448

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PALEOZOIC AND PRECAMBRIAN ROCKS OF ALASKA AND THEIR ROLE IN ITS STRUCTURAL EVOLUTION

By

Michael Churkin, Jr.

Open-file report

1970

This report is preliminary
and has not been edited or
reviewed for conformity with
Geological Survey standards

Contents

Page

Illustrations

Paleozoic and Precambrian rocks of Alaska

and their role in its structural evolution

By Michael Churkin, Jr.

Abstract

Acknowledging that there are large gaps in the knowledge of the geology of Alaska, the following threefold subdivision of Alaska into Paleozoic tectonic elements is proposed: Southern Alaska--the Alaska Range and farther south--is the northern end of the Paleozoic Cordilleran geosyncline that rims the eastern Pacific. Northern Alaska--the northeastern Brooks Range and the Arctic Coastal Plain--is underlain by a pre-Upper Devonian fold belt that may continue around the rim of the Canada Basin into the Franklinian geosyncline of the Canadian Arctic Islands. East-central Alaska, with a thinner, mainly carbonate rock section, seems to be a western extension of the Yukon shelf that separates the circum-Arctic geosynclinal trend from the Cordilleran geosyncline along the Pacific margin of southern Alaska.

In southeastern Alaska, deposition of graywacke, polymictic conglomerate, and argillaceous rocks interbedded with pillow basalts, breccias, and tuffs prevailed throughout most of the Paleozoic. One exception, a widespread red-bed conglomerate and cross-bedded sandstone sequence of Upper Silurian(?) and Lower Devonian age, marks a regional break in sedimentation. Local thick limestones made up of fragmented fossils indicate reef and shallow-water shell bank development. Very rapid facies changes reflect rugged bottom relief largely controlled by volcanic activity. The high proportion of volcanic rocks and some plutonic intrusions of lower Paleozoic age that have closely associated thick lenses of synorogenic boulder conglomerates imply high tectonic mobility. Isolated exposures of similar Paleozoic rocks in the Wrangell Mountains, Alaska Range, and the Alaska Peninsula, suggest that the coarse detrital-volcanic belt of southeastern Alaska rims the northern Pacific Basin and may continue west along the edge of the Bering shelf sea into the Koryak Upland of northeastern U.S.S.R. where similar sequences occur.

In northern Alaska a deformed belt of pre Upper-Devonian strata containing interlayered volcanic rocks occurs in the northeastern Brooks Range. In the Arctic coastal plain farther west boreholes have penetrated steeply dipping, weakly metamorphosed rocks that probably belong to this same fold belt, thereby suggesting that a largely buried and partially destroyed basin or geosyncline of pre Upper-Devonian age (probably early Paleozoic and late Precambrian) lies along the northern edge of Alaska. Thick sections of chert-rich detrital rocks of Upper Devonian and farther north of Mississippian age, lie unconformably on this ancestral Brooks geosyncline and were derived from uplifts within the geosyncline. These clastic deposits that are at least in part of nonmarine origin, continue around the edge of the Canada Basin from Alaska east into Ellesmere Island and west into Wrangell Island. Absolute age determinations indicate that the intrusion of granitic rocks around the margin of the Canada Basin was probably related to the same mid-Paleozoic orogeny that produced the wedge of Upper Devonian-Mississippian conglomerate and sandstone. After the Orogeny, marine shale and carbonate rock were again deposited around the edges of the Canada Basin. In the Brooks Range the base of the Carboniferous section becomes progressively younger northward, and the whole section has more terrigenous detritus in the northern parts of the Range. This northward transgression, plus the fact that the unconformably overlying Permian in bore holes north of the Brooks Range is a chert-pebble conglomerate suggests that in the late Paleozoic a source area existed in the northern Brooks Range and farther north as it had done in the late Devonian.

In east-central Alaska Cambrian through Devonian time is represented by a thin but nearly complete sequence, mainly of limestone. Along the Yukon River, which is the south edge of the Yukon shelf, thin graptolitic shale and chert and, in places, Devonian pillow basalt, indicate a transitional facies into the Cordilleran geosyncline farther south. In the late Devonian, thick nonmarine conglomerate and sandstone were apparently derived from uplifts within the nearby geosyncline, starting the upper Paleozoic cycle of higher tectonic activity in the interior parts of Alaska. Carboniferous rocks in east-central Alaska form a thin sequence of interbedded limestone, shale, and chert. Pre-Permian erosion has removed most of the Carboniferous, and the Permian is a thin sequence of conglomerate, sandstone, and limestone.

Nonvolcanic, nearly pure carbonate sections in the Seward Peninsula and in parts of southwestern Alaska, especially those representing the lower Paleozoic, suggest that the carbonate shelf type of sedimentation characteristic of east-central Alaska may have extended into western Alaska. Similar strata on St. Lawrence Island and on Chukotsk Peninsula indicate that this belt of mainly carbonate rock continues west across the Bering Straits thereby linking the geology of Alaska to Asia.

During the Mesozoic and Cenozoic the broad Paleozoic stratigraphic belts of Alaska were deformed into a large number of troughs and uplifts. Batholithic intrusions, volcanism and metamorphism together with penetrative folding and faulting during the multiple episodes of Mesozoic and Cenozoic orogeny have largely obscured the Paleozoic and older structures. However, the patterns of basins and uplifts in the Mesozoic and, to a lesser degree, in the Tertiary tend to follow the trend of the Paleozoic stratigraphic belts that form their basement.

Around the rim of the northern Pacific basin there are obvious extensions of the fold belts of Alaska into Yukon Territory and British Columbia on the south and Chukotka (northeasternmost U.S.S.R.) on the west. Another, though less obvious, correlation of fold belts is around the edge of the Canada Basin.

In evaluating continental drift in the Arctic, there is no direct evidence for large scale drift between Alaska and Chukotka. In fact, the North American and Eurasian continents probably were connected across the Alaska-Chukotka isthmus during the time of major drift in the Atlantic.

Sea floor spreading that formed the Atlantic Basin seems to have extended across much of the Eurasia Basin part of the Arctic. The bends in various large scale structures in Alaska and Chukotka may be in part results of compression in this narrow continental segment linking Eurasia and North America as the two continents separated across the Arctic and northern Atlantic.

Introduction

Alaska, being a narrow isthmus connecting North America to Eurasia, is a key to understanding the geologic correlations around the northern Pacific on the one hand and the geology of the circum-Arctic areas on the other. Besides serving as a link between North America and Eurasia, Alaska is important in evaluating the ancient histories of the Arctic and northern Pacific Oceans through a study of its continental margins. Finally, Alaska plays a vital role in testing theories of continental drift and sea floor spreading in the Arctic.

Although a number of stratigraphic and tectonic summaries of Alaska have been made, these have focused mainly on Mesozoic and Tertiary rocks (Mertie, 1930b;Smith, 1939; Eardley, 1948; Payne, 1955; Gates and Gryc, 1963). Knowledge of Paleozoic and Precambrian rocks in Alaska has substantially increased since Schuchert's first maps covering North America were published in 1910. To date, however, there is no regional synthesis of the Paleozoic or Precambrian history of Alaska using the latest data to make modern correlation diagrams, lithofacies maps, and paleotectonic maps useful in interpreting earth history. It is my goal here to summarize the present knowledge of the Paleozoic and Precambrian rocks of Alaska and to interpret their role in its tectonic and structural development.

The paper has two parts: 1) regional stratigraphy and 2) tectonic and structural history. The first part attempts a systematic summary of Precambrian and Paleozoic rocks found in Alaska. The second part of the paper is the writer's interpretation of the tectonic and structural evolution of Alaska based on the data presented in the first part and on structural and geophysical data. Because of the great variation in the level of our knowledge of the different areas of Alaska and for the sake of brevity, only the more thoroughly studied stratigraphic successions are discussed. This is done by showing the most important columnar sections for each geologic province. A list of the major literature references is given to guide the reader in obtaining details.

Acknowledging that there are big gaps in the present knowledge of the Paleozoic rocks of Alaska, especially in its southwestern and central interior parts, the writer proposes a three fold tectonic subdivision of Alaska (figs. 1, 17).

Figure 1 near here

Apparently, during most of Paleozoic time sedimentation in Alaska was controlled by the Cordilleran geosyncline in its southern part and by several geosynclinal cycles in northern Alaska along the southern edge of the Arctic Basin. In the interior of Alaska the Paleozoic record is less clear, but at least in east-central Alaska a western extension of the Yukon shelf seemed to have separated these two geosynclinal trends.

Detailed stratigraphic studies have been made in some areas in conjunction with reconnaissance geologic mapping. However, in most places where Paleozoic rocks have been mapped, their ages and stratigraphic succession are poorly known because of structural complexities and incomplete knowledge of fossils and other tools for correlation. The stratigraphic sequences of east-central Alaska and southeastern Alaska are emphasized because they are among the most thoroughly studied, seem to be the most complete, and are the most familiar to me. It must be emphasized that the correlations, and consequently the general interpretations offered, are only preliminary. The accelerated program of geological exploration that has started with the discovery of large oil reserves along the Arctic coast of Alaska will provide much-needed subsurface information that could result in major changes in even the broadest tectonic outline.

For a summary of the Paleozoic stratigraphy and tectonic history of Canada adjacent to Alaska the reader may refer to Gabrielse (1967), Gabrielse and Wheeler (1961), and Ziegler (1969). For a regional analysis of parts of the Soviet Union adjacent to Alaska the following references are useful: (Belyi, 1964; Bogdanov, 1963; Bogdanov and Tilman, 1964; Egiazarov and others, 1965; Gnibidenko, 1969; Krasniy, 1966; Tilman, 1962; Yanshin, 1966.

Acknowledgments

Most of the references to geological investigations in Alaska that are cited here are publications of the U. S. Geological Survey--the organization long responsible for systematically exploring and mapping Alaska. Acknowledgment is due the entire staff of the Alaskan Mineral Resources Branch and to its chief, George Gryc, for making available the latest data. Specific recognition is due the following members of the Survey: E. E. Brabb, for valuable discussions of the stratigraphy and structure of east-central Alaska; D. A. Brew, for familiarizing me with the stratigraphy of the Freshwater Bay-Glacier Bay areas; W. P. Brosgé and Hillard Reiser, for much information on the Brooks Range; R. Chapman, F. Weber and R. Foster, for helicopter reconnaissance and much information on the Livengood district; R. L. Detterman and B. L. Reed, for information on the Alaska Peninsula; G. D. Eberlein, for much of the basic knowledge of the stratigraphy in southeastern Alaska; R. Forbes for information on the Birch Creek Schist; J. M. Hoare and W. H. Condon for data concerning southwestern Alaska; E. H. Lathram, for stimulating discussions on the tectonics of northern Alaska; E. M. MacKevett and J. G. Smith for information on the Wrangell Mountains; L. J. P. Muffler, for a tour of the Kuiu Island area; A. T. Ovenshine, for conodont correlations and Silurian-Devonian stratigraphy of the Kosciusco Island area; W. W. Patton, for data on the Koyukuk River area and St. Lawrence Island; G. Plafker, for discussion of how earth movements in the Gulf of Alaska associated with the 1964 earthquake may relate to the tectonic development of Alaska; B. L. Reed, for acquainting me with part of the Alaskan Range and for

(p. 9a follows)

structural information in the northeastern Brooks Range; D. H. Richter, for data on the stratigraphy of the eastern Alaska Range; C. L. Sainsbury, for an excursion and much structural and stratigraphic information on the Seward Peninsula, and to I. L. Tailleur for information on the structure and stratigraphy of the western Brooks Range.

