (*3*)]. Such observations and speculations led to the theory (*5*) that the Arctic basin is a relatively young ocean basin formed by the rifting of this ancient landmass and the drifting of Alaska from the Canadian Arctic Islands to its present position.

Geological considerations and recent geophysical data presented below have led me to reject the subsidence theory and to consider that the Canada Basin of the Arctic Ocean between Alaska, Siberia, and the Canadian Archipelago is a true and probably very ancient ocean basin floored by oceanic crust and rimmed by an early Paleozoic geosynclinal belt.

Geologic Data and Their Interpretation

In the Brooks Range and in the Arctic coastal plain of Alaska, rocks older than Middle Devonian are known from only a few places. One of these is at the bottom of a borehole at Point Barrow, where argillites were found beneath Triassic rocks. The shallow depth of these more indurated rocks suggested a structurally high basement (*3*). Some Soviet geologists (*4*) interpreted this "basement" as part of the so-called Hyperborean platform of Precambrian age that they believed once extended north of Alaska and Siberia before it sank to become the floor of much of the Arctic basin. I believe, instead, that the argillites are part of the belt of weakly metamorphosed, predominantly siliceous rocks of pre-Late Devonian age that are exposed in various parts of the Brooks Range (*6, 7*). The rocks in this belt appear to be thicker than the predominantly carbonate rocks of early Paleozoic age in east-central Alaska (*8*). This suggests a northward transition from a central Alaskan carbonate shelf into an arctic basin or geosyncline with thick argillaceous rocks (Fig. 1).

Above the weakly metamorphosed rocks in the Brooks Range, limestone and shale formations that contain Middle and Late Devonian fossils have been recognized (*9*). It is my belief that these Devonian and older rocks in northern Alaska are probably western equivalents of similar rocks in the Franklinian geosyncline in arctic Canada (*10, 11*). This geosyncline trends toward Alaska and probably continues underneath younger rocks of the Mackenzie River delta into the northwesternmost part of the Yukon Territory and the Brooks Range in Alaska (Fig. 1). Volcanic rocks characteristic of the northeastern part of the Franklinian geosyncline are not widely recognized in northern Alaska. However, basic intrusive rocks and related volcanic rocks that may be of Devonian age or older are locally present in the Brooks Range (*12*). High magnetic anomalies along the Arctic slope of Alaska suggest that igneous rock masses form a large part of the basement below the thick Mesozoic cover (*3*).

The circumarctic geosynclinal belt was probably not a part of the Cordilleran geosyncline of the Pacific basin, as Gates and Gryc (*13*) suggested it was, but was separated from the Cordilleran geosyncline by a shelf that covered at least east-central Alaska and much of the Yukon Territory (*8, 14*). Figure 2, a reconstruction of lower Paleozoic tectonic features across Alaska, shows the relation of the shelf to both of the geosynclines. During the Early Ordovician to Early Devonian, the site of the Richardson Mountains was an area of accumulation of thick graptolitic shale, bedded chert, and argillaceous limestone (*15*). At the

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same time, however, thin shelf limestones interfingering with thin sequences of graptolitic shale were forming laterally over the rest of the northern Yukon Territory and eastern Alaska (*8*, *14*). Thus, the Richardson Mountains basin, during the Paleozoic, was not a northern extension of the Cordilleran geosyncline (*16*), as Jeletzky (*17*) has already shown for the Mesozoic, but a narrow basin that developed within the Yukon shelf (*8*).

Around the Canada Basin from Wrangell Island east to Ellesmere Island, the widespread occurrence of a wedge of Late Devonian clastic deposits and granitic intrusions of about the same age indicates an orogeny that interrupted the earlier period of marine deposition (Fig. 3). In northern Alaska the latest Devonian rocks (in sharp contrast to the earlier fine-grained calcareous rocks of marine origin) are nonmarine plant-bearing conglomerates and sandstone (*9*). These coarse clastic rocks form a thick wedge [up to 10,000 feet (3,000 meters) thick] in the Brooks Range and appear to have been derived from a northern source (*6*). The vast quantity of varicolored, and in part laminated, chert and argillite fragments suggests that a great thickness of bedded chert and argillaceous rock lay somewhere between the northern Brooks Range and the present continental margin and was the source of the detritus. Middle Devonian plant-bearing shale and conglomerate from the Topagoruk test well (*18*) on the Arctic coastal plain still farther north (Fig. 3) suggest an earlier phase of coarse sedimentation, a forerunner of the Late Devonian earth movements.

In the northern Yukon and Northwest Territories, nonmarine sandstone

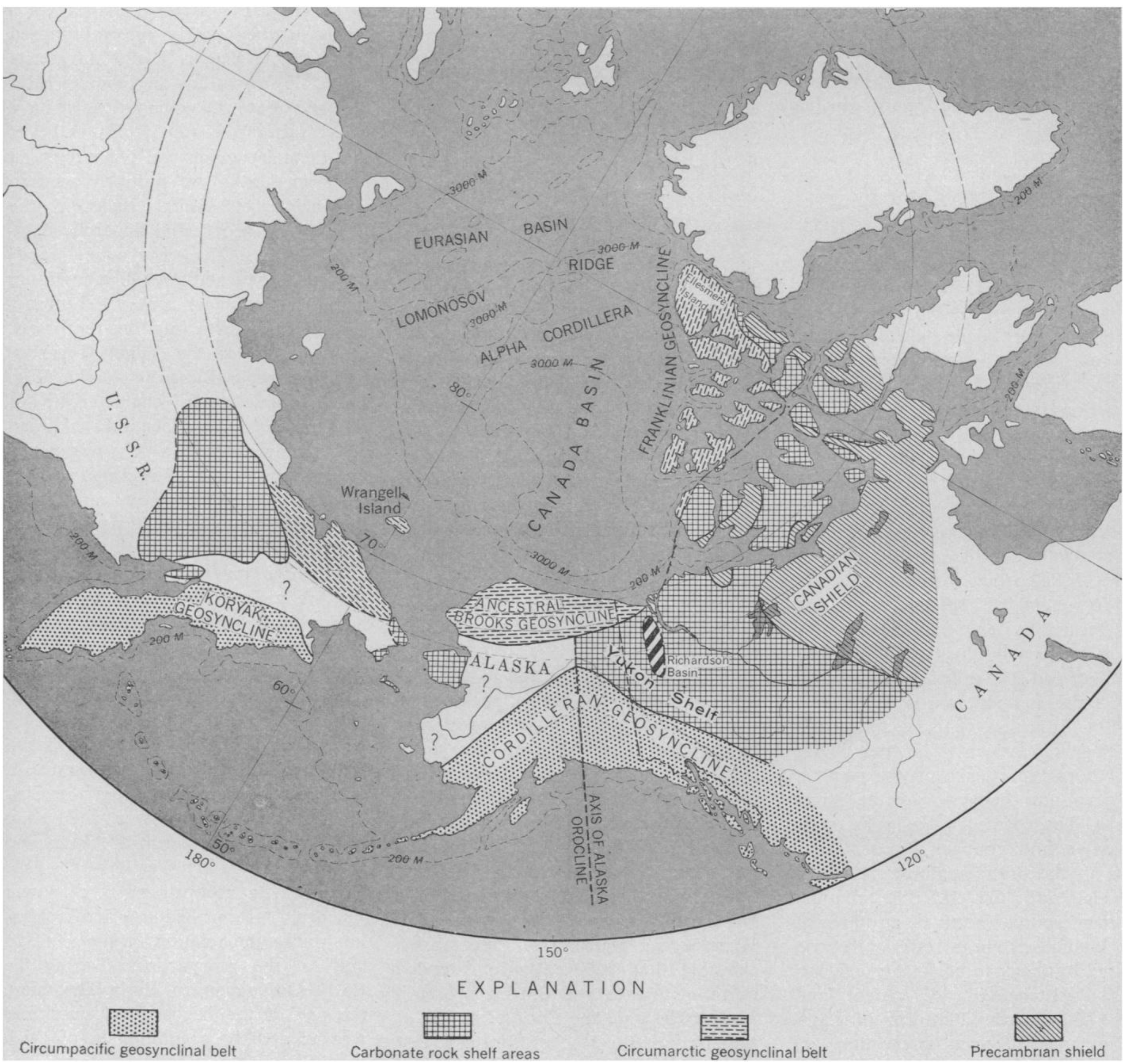

Fig. 1. Tectonic framework of early Paleozoic (pre-Late Devonian) sedimentation. Cordilleran geosynclinal rocks along the axis of the Alaska orocline may be displaced northward as a result of a long period of Pacific sea-floor movement against the continental margin in the Gulf of Alaska.

and shale are the eastern equivalents of the Upper Devonian in northern Alaska (*19*). The occurrence of a similar belt of Upper Devonian detrital rocks in the Canadian Arctic Islands suggests that these Upper Devonian clastics continued around the edge of the Arctic basin from Alaska into Ellesmere Island, a distance of more than 1200 miles (1900 kilometers) (*11*). In Chukotka and Wrangell Island, on the other side of Alaska, similar Upper Devonian conglomerates and sandstones apparently were also derived from the north (*20, 21*).