Special thanks are given to the many paleontologists of the Survey, without whose interest in Alaskan fossils many of the correlations would not have been possible. The "Annotated Bibliography of Alaskan Paleozoic Paleontology" (Dutro, 1956) conveniently summarizes much of their earlier work. More recently, the following paleontologists have been especially helpful in identifying Alaskan Paleozoic fossils: A. K. Armstrong, Jean Berdan, Claire Carter, Helen Duncan, R. C. Douglass, J. T. Dutro, Jr., R. E. Grant, J. W. Huddle, S. H. Mamay, W. A. Oliver, Jr., A. R. Palmer, R. J. Ross, Jr., R. A. Scott, and E. L. Yochelson.

I am especially grateful to the Canadian geologists: J. W. Kerr, J. A. Jeletzky, H. P. Trettin, D. E. Jackson, A. C. Lenz, B. S. Norford, P. A. Ziegler, and E. W. Bamber, and to many Soviet geologists including: N. A. Bogdanov, V. F. Belyi, B. Kh. Egiazarov, G. S. Gnibidenko, Yu. A. Kosygin, L. I. Krasniy, Yu. M. Puscharovsky, and A. L. Yanshin for discussion and much information on the geology of neighboring parts of Canada and Siberia. Thanks are due to the U.S. and Soviet Academies of Sciences for sponsoring my visit to the U.S.S.R. in 1967 and to the Geological Survey of Canada for arranging exchange visits of L. H. Green, E. W. Bamber and J. W. Kerr to Alaska.

Stratigraphy

Precambrian

Until recently, large areas of metamorphic rocks in the central and southern parts of Alaska were considered Precambrian (Smith, 1939; Dutro and Payne, 1957). With the realization that younger formations extend into these areas of high metamorphism, many of these metamorphic complexes are now considered as embracing much younger rocks. Radiometric dating has shown that the metamorphism in the Yukon-Tanana Upland, thought to be dominantly Precambrian, is in some part Mesozoic (Wasserberg and others, 1963). One difficulty in determining that any rocks are Precambrian is that only in a small area of east-central Alaska are there rocks that can be definitely recognized as Cambrian by their fossil content. These are known to stratigraphically overlie still older rocks--the Tindir Group. As a result, many of the previous Precambrian assignments outside this small area, especially in the case of metamorphic rocks, are somewhat in doubt (fig. 2).

Figure 2 near here

Unmetamorphosed rocks.--The term Tindir Group was first applied to a thick sequence of unmetamorphosed sedimentary rocks that conformably underlies fossiliferous Middle Cambrian limestone along the Alaska-Yukon Territory boundary (Cairnes, 1914). Mertie (1933) studied the Tindir in the vicinity of the Yukon River where it is best exposed and subdivided it into seven units.

More recently part of this area was mapped and studied in greater detail (Brabb and Churkin, 1965; 1969). The following five map units, totaling over 11,000 feet, were then established:

Lower Cambrian

Adams Argillite: argillite, siltstone and quartzite; rare limestone lenses and greenstone. Contains archaeocyathids, trilobites, worm(?) burrows and Oldhamia, 300-600 feet thick.

Funnel Creek Limestone: massive limestone and dolomite. Nonfossiliferous. 1,000-1,300 feet thick.

Upper Precambrian

Tindir Group

Thin-bedded limestone member: dark-gray laminated limestone with slabby and platy partings; interbeds of greenish-gray shale, siltstone and sandstone; minor sandy limestone, laminated dolomite, calcareous dolomite and chert-carbonate gritstone. 800-1,500 feet thick.

Dolomitic sandstone and shale member: light-gray, thin- to medium-bedded doloarenite and olive-gray shale; minor gritstone and conglomerate. About 2,500 feet thick.

Basalt and red-bed member: dark-greenish-gray basalt, commonly amygdaloidal and with pillow structure; minor basaltic tuff. Red and grayish-red hematite-rich shale and siliceous iron formation; minor greenish-gray shale, jasper, greenstone-dolomite conglomerate, and vitric tuff and lava, largely replaced by hematite and carbonate. 2,500 feet.

Massive dolomite member: light- to medium-gray, laminated, cliff-forming dolomite; minor chert, doloarenite, silicified dolomite breccia, dolomite-chert gritstone, and dark-gray shale. Cut by diabase dikes. about 3,000 feet thick.

Shale member: grayish-black carbonaceous shale; minor interbeds of quartzite, limestone, and dolomite. Some lenticular medium-gray stromatolite-bearing limestone. Cut by diabase dikes. Base apparently not exposed. A few thousand feet thick.

Diabase dikes, especially abundant in the lower parts of the Tindir, are probably related to the implacement of the stratigraphically higher lavas.

The rhythmically bedded siliceous iron formation that is associated with the conglomerate of mixed composition and the mafic volcanic rocks in the Tindir Group is probably correlative with similar iron-rich beds of the Rapitan Formation (Gabrielse, 1967) in Yukon Territory.

Cairnes (1914, p. 56) originally thought that the Tindir Group was entirely Precambrian or that it may have included Early Cambrian at its top. Mertie (1933, p. 392) considered the Tindir as probably entirely Precambrian, but the oldest fossils then known above the Tindir were Middle Cambrian trilobites. More recent work has shown that archaeocyathids of lowest Cambrian age occur 500 feet above the highest unit of the Tindir (Brabb, 1967). Furthermore, early Cambrian trilobites and archaeocyathids occur in the Adams Argillite more than a thousand feet above the top of the Tindir but no definite discontinuity has been recognized as separating these fossiliferous horizons from the Tindir (Brabb, 1967; Palmer, 1968). Thus, the top of the Tindir Group is considered by Brabb (1967) to mark the top of the Precambrian in east-central Alaska.

The only fossils known from the Tindir are well preserved stromatolites (laminated algal structures) from lenticular limestone in the dolomite and shale unit of the Tindir some 8,000 feet below the early Cambrian fossils (Brabb and Churkin, 1969). A preliminary examination of these stromatolites indicates a close similarity to stromatolites in rocks of late Middle Riphean age from the Aldan Shield of Siberia (M. A. Semihatov, written commun., 1968).

Lithologically, the Tindir resembles the Belt series exposed in more southerly parts of the Cordillera. A direct biostratigraphic correlation of the Tindir with the Belt however, has not been possible because the stromatolites in the Belt, unlike those in the Tindir are not of the columnar or cone-shaped types found to be useful for correlation (Semihatov, oral commun., 1969). A comparison of radiometric dates from the Belt (Obradovich and Peterman, 1968) with those from the Late Precambrian of Siberia suggests indirectly that the upper part of the Tindir is late Middle Riphean in age (950 - 1350 $\pm$ 50 m.y., Semihatov, oral commun., 1969) and correlates with the upper part of the Belt Series.

The base of the Tindir is not known, but rare boulders of granitic rock and gneiss in the upper part of the Tindir suggest that an igneous and metamorphic basement of earlier Precambrian age is not far away. Metamorphic rocks in the Yukon-Tanana Upland have been postulated as representing this earlier Precambrian (Mertie, 1937b), but isotope dating of these rocks has generally not verified their postulated Precambrian age.

In the western part of the Charley River quadrangle, 50 to 70 miles west of the Tindir type area, are unmetamorphosed sequences of limestone, argillite, basaltic lava, and distinctively laminated dolomite that resemble the rocks of the Tindir Group (Brabb and Churkin, 1965). Stromatolites like those in the dolomite and shale member of the Tindir (Semihatov, written commun., 1968) also occur in these western exposures, indicating a much larger distribution of Late Precambrian rocks in east-central Alaska than formerly recognized. Similarly laminated dolomites, again closely associated with basaltic lavas but containing nondiagnostic stromatolites that may be either Proterozoic or Paleozoic (Semihatov, oral commun., 1969), also occur in the Livengood district still farther west (Churkin, unpublished field data).

Along the Porcupine River, some 150 miles north of the Tindir section on the Yukon River, rocks included in the Tindir Group (Cairnes, 1914) are mainly quartzite and dolomite. The following is a composite section made from exposures within a 5 mile distance upstream and downstream from New Rampart House where the International border crosses the Porcupine River (Brosgé and others, 1966):

Devonian

Massive dolomite and limestone. Abundant *Amphipora* and *Cladopora*

Fault Zone

Precambrian (?)

"Tindir Group"

Argillaceous dolomite member: thin-bedded to laminated, platy and slabby. Black chert nodules and layers. About 400 feet thick.

Massive upper dolomite member. About 400 feet thick.

Black shale and thin-bedded limestone member. About 300 feet thick.

Lower dolomite member. About 200 feet thick.

Upper quartzite member: very light-gray, fine-grained, thin-bedded and cross-laminated. About 800 feet thick.

Sandstone and shale member: interbedded quartz-arenite, shale and siltstone; weathers grayish-red. About 250 feet thick.

Lower quartzite, white to light-greenish-gray, fine-grained, cross-laminated. More than 300 feet thick.

Total of 2,650 feet of rock exposed.

Base of section covered.

Correlation of this Porcupine River section with the Yukon River section of the Tindir is not possible with the data at hand. The Porcupine River "Tindir" has some of the lithologies exposed farther south, but has proportionately more dolomite and quartzite and less shale (fig. 3). A brachiopod and gastropod collection from a quartzite

---

Figure 3 near here

---

section 50 miles north of the Porcupine River suggests that some of the Tindir-like rocks in this area may be Paleozoic (Brosgé and Reiser, 1969).

<u>Older schists of uncertain age.</u>--The name "Birch Creek Schist" was first applied to schists in the Circle, Fairbanks, and Fortymile mining districts of the Yukon-Tanana Upland (Spurr, 1898). Various authors subsequently extended the term to include most of the high-grade metamorphic rocks in the interior of Alaska north of the Alaska Range. Then followed a period of restricting the term to include only rocks thought to be Precambrian (Mertie, 1937b). Originally the Birch Creek Schist was assigned to the Precambrian on the basis of its apparent structural position below Paleozoic rocks and its high metamorphic grade. This Precambrian age assignment has continued (Mertie, 1937b;Dutro and Payne, 1957) but without conclusive confirmation of its age based on stratigraphic relations.

The Birch Creek Schist in its type area consists largely of quartz-mica schist and chlorite schist produced apparently by regional metamorphism of mainly sedimentary rocks. Minor amounts of gneiss, marble, serpentine, and greenstone are interlayered with the schist. Well-developed zones of contact metamorphism border most of the granitic intrusions in the Birch Creek Schist. Isotopic measurements using Rb/Sr and K/Ar on micas from the schist and on granites intruding it indicate that the Birch Creek has been partly recrystallized at about 180 m.y. in conjunction with the granitic intrusions (Wasserburg and others, 1963). Besides the usual Mesozoic dates, a 474 ± 35 m.y. date has been obtained analyzing K/Ar from hornblende in the Schist (Forbes and others, 1968). According to Forbes, this early Paleozoic date on the polymetamorphic rocks of the Birch Creek lends support to their being derived in part by metamorphism of Precambrian rocks.

Recent mapping in the Yukon-Tanana Upland (Brabb and Churkin, 1969; H. L. Foster, 1969), the Fairbanks district (Péwé and others, 1966; Forbes and others, 1968) and the northern Alaska Range (Wahrhaftig, 1968; J. Hoare, unpublished data, 1967) indicates that the Birch Creek Schist terrain is composed of polymetamorphosed sequences in which the metamorphic grade as determined by different mineral assemblages changes from place to place. Some of these mineralogical changes accompanied by changes in penetrative structures are abrupt and according to Forbes and others (1968) can be related to juxtaposition of different metamorphic facies by faulting. In the Charley River quadrangle southeast of its type area the biotite- and garnet-bearing Birch Creek Schist grades irregularly into or in places is faulted against lower grade chlorite and sericite schists, phyllite, and sheared conglomerate and chert (Brabb and Churkin, 1969).

In the lower grade rocks relics of original sedimentary layering are readily visible, and in several places marble interstratified with schist contains crinoid columnals (Mertie, 1930b, p. 44) presumably of Paleozoic but possibly younger age. Two of these crinoid localities are especially significant because they occur in rocks along the international boundary that were mapped by Cairnes (1914) as part of the Yukon Group that he considered to be Precambrian in age and to include the Birch Creek Schist.

Fossil fungi of probable Paleozoic age (P. E. Cloud and G. Lucari, oral commun., 1968) have also been identified from within this belt of lower grade rocks.

North and west of its type area the Birch Creek Schist is again rimmed by a belt of lower grade metamorphic rocks. Remnants of shelly fossils in highly deformed and recrystallized limestones in the Crazy Mountains and farther west in the Livengood area indicate that these low grade metamorphic rocks are at least in part Phanerozoic in age (R. Chapman, F. Weber, and M. Churkin, Jr., unpublished field observations). The presence of the trace fossil Oldhamia in phyllitic shale interbedded with quartzite indicates that part of this sequence is probably Cambrian (Churkin and Brabb, 1965b). Positive evidence that the Birch Creek Schist is derived in part from Precambrian strata depends on future isotopic dating of some relic minerals that have not been recrystallized by the Mesozoic intrusions and later structural events, or by definitely establishing the stratigraphic position of the Schist below an as yet undiscovered fossiliferous section of Cambrian age.

In the highlands between the Yukon and Kuskokwim Rivers of western Alaska (fig. 2) there are extensive areas of metamorphic rock whose age has not been accurately determined. These schists, although sometimes correlated with the Birch Creek Schist, are also without any positive evidence of their age.

In Seward Peninsula the oldest rocks long thought to be Precambrian are slate and sandstone at the west tip of the Peninsula and schists of the Kigluaik and Nome Groups in the vicinity of Nome (Moffit, 1913). The Port Clarence Limestone of Ordovician age, the oldest fossil-bearing rock in Seward Peninsula, was believed to overlie these weakly metamorphosed slates of supposed Precambrian age (Collier, 1902; Steidtmann and Cathcart, 1922). Regional mapping by Sainsbury (1969a) indicates that the Ordovician limestones are not in stratigraphic contact with the underlying slate but instead are thrust over the slate. According to Sainsbury (1969a), the Ordovician limestone is conformably underlain by a nonfossiliferous argillaceous and dolomitic limestone sequence several thousand feet thick that could include rocks of Cambrian or even late Precambrian age. The Kigluaik Schist exposed in the west-central part of Seward Peninsula presents the best evidence that it and other high-grade metamorphic rocks in the area are considerably older than the surrounding lower Paleozoic limestones and may be Precambrian. The Kigluaik Schist, consisting mainly of mica-schist, is exposed in a long west-trending structural arch that exposes higher grade gneisses in its core (Collier and others, 1908; Sainsbury, oral commun., 1968). The schistosity and compositional layering are arched along the axis of the structure, and lower grade schists interlayered with marble form the structurally higher parts of the sequence (Sainsbury, oral commun., 1968). Massive limestones rich in lower Paleozoic fossils flank this arch and are essentially unmetamorphosed thereby suggesting that they are considerably younger than the schists.

(p. 22a follows)

Radiometric dating using K/Ar isotopes of metamorphic rocks and associated intrusions in the Seward Peninsula generally indicate metamorphic-plutonic events of Mesozoic age (Sainsbury, 1969a). In exception, Sainsbury (written commun., 1970) has obtained a 750 m.y. date on gneiss from the core of the Kigluaik Mountains using the Rb/Sr whole-rock method. A dike cutting this gneiss, according to Sainsbury, gives a 450 m.y. Rb/Sr date.

Metamorphic rocks with structural and stratigraphic relations similar to those in Seward Peninsula have been described from Chukotsk Peninsula across the narrow Bering Strait (Belyi, 1964; Krasniy, 1966, p. 46; Gnibidenko, 1969). Based largely on their high metamorphic grade, these rocks in Chukotka have generally been considered Precambrian (Tilman, 1962; Belyi, 1964). Radiometric dating (24 separate analyses) shows that in the Chukotsk Peninsula as in other metamorphic terranes around the northwestern Pacific, the age of the metamorphism ranges from Paleozoic to Mesozoic but is mostly Mesozoic in the interval of 130 to 60 m.y. (Gnibidenko, 1969). In eastern Chukotka a number of much older dates, ranging from 1500 to 700 m.y., have been obtained on rocks in the same vicinity as those giving much younger dates (Gnibidenko, 1969). This suggests some Precambrian rock may be involved in the mainly Mesozoic metamorphism. It seems reasonable to consider these metamorphic rocks as earliest Paleozoic where they grade into fossiliferous Paleozoic rocks and as provisionally Precambrian where there is a sharp structural break between them and fossiliferous lower Paleozoic rocks.

In addition to the belt of metamorphic rocks across the center of Alaska, there are metamorphic rocks in other regions of Alaska that some have suspected of being early Paleozoic in age and others have suspected of being Precambrian—the Wales Group of southeastern Alaska (Buddington and Chapin, 1929); a narrow belt along the southern margin of the Brooks Range (Patton, 1957; Brosgé, 1960); and the Neruokpuk Schist of the northeastern Brooks Range (Brosgé and others, 1962; Reiser, 1970). These rocks, without further work, cannot be accurately dated but almost certainly include rocks of Paleozoic age. The occurrence of any strata conclusively dated as Precambrian in these metamorphic complexes has not been recorded. However, the knowledge that granitic rock intruding the Neruokpuk Formation is 430 ± m.y. old (Reiser, 1970) indicates that some earliest Paleozoic and possibly older strata may be included in the metamorphic rocks of the northeastern Brooks Range.

Lower Paleozoic cycle of sedimentation

The Cambrian through Middle Devonian rocks in east-central Alaska seem to be part of a cycle of nearly continuous sedimentation. In contrast, starting in the Late Devonian, apparently older geosynclinal rocks within the Cordilleran and ancestral Brooks geosynclines were uplifted, and wedges of coarse siliceous sediments, in part nonmarine, were deposited towards the interior of Alaska.

Cambrian

Cambrian rocks have been found in Alaska only in a small area at the west end of the Ogilvie Mountains where the Yukon River crosses the International boundary (fig. 4). Fossils of definite Cambrian age

---

Figure 4 near here

---

were first reported here by Cairnes (1914), and the stratigraphic succession has been subsequently described by Mertie (1933) and Brabb (1967). Kobayashi (1935) and Palmer (1968) have described the trilobite and brachiopod faunas.

The Cambrian in most of this area is represented by a limestone and dolomite section that has shale and quartzite in its middle part (fig. 3). In exception the Cambrian exposures in the northeastern part of the area (Jones Ridge to Squaw Mountain) are all limestone and dolomite. The contact of the Cambrian with rocks of the Tindir Group is accordant and probably conformable. The Hillard Limestone at the top of the Cambrian section is overlain by chert and shale (Road River Formation) that has rich late Lower Ordovician graptolite fauna in its basal part (Churkin and Brabb, 1965a). The Road River Formation rests unconformably on different beds of the Hillard Limestone ranging in age from early Upper Cambrian to early Lower Ordovician (Brabb, 1967) (fig. 3).

Abundant specimens of Oldhamia, a fan-shaped trace fossil of probable Cambrian age that occurs in the Adams Argillite, also occur in similar argillite and quartzite near Mount Schwatka and in the Crazy Mountains (fig. 4) about 180 and 100 miles.

respectively, west of the Cambrian section along the International boundary. This suggests that large areas of terrigenous rocks in the central interior of Alaska mapped originally by Mertie (1937b) as "undifferentiated noncalcareous rocks of Devonian age" or as "undifferentiated noncalcareous rocks of Mississippian age" include much older rocks of probable Cambrian age (Churkin and Brabb, 1965b).

Other areas in which Cambrian rocks may eventually be recognized are primarily the areas of Ordovician outcrop shown in figure 5.

Figure 5 near here

Especially promising are the well-bedded limestone sequences on Seward Peninsula where, according to Sainsbury (1969a), there are thousands of feet of argillaceous and dolomitic limestone stratigraphically below massive limestone bearing Lower Ordovician fossils.

Ordovician

Ordovician rocks of different facies have been recognized in many widely separated areas of Alaska (fig. 5). The stratigraphic succession within these areas of Ordovician, however, is known in any detail only in the Eagle area of east-central Alaska (Churkin and Brabb, 1965a), in the Craig area of southeastern Alaska (Eberlein and Churkin, 1970), and in Seward Peninsula (Sainsbury, 1969a). The remaining areas of Ordovician rock shown on figure 5 either have Ordovician fossil collections made during the earliest reconnaissance surveys (localities 2, 3, 4) or are structurally complex areas in which the stratigraphic relations of the Ordovician rocks to other rocks is unknown (localities 5,7).