Some geologists (*1, 2*) thought that, in Late Devonian time, widespread uplift in what is now the Arctic Ocean exposed a Precambrian shield whose erosion provided coarse sediment to nearby parts of Canada, Alaska, and Siberia. However, to judge from the composition of the detritus, its coarse grain size, the wedgelike shape of the sedimentary body, and its mainly nonmarine character, a platform or shield source seems unlikely. Instead, the very similar clastic wedges of Devonian sediment in the Franklinian (*10, 11*), Cordilleran (*22*), and Appalachian (*23*) geosynclines are thought to have been derived from uplifts within the respective geosynclines.

Absolute age determinations of granitic rocks around the margin of the Canada Basin (Fig. 3) indicate that the intrusion of these rocks was probably related to the same mid-Paleozoic orogeny that produced the wedge of Upper Devonian clastic deposits. Granitic rocks in the Romanzof Mountains of the northeastern Brooks Range intrude Devonian or older siliceous sedimentary rocks—the Neruokpuk Formation—that are regionally metamorphosed to the greenschist facies (*24, 25*). These low-grade metamorphic rocks were deeply eroded (as much as 10,000 feet of strata were removed) and then unconformably overlain by Upper Devonian or Mississippian conglomerate (*25*). The lack of feldspar in the conglomerate suggests that the main granite body was not unroofed at this time, but the presence of tourmaline-quartz pebbles and cassiterite suggests that igneous material genetically related to the intrusive was available as a source (*25*). Lead-alpha age determinations on zircon from the granite give ages of 310 ± 35 and 405 ± 45 million years (*24*). Potassium-argon determinations on biotite from the same rocks give much more recent dates (128 and 125 million years ago), but the biotite may have been affected by a Mesozoic deformation (*24, 25*).

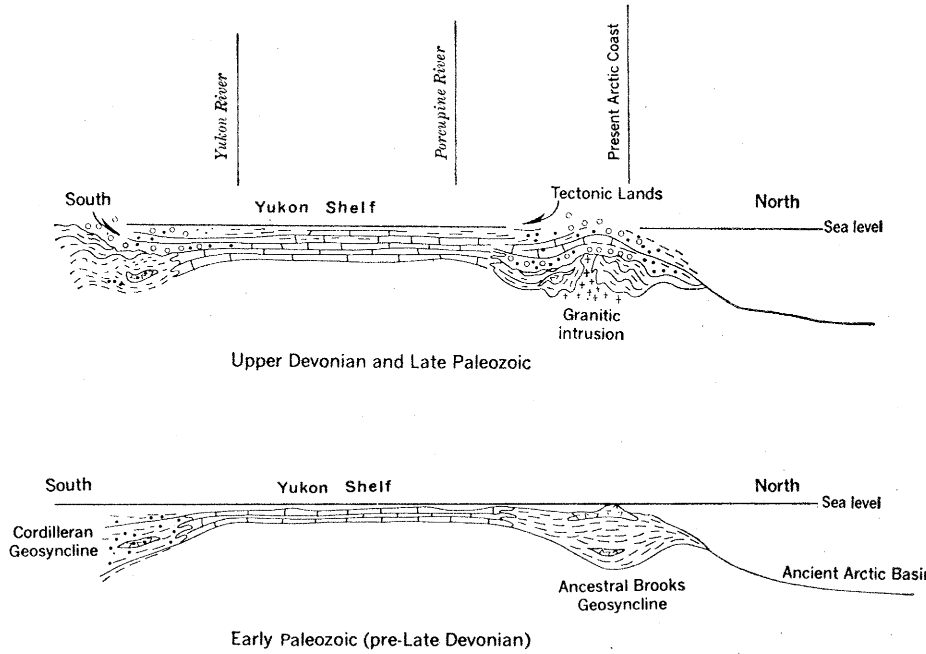

Fig. 2. Interpretation of the tectonic development of northern Alaska in the Paleozoic. The cross sections are drawn along the boundary (141°W) between Alaska and the Yukon Territory.