Two facies of Ordovician rocks are developed in the Charley River area near the International Boundary (fig. 6). Along the south edge

---

Figure 6 near here

---

of the area graptolitic shale and chert (Road River Formation) form a belt that extends for 35 miles along the Yukon River. Only 7 miles north of exposures of the graptolite shale facies is a contemporaneous pure limestone section (Jones Ridge Limestone) that is several times as thick as the graptolitic shale. This abrupt change in lithology is believed to reflect a rapid facies change and is comparable to similar changes of graptolite shale into carbonate rock farther east in Yukon Territory (Churkin and Brabb, 1967).

The graptolitic shale and chert section, Road River Formation, rests unconformably on the Hillard Limestone. The base of this section is marked by a few feet of black bedded chert and chert conglomerate containing a coquina of phosphatic shells of the pod-shaped crustacean, Caryocaris (Churkin, 1966). A rich sequence of graptolite faunas indicates that the Road River includes all of the Ordovician except for the earliest Ordovician (Tremadocian and lower part of the Arenigian). The Road River Formation is discontinuously exposed, but in all the sections that span the Ordovician-Silurian boundary there is no evidence of a stratigraphic break coinciding with the systemic boundary (Churkin and Brabb, 1965a).

In the Jones Ridge area near the Alaska-Yukon Territory boundary the Ordovician is represented by pure limestone except for a 60 foot largely covered interval of chert, shale, and minor limestone that may represent a wedge of Road River Formation lithology (Brabb, 1967). Farther north, along the international boundary the Ordovician seems to be represented by a pure limestone section that continues north as far as the Porcupine River. Along the Porcupine River itself, there are a few outcrops of very fine grained limestone that contain the easily identifiable tabulate coral Tetradium together with other Ordovician shelly fossils (Kindle, 1908; Brosgé and others, 1966).

Outside of east-central Alaska the only other areas with Ordovician sections that are mainly carbonate rock lie in western Alaska. In the Seward Peninsula the Port Clarence Limestone and a number of mappable subdivisions consist mainly of limestone but also have dolomitic and argillaceous interbeds. In the central York Mountains these rocks aggregate at least 8,000 feet in thickness and represent Early, Middle, and Upper Ordovician (Sainsbury, 1969a).

Farther south in the upper reaches of the Kuskokwim River, northeast of McGrath, Ordovician shelly faunas have been reported from a nearly pure limestone and dolomite section (Eakin, 1918; Brown, 1926). The Holitna Group of essentially pure carbonate rock further west in the central Kuskokwim area may also be Ordovician because Silurian and Devonian faunas were collected from the upper horizons of the Holitna Group (Cady and others, 1955). Further south in the White Mountain area, Ordovician fossils were found in limestone sections that have many interbeds of argillaceous, silty, and sandy rocks (Sainsbury, 1965). Very similar Ordovician limestones on Chukotsk Peninsula (Krasniy, 1966, p. 74; S. G. Byalobzheskii, oral commun.; Gnibidenko, 1969) suggest this belt of carbonate rock in west-central Alaska continues from Seward Peninsula west beneath the Bering Strait to the northeastern tip of U.S.S.R.

In the Terra Cotta Mountains of the Alaska Range south of Farewell, a thin though relatively complete section several thousand feet thick of graptolitic shale interbedded with limestone and sandstone has been established as ranging in age from the earliest Ordovician through the Silurian (M. Churkin and B. L. Reed, unpublished data). These sections in the Alaska Range, like the Road River Formation farther east, suggest a transition from the carbonate rock facies exposed in isolated areas across the center of Alaska to the coarse detrital rock sequences of southeastern Alaska.

In contrast to the predominantly carbonate facies of Ordovician rock in the interior and western parts of Alaska, a thick sequence of graywacke, argillaceous rock, and conglomerate rich in volcanic detritus and interlayered with pillow lavas, tuffs, and breccias is exposed in southeastern Alaska (Buddington and Chapin, 1929; Sainsbury, 1961; Eberlein and Churkin, 1970). Limestone is absent in this sequence except for occasional thin lenses of nonfossiliferous dark limestone and for rare cobbles and boulders of dense limestone in graywacke conglomerates rich in volcanic detritus.

Graptolite faunas in this sequence indicate all of the major subdivisions of the Ordovician are present except for the lower parts of the Early Ordovician (Tremadocian and lower Arenigian) which may be present but may not be exposed since the base of the section is not known. Deposition of the graywacke-volcanic assemblage was continuous through most of the Ordovician and Lower Silurian (Llandoverian) but changed locally into very thick limestone accumulation by Middle Silurian (Wenlockian) time (Eberlein and Churkin, 1970).

The volcanic rocks that appear sporadically throughout the entire Paleozoic section of southeastern Alaska are alkali-rich basaltic to andesitic pillow lavas, breccias, and tuffs grading in many places into volcanic conglomerates and sandstones. Graptolites from inter-bedded shales in the lower part of the section date a succession of submarine volcanism from different centers during Early Ordovician through Early Silurian time.

Local disconformities and thick wedges of volcanic boulder conglomerate indicate repeated uplift that was in part probably related to volcanism. A potassium-argon isotope date of 446 ± 22 m.y. on a quartz monzonite pluton in Prince of Wales Island (Lanphere and others, 1964) further indicates that a period of magma generation accompanied the orogenic activity. Granitic boulders in the Ordovician conglomerates could have been locally derived from intrusions of about this age.

In contrast to the generally coarsely detrital sediments in southeastern Alaska there is a lithofacies of thinly and rhythmically interbedded black chert and siliceous graptolitic shale (member of the Point Descon Formation). These rocks in their lithology and fossils very closely resemble parts of the Road River Formation of east-central Alaska and the graptolitic shales in the Terra Cotta Mountains of the Alaska Range..

Silurian

The Silurian rocks closely parallel the pattern of sedimentary facies established in Ordovician time. Furthermore there does not seem to be a promounced break in sedimentation across the Ordovician-Silurian boundary anywhere in Alaska (Churkin, in press).

The best known Silurian rocks are in the Yukon-Porcupine River area and in southeastern Alaska (fig. 7). Other areas shown on

---

Figure 7 near here

---

figure 7 from which Silurian fossils have been reported but where the stratigraphy is less well known are the Livengood-White Mountains area; the Nixon-Fork area in the upper Kuskokwim River drainage; the middle Kuskokwim area; and the central York Mountains of Seward Peninsula.

In the southern Brooks Range, the widely distributed massive limestone (Skajit Limestone) was assigned to the Silurian until Dutro (in Brosgé and others, 1962) determined that the large brachiopods in the Skajit first thought to be Conchidium, a Silurian guide fossil, are really Stringocephalus, a cosmopolitan genus known only from the Devonian (fig. 8). More recently, a

---

Figure 8 near here

---

pentameroid brachiopod of probable Silurian age (Dutro, in Tailleur and others, 1967) is reported from limestone mapped as Skajit in the northeast part of the Baird Mountains of the western Brooks Range. Silurian and older rocks may also be present in the low-grade metamorphic belt in the southern Brooks Range, within the thick Neruokpuk Formation of the northeastern Brooks Range (especially since Silurian graptolites have been reported in close association with the Neruokpuk Formation of the Baird Mountains) and in the Sadlerochit Mountains where a thick sequence of mainly dolomite occurs below limestone of Devonian age (Dutro, 1970). A single potassium-argon isotope date of 475 m.y. on hornblende from a mafic volcanic rock in the Doonerak Mountain area of the south-central Brooks Range suggests that the volcanic rock and associated slate and shale there may be Ordovician (Lanphere, 1965), thus supporting an early Paleozoic age for some of the weakly metamorphosed nonfossiliferous rocks that are widely distributed in the Brooks Range.

A few collections from limestones on Seward Peninsula have been reported to contain Silurian and Devonian shelly fossils along with the more numerous Ordovician faunas (Smith and Eakin, 1911; Sainsbury, 1969a). Undoubtedly, with further work it will be possible to separate units of widely varying ages in this area of predominantly carbonate rocks. Work in progress by C. L. Sainsbury in the Don River area north of Teller has established a richly fossiliferous limestone-dolomite succession that spans the Ordovician-Silurian boundary with no apparent stratigraphic break. The essentially pure carbonate rocks in the Kuskokwim region suggest that this stratigraphic belt covers much of southwestern Alaska before it becomes an argillaceous facies along the southern margin of the Kuskokwim region (Cady and others, 1955).

Farther south, in the Alaska Range, Silurian rocks had not been reported until recently. The Paleozoic sequences there are mainly siliceous detrital and volcanic rocks that appear to be transitional and, in some cases, similar to the volcanic-rich siliceous detrital facies of southeastern Alaska. In 1969 the first Silurian fossils were found in this remote area (M. Churkin, B. L. Reed, and J. W. Kerr, unpublished data). They are well-preserved graptolite faunas near the top of a rather thin interval of rhythmically interbedded shale and siliceous shale. Subsequently, Silurian graptolites have been found from a number of horizons in a stratigraphically higher platy limestone and sandstone section.

In the central interior of Alaska and extending across the Porcupine-Yukon triangle is an area of discontinuous exposures of carbonate rock of Silurian age. These start in the White Mountains north of Fairbanks where the 2,500-foot-thick Tolovana Limestone rests on a thick sequence of siliceous clastic rocks and volcanics, the Fossil Creek Volcanics, reportedly of Ordovician age (Mertie, 1937b). In detail the massive Tolovana Limestone and dolomite is directly underlain by a poorly exposed section several feet thick of tuffaceous carbonate rock containing tabulate corals in growth position (M. Churkin, Jr., R. Chapman, and F. Weber, 1968, field observations). The tuff grades lower into volcanic boulder conglomerate which in turn lies on a section thousands of feet thick of siliceous clastic rocks and pillow lavas, the Fossil Creek Volcanics proper.

Farther east along the Porcupine River massive limestone and dolomite of Silurian age form high bluffs in the lower Ramparts area. A thin (100-foot thick) unit of black shale best exposed at the mouth of the Salmontrout River has Upper Silurian (Ludlovian) graptolites in its lower part and Lower Devonian graptolites in its upper part (Churkin and Brabb, 1967). Similar shale with the same Upper Silurian graptolites is exposed downstream in the Lower Ramparts where it seems to overlie the massive Silurian carbonate rocks. Thus the Silurian succession along the Porcupine River resembles the Ordovician facies on the Seward Peninsula, being mainly carbonate rock with a thin horizon of graptolitic shale. Apparently the predominantly carbonate facies exposed along the Porcupine River continues south into the Charley River quadrangle, where the Silurian section rapidly changes from carbonate rock at Jones Ridge to the pure graptolitic shale and bedded chert farther south along the Yukon River. The Silurian-Devonian boundary in the Porcupine River section as in the Yukon River Section is not marked by a stratigraphic break in graptolite succession.