Granitic intrusions farther east along the edge of the Canada Basin (Fig. 3) seem to be of about the same age as those in the Brooks Range, indicating a mid-Paleozoic period of widespread magmatic activity along the edge of the basin, probably just prior to, or contemporaneous with, the uplift that led to the deposition of the thick Upper Devonian sediments (*11*). In nearby northern Yukon Territory the granitic rocks of Mount Sedgwick give ages of 355 million years (*26*), and those of Mount Fitton, ages of 353 and 370 million years (*26, 27*). Much farther east, in the Franklinian eugeosyncline, granitic rocks of Axel Heiberg Island gave ages of 360 million years, and those on Ellesmere Island, of about 335 million years (*11*).

Besides the Devonian orogeny outlined above, there is evidence in Ellesmere Island, where the oldest known rocks bordering the Canada Basin are exposed, of several earlier periods of orogenic activity within the Franklinian geosyncline (*28*).

After the Late Devonian orogeny, thick marine strata were again deposited in northern Alaska in a basin along the present site of the Brooks Range, in the Arctic Islands in the Sverdrup Basin (*10*), and in northern Chukotka and Wrangell Island in the Chukotka geosyncline (*20*) (Fig. 4).

In the Brooks Range, the Carboniferous rocks are mainly limestone and dolomite, with variable amounts of interbedded shale and chert (*6*). The base of this section becomes progressively younger and more detrital in the northern parts of the Brooks Range. This northward transgression, plus the fact that the unconformably overlying Permian (in boreholes north of the Brooks Range) is a coarse chert-pebble conglomerate, suggests that in the late Paleozoic a source area existed north of the Brooks Range (*6*). Renewed uplift of the pre-Late Devonian ancestral Brooks geosynclinal belt probably provided the detritus during the Carboniferous and Permian, as it had done in the Late Devonian (Fig. 2).

West of the Brooks Range the nearest upper Paleozoic rocks are on Wrangell Island and Chukotka (*21*). On Wrangell Island the Mississippian rocks, like the conformably underlying Upper Devonian rocks, are very similar to, but thicker than, those in the Brooks Range. A Permian and Triassic section of varicolored sandstone, shale, and some limestone unconformably overlies different horizons of the Mississippian, and again there is a general similarity to the stratigraphy of the

Brooks Range. The Upper Devonian-through-Permian section in Chukotka is similar to that in Wrangell Island, except that in Chukotka the Upper Devonian detrital rocks are fine-grained sandstones instead of conglomerates. This relationship also suggests a northern source of detrital sediment (*21*).

East of the Brooks Range an even thicker sequence of Carboniferous and younger rocks that lies unconformably on the older Paleozoic strata of the Franklinian geosyncline forms the Sverdrup Basin (*10*). The available data show some similarities in the stratigraphic succession between the Sverdrup Basin and the Brooks Range basin. However, the thin and patchy development of Mississippian nonmarine sandstone and shale in the Sverdrup Basin (*29*) contrasts with the broad development of thick carbonate rocks in the Brooks Range basin. The presence of evaporates in the Sverdrup but not in the Brooks Range basin also suggests that these basins were separated, perhaps by the Prince Patrick uplift (*19*).

In summary, despite the apparent differences in stratigraphic succession, the overall similarity, with respect to the upper Paleozoic rocks, between the Sverdrup Basin of arctic Canada, the Brooks Range basin of northern Alaska, and the Chukotka geosynclinal belt of the Soviet arctic suggests that these features represent parts of a belt of sedimentary basins that rimmed the Arctic Ocean.

Geophysical Data and Their Interpretation

The interpretations of geophysical data vary concerning the nature of the rocks that floor the Arctic basin. Most of the geophysical data, however, indicate that a thick body of sediment lies north of the Brooks Range and that oceanic crust floors the deep Canada Basin still farther north. Magnetic profiles over the continental shelf north of Alaska are nearly flat or show only minor fluctuations in magnetic intensity, like the profiles across the Franklinian geosyncline. This bears out the idea that thick sedimentary sections may continue north of Alaska out under the continental shelf (*30*).

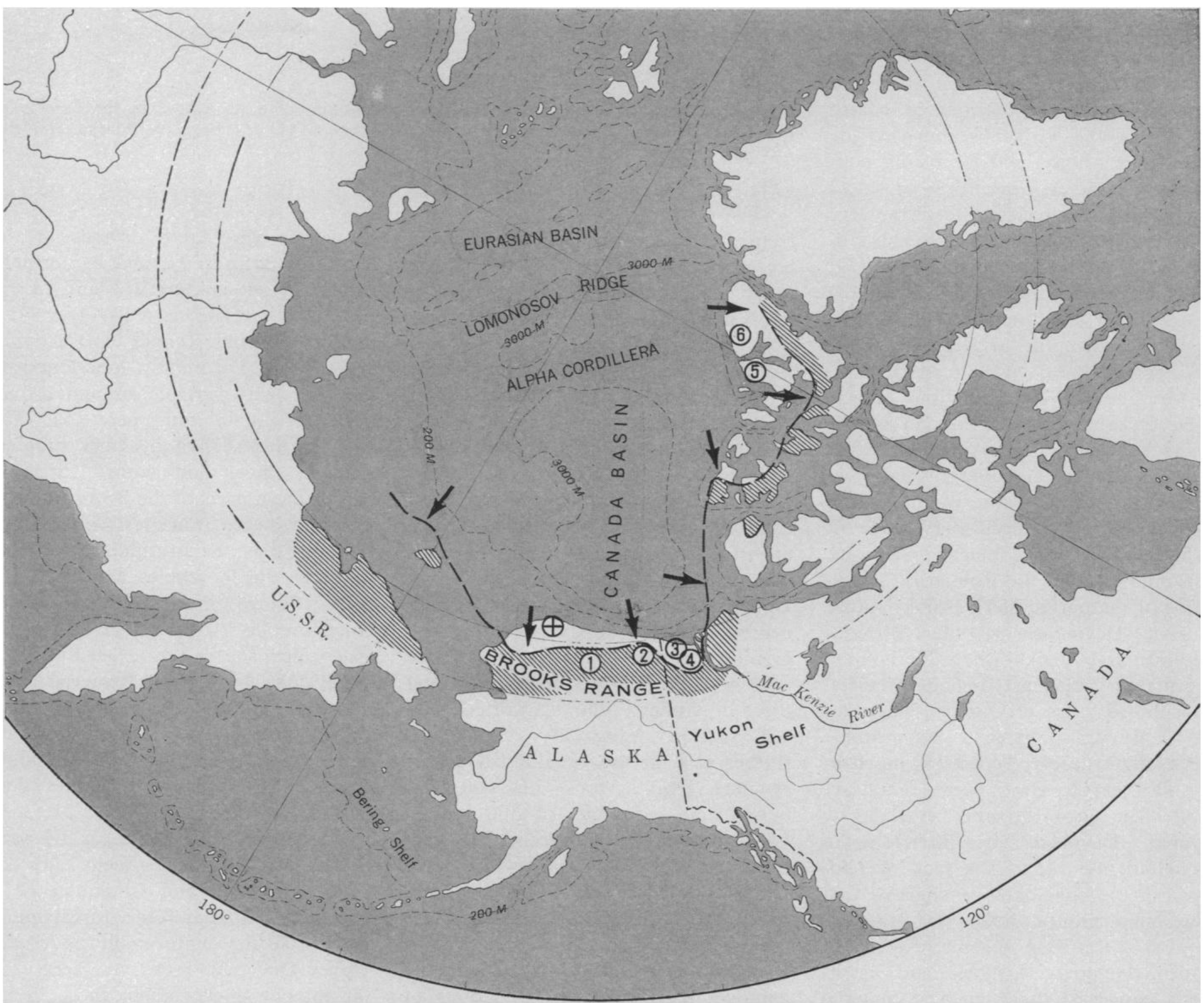

Fig. 3. Devonian clastic wedge deposits and intrusive rocks. (Dashed line) Northern limit of Upper Devonian clastic rocks. (Arrows) Major sources of detritus. (Circled numbers) Intrusions with absolute age in millions of years, as follows (K/Ar = potassium/argon technique; Pb/α = lead/alpha technique): ① mafic dike, 370, Mount Doonerak area, K/Ar (*12a*); ② granitic pluton, 310, 405, Romanzof Mountains, Pb/α (*24*); ③ granitic pluton, 355, Mount Sedgwick, K/Ar (*26*); ④ granitic pluton, 353, 370, Mount Fitton, K/Ar (*26, 27*); ⑤ granitic pluton, 360, Axel Hieberg Island, K/Ar (*11*); ⑥ foliated granitic pluton, 335, Phillips Inlet, Ellesmere Island, K/Ar (*11*). ⊕ Middle Devonian clastic rocks in Topagoruk well.

In the Canada Basin north of the shelf, no surface earthquake waves of short period, the Lg phase, have been detected (*31*). Since the Lg phase is known to be transmitted long distances through continental crust only, and not through oceanic crust, it is concluded that the crust below the Canada Basin is oceanic (*31*). A study of dispersion of Rayleigh waves and Love waves (*31*) indicates crustal thicknesses in this region intermediate between typical oceanic and typical continental crust. Gravity data (*32*) indicate a thinning of the crust from about 35 kilometers under the Brooks Range to 17 kilometers about 700 kilometers north of the coast of Alaska, thus supporting the seismic evidence of an oceanic crust for the deep Canada Basin north of the shelf.