From east-central Alaska this thin graptolitic shale and chert section continues eastward into Yukon Territory where it is interrupted by a thick limestone buildup in the South Illtyd Range and finally grades into a platform section of dolomite mantling the Canadian shield in Northwest Territories (Churkin and Brabb, 1967, fig. 10). In a north-easterly direction from the Charley River area the graptolitic shale and chert thicken into the Richardson Mountains, the type area of the Road River Formation (Jackson and Lenz, 1962).

9 and 10). The limestone itself varies from the light-colored massive

Figures 9 and 10 near here

sublithographic limestone that makes up much of Heceta Island (Heceta Limestone) to the dark thin-bedded argillaceous limestone (Tidal Formation) in Glacier Bay. Locally, thick lenses of polymictic conglomerate rich in volcanic detritus, limestone breccia, sandstone, and argillaceous rocks are interbedded with the purer limestone. Most of these limestones are rich in corals, stromatoporoids, brachiopods, gastropods, pelecypods, bryozoa, and calcareous algae. However, calcareous sandstone and argillite (Bay of Pillars Formation) that contains Upper Silurian graptolites show that limestone deposition in restricted areas did not commence until the Late Silurian (Muffler, 1967).

Lower and Middle Devonian

Devonian rocks are widespread in Alaska and form a nearly continuous belt in the Brooks Range across the northern part of the state (fig. 11). The Devonian System in Alaska has recently been

---

Figure 11 near here

---

summarized for the International Symposium of the Devonian System held at Calgary (Gryc and others, 1967; Tailleur and others, 1967; Churkin and Brabb, 1967).

In the northern and east-central parts of Alaska the Middle and more rarely the Lower Devonian sections of mainly limestone and dolomite are part of a lower Paleozoic cycle of nearly continuous sedimentation that started in the latest Precambrian or Cambrian. Other areas of predominantly carbonate rocks are in the Seward Peninsula and in the Kuskokwim River region where relatively pure carbonate sections are known to contain Devonian as well as Silurian and Ordovician faunas (fig. 11).

In addition to these areas, more recent studies report the following occurrences of Devonian carbonate rock: a dolomite section on St. Lawrence Island that lies below limestone that correlates with the Lisburne Group of Carboniferous age (Patton and Dutro, 1969); coral-rich limestone just south of Farewell in the Alaska Range (Reed, oral commun., 1968; Churkin, unpub. field observations, 1969); and limestone and dolomite in the Sadlerochit Mountains of northeastern Alaska (Dutro, 1970).

Besides these nearly pure carbonate sections are widely scattered areas of mainly siliceous detrital and volcanic rocks that include subordinate limestones with Devonian fossils (locs. 8-13). These probably represent a northern continuation of the stratigraphic belt in southeastern Alaska.

The section of thinly and rhythmically interbedded dark shale and chert (McCann Hill Chert and the uppermost part of the Road River Formation) in the Eagle area of east-central Alaska seems to represent an intermediate facies separating the mainly carbonate rocks found farther north from the siliceous detrital and volcanic rocks in southeastern Alaska (fig. 12). This relatively thin shale and chert

---

Figure 12 near here

---

section of Lower Devonian age grades eastward into thicker limestone in the Nahoni Range-Blackstone River area of Yukon Territory (Churkin and Brabb, 1967, fig. 10). The Silurian-Devonian boundary in this graptolitic shale sequence is placed above a *Monograptus nilssoni*-*Linograptus* fauna of Late Silurian age and below shale with *Monograptus yukonensis* in accordance with modern interpretations of this boundary elsewhere. Above the shale with *M. yukonensis* are thin limestone beds with a remarkably varied shelly fauna of Lower Devonian age (Churkin and Brabb, 1967). At Jones Ridge, a short distance north of the Yukon River, these limestones thicken markedly.

Much farther north, the argillites beneath Triassic rocks at the bottom of a bore hole at Point Barrow (Payne and others, 1951) and Lower or Middle Devonian plant-bearing shale and chert-pebble conglomerate from the Topagoruk test well 50 miles farther south (Collins, 1958) seem to indicate a northward change of the Brooks Range Devonian carbonate section into siliceous terrigenous rocks. In the northeastern Brooks Range the largely clastic Neruokpuk Formation may include equivalents to these Devonian rocks found in the subsurface. However, in the Sadlerochit Mountains farther north there is a thick Devonian and probably older carbonate section (Dutro, 1970). The Sadlerochit Mountain section is difficult to interpret. It may be an isolated buildup of carbonate rock or may indicate another major belt of carbonate rocks parallel to those of the central Brooks Range (fig. 11).

The Devonian of southeastern Alaska, like the underlying Ordovician and much of the Silurian, is mainly a graywacke, shale, and conglomerate sequence interbedded and intertongued with basaltic to andesitic pillow lava, breccia and tuff. These submarine lavas and associated sedimentary rocks rich in volcanic detritus grade rapidly into thick limestones made largely of fragmented fossils, especially in Glacier Bay, Freshwater Bay, and in several places along the west coast of Prince of Wales Island (fig. 10).

A good example of rapid facies change is seen in the vicinity of Craig where a nearly pure limestone section about 1,000 feet thick (Wadleigh Limestone) composed mainly of varying proportions of fragmented corals and stromatoporoids, intertongues at a place 4 miles to the south with 1,500 feet of basaltic tuff, breccia, and pillow lava. Several miles farther south this limestone is entirely absent, apparently due to a facies change into a thick sequence (Port Refugio Formation) of pillow basalt, tuff, and volcanic breccia that is interbedded with graywacke, conglomerate, and shale (Eberlein and Churkin, 1970). The only limestone known in the sequence is a silty and tuffaceous limestone only a few tens of feet thick.

The base of the Devonian section over a large area of southeastern Alaska is marked by a distinctive unit of predominantly conglomerate, sandstone and shale, the Karheen Formation, that is characterized by redbeds and festoon crossbedding. In the Heceta-Tuxekan Islands area, the Karheen conformably overlies massive limestone (Heceta Limestone) of Upper Silurian age and according to Kirk and Amsden (1952) has an Upper Silurian brachiopod fauna above its base. Conodonts (A. T. Ovenshine, written commun.) and a tentaculitid fauna (C. Carter, written commun., 1969) from these beds seem to suggest instead an Early Devonian age. Farther south the Karheen Formation rests unconformably on Ordovician to Lower Silurian volcaniclastic rocks and has an unusual assemblage of graptolites, vascular plants, and corals of Lower Devonian age (Churkin and others, 1969; Churkin and others, 1970).

Upper Paleozoic cycle of sedimentation

Upper Devonian

The Upper Devonian is dominated by clastic rocks throughout the State. Chert pebble conglomerate, sandstone and shale (Kanayut and Hunt Fork Formations of the Brooks Range and the Nation River Formation of east-central Alaska) derived from uplifts within adjacent geosynclinal belts started a cycle of thick accumulation of coarse siliceous detrital sediments in the interior of Alaska (fig. 13).

Figure 13 near here

In the northeastern Brooks Range, Mississippian conglomerate (Reiser, 1970) unconformably overlies the Neruokpuk Formation (regionally metamorphosed Devonian(?) and older siliceous sedimentary rocks), and as much as 10,000 feet of Neruokpuk strata were removed by erosion below the unconformity (Reed, 1968).

Much farther south and on the other side of the Yukon shelf, similar coarse clastic rocks (Nation River Formation) have a gradational contact with Devonian siliceous shale and chert below. However, clastic rocks similar to the Nation River Formation in the Livengood district lie with a marked unconformity on altered mafic volcanic rocks and serpentinites, and the basal conglomerate has fragments of these igneous rocks (Foster, 1967; F. Weber and M. Churkin, 1968, field observations). This suggests that the Devonian clastic sediments in the interior of Alaska had a source separate from similar clastic rocks in the Brooks Range.

In southeastern Alaska there is similar evidence that plutonic activity and synorogenic uplift affected the Cordilleran geosyncline at various times during the Paleozoic (Lanphere and others, 1964; Brew and others, 1966; Eberlein and Churkin, 1968). Branched plant stems and spores are common in many of these clastic sediments and suggest a nonmarine or, more probably, a near-shore deltaic origin.

Absolute age determinations of granitic intrusion in the northeastern Brooks Range and in other places around the edge of the Arctic Ocean basin indicate that plutonic activity was probably related to the the same mid-Paleozoic uplifts that produced the wedge of Upper Devonian clastic sediments (Tailleur and others, 1967; Trettin, 1967; Churkin, 1969).

Carboniferous

Fossils of Carboniferous age have been found in Alaska in different lithic sequences ranging from pure limestone to predominantly volcanic rocks (fig. 14). Although rocks of Mississippian age

---

Figure 14 near here

---

are widespread, rocks of Pennsylvanian age have only recently been positively identified and their known distribution is limited.

The most continuous belt of Mississippian rocks in Alaska is along the Brooks Range. The Mississippian is represented there by the Lisburne Group, a 2,000- to 4,000-foot-thick, essentially carbonate section that has variable amounts of nodular chert and minor shale (Bowsher and Dutro, 1957; Brosgé and others, 1962; Armstrong, 1970) (fig. 15). The Mississippian carbonate rocks are

---

Figure 15 near here

---

generally separated from the Upper Devonian conglomerate and sandstone by a 100- to 1,000-foot thick unit of shale and argillite (Kayak Shale) that has sandstone in its lower part and limestone at its top (Tailleur and others, 1967; Brosgé and Tailleur, 1970).
In exception, in the Sadlerochit Mountains in the northeast corner of Alaska, the Kayak is locally absent or very thin and Mississippian carbonate rocks rest unconformably on Devonian limestone and dolomite and in places on clastic rocks of Devonian(?) age (Reiser, 1970; Armstrong and others, 1970). Above the basal shale, carbonate rocks progressively overlap one another to the north, so that in the central Brooks Range they are Lower and Upper Mississippian and further north in the northeastern Brooks Range the section ranges from Upper Mississippian at its base through the Middle Pennsylvanian at its top (cf. Brosgé and others, 1962; Armstrong and others, 1970). On the Lisburne Peninsula, at the west end of the Brooks Range, Campbell (1967, p. 6) also reports that the base of the Lisburne may transgress

(p. 45a follows)

time, becoming progressively younger--Early Mississippian in the south to early Late Mississippian in the north. This suggests a northward migration of an essentially west-oriented shoreline through much of Carboniferous time.