In part of the Canada Basin and Alpha Cordillera (or Alpha Rise) the closely spaced, high-amplitude magnetic anomalies are thought by some geophysicists to resemble areas in the Canadian Shield (*30*), but Ostenso (*33*) does not agree that they are correlative. Instead, parallel bands of magnetic anomalies extending for hundreds of kilometers in a zone 500 to 1000 kilometers wide along the Alpha Cordillera are thought by Vogt and Ostenso (*34*) to be more like magnetic features characteristic of mid-ocean ridges (*35*). They therefore conclude (*34*) that the Alpha Cordillera is a "fossil" mid-oceanic ridge. The Canada Basin would thus appear to be a small ocean basin possessing an oceanic crust and mid-oceanic ridge, and rimmed to the south by a mobile belt.

Speculations on the Origin of the Canada Basin

Whatever the age of the Arctic Ocean and whatever its origin—whether it is a permanent primary ocean or a secondary basin formed by rifting or subsidence of a continental landmass—it seems from all the geophysical data available to be a true ocean basin floored by oceanic crust. If the hypothetical Hyperborean Shield had been depressed to form the floor of the deep

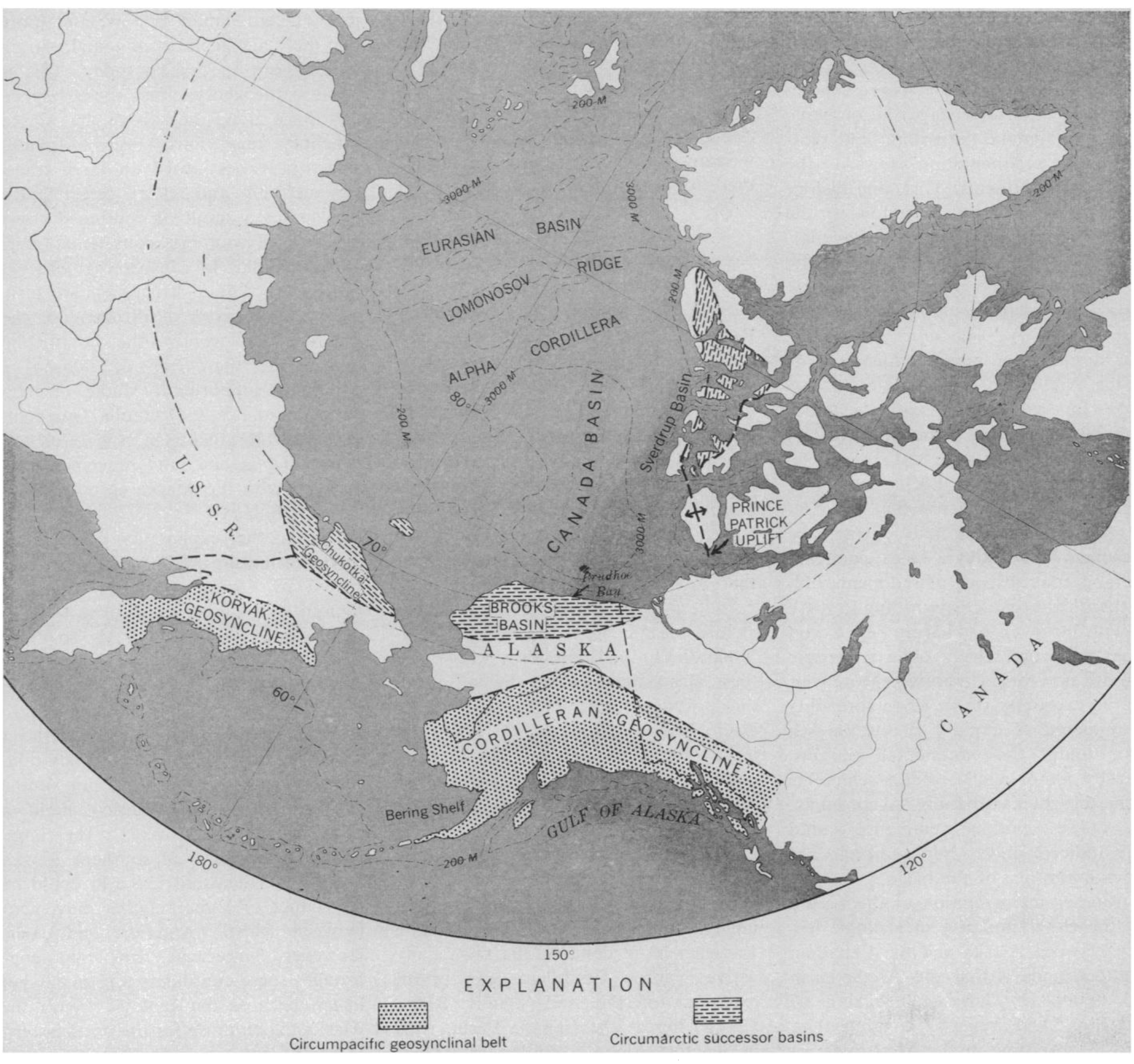

Fig. 4. Tectonic framework of late Paleozoic (Late-Devonian-to-Permian) sedimentation.

Canada Basin, a subsequent major change in its composition would have had to occur to provide the present-day geophysical characteristics of the basin floor. It has been suggested that continental crust has changed into oceanic crust in the Arctic Ocean, in the Black Sea, and in the Sea of Okhotsk, but no satisfactory mechanism has been proposed (*4*).

The Paleozoic tectonic history of the southern rim of the Canada Basin resembles that of the northeastern margin of the Pacific basin. However, the rim of the Canada Basin is less well known and more difficult to interpret because of the thick Mesozoic and Cenozoic cover in northern Alaska. The Arctic and Pacific basins, even though differing greatly in size, seem to have in common a long history of geosynclinal development along their borders—a history extending back at least into the early Paleozoic. These geosynclines or mobile belts are characterized in their later stages by orogenic uplifts, magmatic intrusion, and clastic-wedge sedimentation toward the bordering continents. This long history of orogenic activity, common to the Pacific and the arctic continental margins of Alaska, may be a result of the thrusting of the ocean floors against Alaska [a possible example of sea-floor spreading (*36*)]. The time, magnitude, and direction of any continental drift in the Arctic that is theoretically possible in association with sea-floor spreading is anyone's guess, in view of the meagerness of the data available. As