Assuming a shallow shelf existed north of the Brooks Range and that the Lisburne Group was deposited in a northward marine transgression onto this shelf a series of facies maps have been drawn for various subdivisions of Carboniferous time by Armstrong and Mamet (1970). They also proposed the following depositional model of environments from south to north: starved basin (lime mud and chert), slope (lime mud), crinoid garden (crinoid and bryozoan-rich clean carbonate sandstone), oolite bank, back bank (bryozoan-crinoid sandstone with an increase in lime mud landward), and supratidal flat (lime mudstone and dolomite).

South of the Brooks Range, Carboniferous rocks are known from many small areas widely separated by Mesozoic rock cover or whose lateral connections are obscured by igneous or metamorphic activity.

In the Porcupine-Yukon Rivers area Mississippian and probably some part of the Pennsylvanian (Brabb and Churkin, unpublished data) are represented by a section of interbedded limestone and shale that forms the rhythmically banded section at Calico Bluff. A thin-bedded chert and shale unit of Mississippian age (Ford Lake shale) lies below the limestones of the Calico Bluff Formation and separates them from the underlying sandstone, conglomerate, and shale (Nation River Formation) of Upper Devonian age (Brabb, 1969; Brabb and Churkin, 1969). Pre-Permian erosion in this area has removed much of the Carboniferous section (Churkin and Brabb, 1967, figs, 9, 10).

In the northwestern part of the Yukon-Tanana region there is a poorly known sequence of mainly noncalcareous sedimentary rocks including banded cherts (Livengood chert) that, on the basis of a few scattered fossil collections from rare limestones, had been assigned to the Mississippian (Mertie, 1937b). The occurrence of Oldhamia from Mertie's belt of "undifferentiated noncalcareous rocks of Mississippian age" suggests that at least some of the rocks previously considered Mississippian are probably Cambrian (Churkin and Brabb, 1965b;Churkin, 1968 field data). More work is clearly necessary in this structurally complex region to determine the distribution and stratigraphy of Carboniferous rocks.

Siliceous detrital rocks and volcanic rocks southwest of the Yukon-Tanana region in the Kaiyuh Hills area and in the Kuskokwim drainage (Mertie, 1937a;Cady and others, 1955) have been questionably assigned to the Mississippian on the basis of lithic similarity and their supposed stratigraphic position below fossiliferous Permian. No conclusive evidence supporting a Carboniferous age for any rocks in this vast region is known to date.

This same lower Yukon-Kuskokwim area during the Devonian was a southwestern extension of the predominantly carbonate sedimentation that affected east-central Alaska. However, in the Permian and presumably starting with the Carboniferous, southwestern Alaska as far north as Norton Sound was an area of siliceous detrital and volcanic rock sedimentation (Cady and others, 1955, fig. 4). Farther west on St. Lawrence Island, there is a section at least 1,000 feet thick of limestone and cherty limestone that closely resembles both lithically and faunally the Mississippian of the Brooks Range (Patton and Dutro, 1969). Furthermore, the presence on St. Lawrence Island of Devonian dolomite below the Mississippian Limestone and a section of Triassic and, possibly Permian siltstone, shale, and chert above it further indicates a close correlation of the section with those in the Brooks Range. Coral-bearing limestone of probable Mississippian age has been reported from the vicinity of Cape Prince of Wales at the east tip of Seward Peninsula (Steidtman and Cathcart, 1922). Sainsbury (oral commun., 1970) verified the presence of probable Lisburne limestone there but, according to him, the limestone is a structurally isolated and largely recrystallized mass difficult to correlate. Thus, in widely separated areas along the far western edge of Alaska, one finds a predominantly limestone facies north of Norton Sound that rims the volcanic-rich siliceous detrital facies of probably partly contemporaneous age in the Lower Yukon-Kuskokwim region.

In the eastern Alaska Range a variety of rocks have been questionably assigned to the Mississippian because they seem to be structurally below fossiliferous Permian rocks and lithically resemble rocks (Strelna Formation) that contain Mississippian fossils in a parallel belt nearly 100 miles farther south. These sequences of questionable Mississippian age consist of sandstone, argillaceous rock, and conglomerate that are interlayered with prominent volcaniclastic rocks and mafic lava flows (Moffit, 1954). Limestone is relatively rare in the section, and all rocks have been altered in various degrees by low grade regional metamorphism. Southwest of Fairbanks on the north side of the Alaska Range the tabulate coral Syringopora, found in the Totatlanika Schist, suggests a post-Ordovician, possibly Mississippian, age (Wahrhaftig, 1968). According to Wahrhaftig the schist is derived mainly from volcanic rocks. Minor interbedded fossiliferous limestone lenses indicate a submarine origin.

South of the Alaska Range the Strelna Formation, originally dated as Mississippian by corals and brachiopods, is exposed along the Chitina Valley separating the Wrangell Mountains from the Chugach Mountains farther south (Moffit, 1938). The Strelna Formation is a complex of greenstone (bedded basaltic lavas and tuffs) interstratified with argillite, greenschist, chert, and minor fossiliferous marble that is estimated to be in excess of 6,500 feet thick; neither its top nor base is known. Work in progress by E. M. MacKevett, Jr. suggests that the formation has Permian brachiopods in its type section. Furthermore, the general stratigraphy of the Strelna, although it is more metamorphosed, resembles parts of the Permian section nearby (E. M. MacKevett, Jr., oral commun., 1969). Somewhat higher grade quartz-mica schists and amphibolite schists (the Klutina Series, and the Dadina Schist), west and north(?) of the Chitina Valley, are correlated with the Strelna Formation (Moffit, 1938).

In several parts of the Alexander Archipelago of southeastern Alaska there are volcanic-rich sequences similar to those in the Chitina Valley. These are the most southerly exposures of Carboniferous rocks in Alaska and are especially important in that the rocks are generally not altered and contain very abundant shelly fossils that permit detailed correlations in an area of rapid facies changes. Within southeastern Alaska the northerly exposures of Mississippian strata on Chichagof Island are predominantly limestone (fig. 10). Farther south in the Keku Strait area the Mississippian and Pennsylvanian section is limestone with volcanic and chert members in its lower part (Muffler, 1967). Still farther south in the Craig-Klawak and Sumner-Shelikof Island areas the Mississippian and Pennsylvanian are represented by a mainly limestone section that has chert in its lower part (Eberlein and Churkin, 1970).

Pennsylvanian rocks have not been widely recognized in Alaska. In the Brooks Range, Pennsylvanian faunas have been recognized only from the upper parts of the Lisburne Group (Brosgé and others, 1962; Armstrong and Mamet, 1970). Recent mapping in the Yukon River area (Brabb and Churkin, 1969), combined with paleontological studies from the upper Calico Bluff Formation, suggest that there are a few places in east-central Alaska where Pennsylvanian rocks occur. However, most of the Pennsylvanian and a large part of the Mississippian in east-central Alaska have been removed by erosion so that Permian strata in many places rest unconformably on rocks of Devonian age (Brabb and Churkin, 1967).

Farther south in the Rainbow Mountain area of the Alaska Range a thick succession (about 7,000 feet thick) of volcanic graywacke, tuff, siltstone, and limestone of Pennsylvanian age has been recently recognized (Rowett, 1969).

In contrast to most of Alaska where Pennsylvanian fossils are difficult to identify or are missing, Pennsylvanian rocks in southeastern Alaska are recognized by rich shelly faunas including an abundance of fusulinids (Dutro and Douglass, 1961; Douglass, 1968, written commun.). The Pennsylvanian rocks in southeastern Alaska occur on Kuiu Island (Dutro and Douglass, 1961) and in two areas on the west side of Prince of Wales Island (Eberlein and Churkin, 1970). They are predominantly limestone with varying amounts of nodular chert and contain some chert and quartz detritus.

Permian

Permian rocks are known from essentially all the areas in Alaska that contain older Paleozoic rocks (fig. 16). Seward Peninsula, where

---

Figure 16 near here

Permian has not been reported to date, is a noteworthy exception. In general, Permian sedimentation throughout southeastern Alaska (Muffler, 1967; Brew, 1968), the Wrangell Mountains (Smith and MacKevett, 1970), and the eastern Alaska range (Richter, written commun., 1968; Rowett, 1969; Petocz, 1970) closely paralleled the pattern that developed in the Carboniferous of deposition of sequences rich in volcaniclastic and volcanic rocks. In addition good Permian faunas are known from the lower Yukon-Kuskokwim area of southwestern Alaska where fossiliferous limestones 500-1,000 feet thick are known to grade stratigraphically upward into mafic lavas and tuffs over 4,500 feet thick (Mertie, 1938; Smith, 1939, p. 33). In the Goodnews Bay district, on the coast of the Bering Sea, Permian brachiopods were first reported (Smith, 1939, p. 33) from limestone associated with red and black slates. Subsequent mapping there indicates that the Permian limestone grades laterally into greenstone (Hoare and Coonrad, 1961).

Permian limestone in close proximity to basaltic breccias, agglomerates, and flows is known from a tiny islet off Cape Kekurnoi on the southeast side of the Alaska Peninsula opposite Kodiak Island (Hanson, 1957). This isolated exposure of Permian rock is separated from the nearest Paleozoic rocks in the Kuskokwim area by over two hundred miles of Mesozoic and Quaternary cover.

Even more isolated than the Permian Limestone at Cape Kekurnoi is the report of Pennsylvanian or Permian plants from Adak Island in the middle of the Aleutian Island arc a thousand miles to the west (Coats, 1956). The plant material consists of about a dozen well-preserved leaf impressions in a fine-grained volcanic sandstone considered by Coats as part of a largely basalt unit that is similar in appearance to the Tertiary and Quaternary volcanic rocks that form most of the Aleutian Islands. In an attempt to explain this unique occurrence of Paleozoic rock in the Aleutians the plant locality on Adak Island was studied and the sandstone matrix surrounding the plants was found to contain abundant pollen and some pelecypods that are diagnostic of Tertiary age (Scholl and others, in press). It is concluded that these plants, although remarkably similar to Paleozoic species, are Tertiary.

In the Lake Iliamna-Kamishak Bay area of the upper Alaska Peninsula, in Kenai Peninsula, and in Kodiak Island, fossiliferous Upper Triassic limestone conformably overlies mafic volcanic flows, breccias, and tuffs that have been questionably assigned by various authors to the Permo-Triassic (Burk, 1965). In these areas, sequences of slate, graywacke, chert, and volcanic rock of unknown age seem to be older than the predominantly volcanic sequences underneath the Triassic limestone. Considered still older, probably Paleozoic or Precambrian, is a metamorphic complex of marble, schist, gneiss, and quartzite. Large granitic batholiths that have reconstituted much of the rocks in the area are known to be Jurassic and some are as young as late Cretaceous (Reed and Lanphere, 1969). Thus, some of the more metamorphosed rocks, presumed to be the oldest, could be as young as early Mesozoic. The single exposure of fossiliferous Permian at Cape Kekurnoi suggests that detrital-volcanic rock facies of southeastern Alaska extended during the Upper Paleozoic into what is now part of the Alaska Peninsula.

Permian rocks are widely distributed in the Wrangell Mountains and adjacent parts of Canada (Moffit, 1938; and Smith and MacKevett, 1970). The Permian in this area consists of a slightly metamorphosed sequence (Skolai Group) over 8,000 feet thick of submarine basaltic flows, breccias, and tuffs that are interbedded with volcaniclastic sediments, shale, and chert (Smith and MacKevett, 1970). Cliff-forming massive limestone near the top of the sequence consists mainly of fragmented shelly fossils that indicate a Permian and probably Early Permian age. Age data are lacking on the underlying volcanic flows and volcaniclastic rocks. The base of the sequence has not been recognized, but if the more highly metamorphosed and deformed rocks (Streina Formation) in the area are actually Mississippian in age, then this suggests that a structural discontinuity separates two sequences of different metamorphic grade (MacKevett, oral commun.). Locally, the Skolai Group is overlain disconformably by Middle Triassic strata and, more extensively, by the Nikolai Greenstone of Late Middle and/or early Late Triassic age (Smith and MacKevett, 1970).

Farther north, in the upper Copper River valley and eastern Alaska Range, there is a Permian section characterized by an abundance of volcanic rocks interbedded with calcareous sediments (Mendenhall, 1905; Moffit, 1954). In the vicinity of Mankomen Lake, (type section of the Mankomen Formation), the stratigraphic section, mainly argillaceous and sandy sediments about 5,000 feet thick, includes a series of massive limestone lenses up to 500 feet thick (D. Richter, written commun., 1969). According to Richter, these rocks are conformably underlain by 200-1700 feet of fine- to coarse-grained volcaniclastics that contain Permian corals and fusulinids, and these rocks in turn are underlain by andesitic lavas of Pennsylvanian(?) age. Overlying the Mankomen Formation is a section, about 5,000 feet thick, of amygdaloidal basalt that has Permian brachiopods in massive reef-like limestones. Stratigraphically higher are Triassic and Jura-Cretaceous strata that rest on the Permian lavas with angular unconformity.

Farther west, in the Rainbow Mountain-Delta River area of the Alaska Range, the Permian section is characterized by volcanic and marine sedimentary strata rich in volcaniclastic detritus (Rowett, 1969; Petocz, 1970). As in the Permian sections near Mankomen Lake farther east, richly fossiliferous limestones occur in the upper part of the section, and the lower part is mainly volcaniclastic rock interlayered with argillaceous and graywacke sediments. Detailed stratigraphic studies in this part of the Alaska Range, coupled with studies of coral faunas (Rowett, 1969) and of fusulinid faunas (Petocz, 1970), make this section an important reference point for Permian correlations not only in Alaska but with sections that have similar boreal faunas in U.S.S.R., Canada, Greenland, and Spitsbergen.

In the Nation River area north of the Alaska Range, the Permian is represented by relatively pure, massive limestone--the Tahkandit Limestone. The Tahkandit is only about 350 feet thick and has glauconitic sandstone and chert-pebble conglomerate at its base where it unconformably overlies the Nation River Formation of Upper Devonian age (Brabb and Churkin, 1967; Brabb and Grant, in press). East, west, and north of its type area near the mouth of Nation River, the Tahkandit brachiopod fauna is found in limy interbeds that are part of a predominantly detrital facies of chert-pebble conglomerate, sandstone, and siltstone--the step conglomerate (Brabb and Churkin, 1969). Permian brachiopods are also known from limestone beds in predominantly argillite sections exposed in the upper Black River, some 50 miles north of the type Tahkandit (Brabb, oral commun., 1968).

Still farther north, on the Porcupine River, several hundred feet of sandy, productoid brachiopod-rich limestone with minor shale and chert interbeds of Carboniferous age is overlain by medium-dark-gray siltstone with rare corals, brachiopods, and cephalopods of Permian age (Brosgé and others, 1966).

At the west edge of the Yukon Flats, an assemblage of basaltic flows, tuffs, and breccias including smaller amounts of interbedded chert, shale, and sandstone--the Rampart Group--has been assigned to the Mississippian on the basis of a few bryozoa from a lens of limestone questionably within the volcanic sequence or possibly from a somewhat older horizon (Mertie, 1937b, p. 126-127). Examination of new collections, as well as the old collections, shows that this limestone bed is within the volcanic sequence and is more likely to be Permian than Mississippian (Brosgé and others, 1969). The limestone itself is composed largely of pelecypod prisms like those of Inoceramus and, in this respect, resembles similar prisms in Permian limestone beds in east-central Alaska (Tahkandit Limestone) and in southwestern Alaska (Gemuk Group). Hornblende from gabbro that seems to intrude the Rampart volcanic rocks has an age of 205 ± 6 m.y. (Triassic) based on potassium-argon isotope dating (Lanphere, in Brosgé and others, 1969).

Igneous rocks similar to those of the Rampart Group but with a smaller proportion of associated sedimentary rocks are found farther east in the Crazy Mountains and in the vicinity of Circle along the south edge of the Yukon Flats. These mainly fine-grained igneous rocks of basaltic composition were described by Mertie as the Circle Volcanics and correlated on the basis of lithic similarity with the Rampart Group (Mertie, 1937b, p. 127-128). A potassium-argon isotope date of hornblende from the Circle Volcanics is 220 m.y. (M. Lanphere, written commun., 1968). This is a Triassic date that closely corresponds to the 205 m.y. age of gabbro that seems to intrude Rampart volcanic rocks (Brosgé and others, 1969). Aeromagnetic surveys indicate that igneous rocks underlie much of the Yukon Flats and suggest that the Circle Volcanics continue west with little interruption and possibly connect up with the Rampart Group volcanics (Brosgé and others, 1970). More recent work in this area indicates that the Circle Volcanics in their type area along the Yukon River and farther west in the Crazy Mountains do not have textural or structural characteristics that are exclusively volcanic (Churkin, 1968, unpublished field data). The Circle Volcanics, like the volcanics of the Rampart Group, are reported to have many siliceous sedimentary rocks interlayered with them (Mertie, 1937b). However, an examination of the best exposures of Circle Volcanics in contact with sedimentary rocks indicates that the "volcanics" have very fine grained chilled margins and that the sedimentary rocks, mainly argillites and quartzitic sandstones, next to them are re-crystallized so that

(p. 60a follows)

argillaceous sediments are spotted slates (Churkin, 1968, field data). Furthermore, the Circle Volcanics in detail have cross-cutting relations with the sedimentary rocks, and fragments of the sedimentary rocks have been incorporated into the intrusive rocks, in places making up large selvages. Away from these contacts the Circle Volcanics are diabases or coarse grained gabbros that are generally porphyritic and, in places, have mineralogical layering. Taking all these features into account, I believe the Circle Volcanics are not lavas but intrusive rocks of probable Triassic age. Whatever the age of the Circle Volcanics, upper Paleozoic or Triassic, their intrusive origin explains the absence of volcanic detritus in the surrounding sedimentary rocks of this span of geologic time.

Permian rocks are widely distributed along the Brooks Range (figs. 15 and 16) and are generally represented by only a few hundred feet of argillaceous rocks, chert, sandstone, and conglomerate of the Siksikpuk and the lower part of the Sadlerochit Formations (Brosgė and others, 1962; Bowsher and Dutro, 1957; Patton and Tailleur, 1964; Campbell, 1967; Detterman, 1970). The Sadlerochit Formation is the main reservoir rock in the Prudhoe Bay Oil Field (Rickwood, 1970) (fig. 15). An erosional hiatus representing much of Pennsylvanian time separates these Permian clastics from the Lisburne carbonate rocks, but the time gap decreases towards the northeastern Brooks Range where the Lisburne ranges upward into the Middle Pennsylvanian (Armstrong and others, 1970). All these Permian clastics in turn are overlain disconformably by the thin sequence of oil shale, limestone, and sandstone of the Shublik Formation of Triassic age (Brosgė and others, 1962; Detterman, 1970).

A notable exception to this general stratigraphic sequence of Upper Paleozoic rocks is the enigmatic section of Mississippian and Permian arkosic sandstone and limestone of the Nuka Ridge area on the north slope of the DeLong Mountains (Tailleur and Sable, 1963; Tailleur and Brosgė, 1970).

Up to this point, the paper has attempted to summarize the stratigraphic data available on Paleozoic and Precambrian rocks in Alaska. The remainder of the paper that follows attempts to interpret their tectonic significance and their role in the structural evolution of Alaska.

Interpretation of stratigraphic data-tectonic framework of sedimentation

Precambrian

The Tindir Group of east-central Alaska, the only definite Precambrian known in Alaska, is at the northwest end of a long belt of late Precambrian strata that runs south across Yukon Territory and British Columbia into the northern Rocky Mountains of Alberta, Washington, and Idaho. The better exposed sections of these rocks measure tens of thousands of feet. The great thickness of sedimentary rocks (including minor basaltic lavas) that are distributed in this long belt indicates a major cycle of sedimentation of geosynclinal proportions.

No regional unconformities were found within the Tindir Group, and it seems to be accordantly overlain by fossiliferous Cambrian rocks. Farther to the southeast the tops of both the Purcell and Windermere Series of late Precambrian age (Belt Series in U.S.) that may be correlative with the Tindir are marked by unconformities. Over large areas these unconformities are ill defined, but their existence has been proved by regional mapping (Yates and others, 1966). In parts of southern Yukon Territory, a strong unconformity within the Proterozoic separates Purcell rocks from the overlying Windermere Series (Gabrielse, 1967), and the Windermere in turn is progressively removed by erosion below the Cambrian. The Tindir is correlative with a still undetermined part of the Belt Series farther south. Paleontological studies of stromatolites (laminated algal structures) from the Tindir may further define the age of the Tindir and permit closer correlation with the Belt Series farther south, on the one hand, and on the other with the stromatolite-rich Late Precambrian rocks of the Siberian Shield farther west.

The base of the Tindir is not known, but occasional boulders of granitic rock and gneiss in the Tindir suggest that an earlier Precambrian igneous and metamorphic basement is not far away. Uplifts of metamorphosed rock in the central interior of Alaska, particularly the Birch Creek Schist, have been postulated as representing earlier Precambrian. K/A isotope dating, however, has not verified their Precambrian age. Preliminary Rb/Sr isotope dating of schists in the same area and in the Seward Peninsula has produced a number of Paleozoic and Precambrian dates and there now appears to be more hope of unraveling the pre-Mesozoic metamorphic history of Alaska.