in the case of the Pacific and other major oceans, the theory that the Arctic Ocean was formed during the Mesozoic is based to a large extent on the apparent absence of sediments older than Mesozoic. Deep drilling in these oceans, however, has hardly begun, and rocks of progressively older Mesozoic age are now being reported. Moreover, the very process of sea-floor spreading is supposed to rapidly sweep the sea floor under the continental margins, thereby removing the oldest sediments from direct examination. Accordingly, the oldest sea-floor sediments would then indicate only a minimum and not a maximum age of the basin.

Another interpretation of the reason for the close similarity in geologic history between Alaska and the Canadian Arctic Islands is that the Arctic basin was created by large-scale rifting (*5* and Fig. 5). Carey (*5*) suggests that, before some time in the Mesozoic, the arctic coast of Alaska adjoined the coast of arctic Canada. Large-scale tensional rifting of Canada from Alaska and Siberia, in his interpretation, created the Arctic basin. A relative clockwise rotation of North America from Asia to its present position supposedly created the Alaska orocline—a complementary compressional feature identified by a sharp bend in the structures of southern Alaska. Large-scale thrusting in northwestern Alaska has also been considered to be a product of this rifting (*37*).

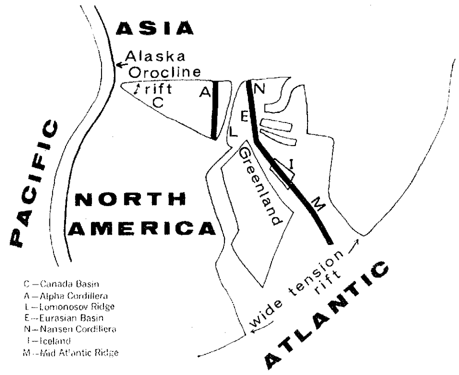

Fig. 5. Carey's concept of drifting.

If both the Canada and Eurasian basins were formed during a single period of scissor-like rifting (*5*), it is difficult to explain the Lomonosov Ridge, a narrow, presumably nonvolcanic, continental outlier that is oriented at right angles to the direction of rift but seems not to be offset (*38*). A south-trending belt of deformed Paleozoic sialic rocks on the northern coast of Ellesmere Island has been found to line up with the submarine Lomonosov Ridge (*28*), supporting the view that the ridge is of continental origin. Furthermore, both the Alpha and Nansen cordillera that have been interpreted as mid-oceanic ridges are oriented nearly parallel to the Lomonosov Ridge, and they also seem not to be offset by the postulated rift. When the Arctic basin is considered as a whole, the large differences between the Canada and Eurasian basins indicate that its overall tectonic history has been far too complicated to be explainable by a single episode of rifting. It is readily apparent from the bathymetry that the Eurasian basin is elongated at right angles to the Canada Basin. The Eurasian basin contains the seismically active Nansen Cordillera, a youthful extension of the mid-Atlantic Ridge (*39*), whereas the Canada Basin, with its inactive Alpha Cordillera, probably is a much older depression.

One other possible explanation of the bend in Alaskan structures—an explanation that I favor and that does not require the proposed scissor-like rifting hinged at a point in southern Alaska—is that there was a long period of regional stress oriented against the continental margin in the Gulf of Alaska. In the center of Alaska, north of the Alaska Range, volcanic-rich geosynclinal rocks form a wedge against the attenuated carbonate shelf (*8* and Fig. 1). These geosynclinal rocks, by analogy with the present-day development of geosynclines along continental margins, probably reflect in their distribution much of the original curvature of the continental margin in Paleozoic time. Originally the curve in the distribution of the Paleozoic geosynclinal rocks may have been less pronounced than it is now, and more like the bend in the continental margin in the Gulf of Alaska today. This is because the geosynclinal rocks, especially those along the axis of the Alaska orocline, may have been displaced structurally northward on large transcurrent faults and related thrust faults, perhaps as a result of continued stress against the southern continental margin of Alaska in Mesozoic to Recent time (*8*). These structures, in turn, may be the result of thrusting of the Pacific floor against the continental margin in the Gulf of Alaska—a hypothesis supported by studies of magnetic anomalies (*36*), faults and folds in Cenozoic rocks in the Gulf of Alaska (*40*), and land movements associated with the Alaska earthquake of 1964 (*41*).

Still another explanation of the bend in the strike-slip faults of Alaska, suggested by Grantz (*42*), involves the hypothesis of continental drift (which, again, may be related to sea-floor spreading). According to Grantz, the Alaska orocline "may be the eastern half of a large buckle in western Alaska and the Bering Shelf, produced mainly by drift of North America relatively toward Eurasia, and not simple rotation of North America about a pivot in central Alaska." The large bends in structures of southern Alaska and the northeastern U.S.S.R. could be a product of some relative movement between North America and Asia. However, large-scale drift that once brought these continents together is not likely, because the geologic trends for Alaska match those for the northeastern U.S.S.R. not only for the Cenozoic (*43*) but also for the Paleozoic (*8*, *21*).

Economic Implications

Since large reserves of petroleum have been discovered in Paleozoic and Triassic rocks at Prudhoe Bay and Sag River on the Arctic coastal plain of Alaska (*44*), it is important to make regional correlations in the Arctic to determine the extent of this petroleum province. If the Paleozoic stratigraphic belts of northern Alaska continue into the Canadian Arctic Islands, as I believe the available data indicate, then it appears that large areas of these islands and the intervening Mackenzie River delta are excellent prospects for petroleum exploration.

Summary

The geology of the margin of the Canada Basin, together with geophysical data, leads me to reject the continental subsidence theory for the origin of the deep Canada Basin. Instead, the Canada Basin is, I believe, a true and probably very ancient ocean basin floored by oceanic crust and rimmed by an early Paleozoic geosynclinal belt. In the Upper Devonian, uplifts in this circumarctic geosyncline, accompanied by granitic intrusion, produced a wedge of coarse clastic sediments (exogeosyncline) that spread southward onto adjoining areas of Alaska, Canada, and Siberia. In both northern Alaska and the Canadian Arctic Islands, thick sequences of upper Paleozoic and younger strata were deposited unconformably on the rocks of the early Paleozoic geosyncline, showing a similarity in tectonic history between the areas.

The Paleozoic history of the southern rim of the Canada Basin resembles that of other mobile belts bordering North America. The movement of the floor of the Arctic Ocean against the continental crust of North America (sea-floor spreading) would provide a mechanism to account for the long history of orogenic activity along the basin margin.

The sharp bend in the structural elements of southern Alaska (the Alaska orocline) has been cited as evidence of clockwise rotation of the Arctic Islands of Canada from Alaska and the Soviet Arctic to their present position during the Mesozoic. However, the geologic and geophysical evidence available indicates that the Arctic basin has a longer history, extending into the Paleozoic, and that this bend in Alaskan structures may have been largely caused by spreading of the Pacific sea floor against the continental margin in the Gulf of Alaska.

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