Lower Paleozoic

Cambrian through Middle Devonian rocks in east-central Alaska are part of a cycle of nearly continuous sedimentation (Churkin and Brabb, 1967) (fig. 1). Elsewhere in the interior and northern parts of Alaska, Devonian and in places Silurian and Ordovician rocks have been reported from a number of widely separated areas. Unfortunately, most of these stratigraphic successions are structurally complex and incomplete. Cambrian rocks, although known with certainty only from east-central Alaska, probably occur in the Alaska Range (Churkin and Reed, 1969, field data) and in Seward Peninsula (Sainsbury, 1969a). Coarse clastic deposits of Late Devonian age in east-central Alaska and of Late Devonian and Mississippian age in the Brooks Range indicate indirectly sources of argillite and chert probably of early Paleozoic age within the Cordilleran geosyncline to the south and from the ancestral Brooks geosyncline in the north respectively (fig. 12). Isotope age determinations of granitic rocks around the margin of the Canadian Basin (fig. 13) indicate a period of intrusion probably related to the same mid-Paleozoic orogeny that produced these clastic wedge deposits and marks the end of the lower Paleozoic sedimentation cycle.

Cordilleran geosyncline.--In southeastern Alaska where Lower Paleozoic rocks are exposed along the present continental margin, sedimentation was essentially continuous from the Lower Ordovician, the oldest rocks in the area, into the Upper Silurian (fig. 10). The high proportion of volcanic and volcaniclastic rocks together with conglomerates of mixed composition, rapid facies changes, and local disconformities in this section imply rapid sedimentation in a tectonically active area. In the early Devonian a widespread sequence of terrigenous clastic rocks including red beds (Karheen Formation of Eberlein and Churkin, 1970) marks a significant break in sedimentation within the southeastern Alaska part of the Cordilleran geosyncline (Ovenshine and others, 1969; fig. 13). This same conglomerate has been assumed to be a tillite and has been cited as evidence of Paleozoic glaciation (Kirk, 1918). However the latest work has not revealed any data to support a glacial origin.

Thin to very thick lenticular biogenic limestones of Silurian and Devonian age occur in the section of the Cordilleran geosyncline exposed in southeastern Alaska (fig. 10). The high proportion of reef-building corals and stromatoporoids in these limestones suggests that nearby reefs were periodically fragmented to provide the enormous volume of fossil fragments in the limestones. I have seen in the Willoughby limestone of Silurian age in Glacier Bay and in Devonian limestone at several places on the west coast of Prince of Wales Island small patch reefs with coral and stromatoporoid skeletons preserved encrusting each other in growth position. In most of these limestones a nearshore shallow-water environment of deposition is indicated not only by the shelly fauna but also by stromatolitic algae, intra-formational breccias and oolitic limestone. In some of the limestone thick lenses of breccia and conglomerate rich in volcanic fragments suggest development of the limestone around volcanic centers and other prominences on the sea floor.

Lower Paleozoic rocks of the coarse detrital, volcanic-rich facies of southeastern Alaska are known farther south in the San Juan Islands and in the northern Cascade Mountains of Washington (Danner, 1966) and in the Klamath Mountains of northern California (Irwin, 1966; Churkin and Langenheim, 1960). From southeastern Alaska this part of the Cordilleran geosyncline, rich in volcanic rocks, probably continued westward and may have connected with similar rocks of the Paleozoic geosyncline in the Koryak Mountains of Northeast U.S.S.R. (Bogdanov and Tilman, 1964; Belyi, 1964; Egiazarov and others, 1965). In south-central and southwestern Alaska, poorly known and structurally complex terranes of detrital sedimentary and volcanic rocks that contain some fossiliferous limestones are part of this Cordilleran geosynclinal belt. These widely separated sequences probably are part of a stratigraphic belt that more or less rimmed the northern Pacific Basin and that now is largely buried by younger rocks or obscured by regional metamorphism and plutonic activity mainly of Mesozoic age (fig. 1) (Churkin, 1969).

A thick carbonate-quartzite sequence (The Millard miogeosynclinal belt of Kay, 1947) should theoretically lie north of the volcanic-rich eugeosynclinal belt of southeastern Alaska. Except for the thick carbonate rocks in the Kuskokwim River region of southwestern Alaska (Cady and others, 1955; Sainsbury, 1965) and possibly in Seward Peninsula (Sainsbury, 1969a) thick sequences of pure carbonate rock are virtually unknown in central Alaska (fig. 1). However, in parts of the Alaska Range limestone sections especially those of Devonian age have been reported (Moffit, 1938; Brooks, 1911; B. Reed, oral commun., 1968). These isolated limestone masses are inliers surrounded by predominantly terrigenous rocks and probably represent biogenic limestone buildups in a predominantly clastic section as do the similar limestones in southeastern Alaska. In the Eagle area of east-central Alaska Paleozoic sedimentation started with the deposition of thin Cambrian limestone conformable on late Precambrian strata. Rapid changes in lithofacies, the presence of oolitic intraformational boulder and edgewise conglomerate, rich trilobite, brachiopod, and archeocyathid faunas suggest a shallow-water turbulent marine environment for the area during most of the Cambrian (Brabb, 1967).

In contrast to the generally coarsely detrital rocks in southeastern Alaska is a thinly and rhythmically interbedded black chert and siliceous shale lithofacies in east-central Alaska that has thin interbeds and partings of graptolitic shale (Churkin and Brabb, 1965a). Lower Ordovician through Lower Devonian, a span of about 100 million years, seems to be represented here by only 900 feet of section without any sign of a significant stratigraphic break. This unusually thin stratigraphic section probably represents a long period of slow, deepwater sedimentation. These siliceous rocks continue east into northern Yukon Territory where they thicken to form the Richardson Basin (Jackson and Lenz, 1962). A similar graptolitic shale section that again spans most of the Ordovician and the lower Silurian in less than a 1,000 feet of section has recently been found in the Alaska Range southeast of Farewell (Churkin, Reed, and Kerr, 1969 and 1970 field data). Similar, but in places reportedly much thicker, sequences of chert and graptolitic shale, which in addition contain minor amounts of pillow basalt, characterize the Frazer eugeosynclinal belt of the central Great Basin that lies between the volcanic-rich, coarsely detrital rocks in the Klamath Mountains and the predominantly carbonate-quartzite rocks of the miogeosyncline in the eastern Great Basin (Roberts and others, 1958; Churkin and Kay, 1967).

Yukon Shelf and Richardson Basin

The predominantly limestone and dolomite facies of the Silurian and the Devonian cover large areas across the central part of Alaska (east-central Alaska, part of southwestern Alaska and Seward Peninsula), and extend north into parts of the Brooks Range. These rocks, especially in east-central Alaska where they have been most thoroughly studied, seem to be thin shelf carbonate deposits that bordered the Cordilleran geosyncline on the north. The considerably thinner siliceous shales that separate these two contrasting sequences seem to represent a thin but nearly complete stratigraphic sequence transitional from the shelf carbonates on the north to the mainly coarse detrital rocks with abundant interlayered volcanic rocks in the south.

In the early Paleozoic, and especially during the deposition of the Road River Formation (Lower Ordovician to Lower Devonian), the site of the Richardson Mountains in northern Yukon Territory was an area of accumulation of thick graptolitic shale, bedded chert, and argillaceous limestone (Jackson and Lenz, 1962). The area of Road River sedimentation apparently progressively spread from the Richardson Mountains in Early Ordovician time to include most of Yukon Territory by the end of the Silurian (Norford, 1964). At the same time, however, thin shelf limestones interfingering with thin sequences of graptolitic shale were forming laterally over the rest of northern Yukon Territory and eastern Alaska (Churkin and Brabb, 1967). Thus the Richardson Mountains basin during the Paleozoic was not a northern extension of the Cordilleran geosyncline (Martin, 1961), as Jeletzky (1962) has already shown, but was a narrow basin that developed within the Yukon Shelf (Churkin and Brabb, 1967). In conclusion, during the Early Paleozoic, the Yukon Shelf in east-central Alaska and possibly extending farther west across the center of Alaska seems to have separated two distinct geosynclinal belts, the Cordilleran geosyncline in the south from the Ancestral Brooks geosyncline on the north (fig. 1).

Ancestral Brooks geosyncline.--In the Brooks Range and on the North Slope, few rocks have been firmly dated as pre-Middle Devonian (pre-Skajit Limestone). However, in the southern Brooks Range and, more certainly, in the northeastern Brooks Range, there are thick sequences of weakly metamorphosed, predominantly siliceous rocks of pre-Late Devonian age (Brosgé, 1960; Brosgé and Tailleur, 1970). These include the Neruokpuk Formation in the northeastern Brooks Range, a thick sequence mainly of detrital sedimentary rocks (Reed, 1968) but including mafic lavas, intrusive rocks, and volcaniclastic sediments (Reiser, 1970). Similar rocks with rare Devonian fossils and including mafic dikes of Paleozoic age form a narrow belt along the axis of the Brooks Range (Brosgé and Reiser, 1964; 1965). Argillites beneath Triassic rocks at the bottom of a borehole at Point Barrow (Payne and others, 1951) may belong to the belt of weakly metamorphosed siliceous rocks exposed in the northeastern Brooks Range. High magnetic anomalies along the Arctic Slope of Alaska suggest that igneous rock masses like those in the northeastern Brooks Range form a large part of the basement below the Mesozoic cover farther west (Payne and others, 1951). In general, these rocks in the Brooks Range and farther north appear to be thicker and are more detrital than the predominantly carbonate rocks of early Paleozoic age in east-central Alaska. This suggests a northward transition from a central Alaskan carbonate shelf into a now largely buried and partially destroyed Arctic Basin or geosyncline (Churkin, 1969).

Devonian(?) and older rocks included in the Neruokpuk Formation seem to thicken and become more detrital in the Brooks Range north of the Yukon Shelf, thereby suggesting a northward transition into a now largely buried and partially destroyed arctic basin or geosyncline (Churkin, 1969). Still farther north in the Shublik and Sadlerochit Mountains adjacent to the arctic coastal plain there are 6,500 feet of limestone and dolomite below limestone of Carboniferous age (Dutro, 1970). Devonian fossils occur in the upper 200 feet of this sequence but its lower part may represent much of the earlier Paleozoic as well. The lateral extent of these carbonates is unknown, and thus their regional significance is unclear. The carbonate rocks may represent a major facies change as the arctic coast is approached or a localized area of carbonate in a predominantly terrigenous section. If parts of the Neruokpuk Formation (a thick sequence of mainly detrital sedimentary rock that includes lavas) in the northern part of the Brooks Range and in the British Mountains of northern Yukon Territory are equivalent to rocks of the northern (eugeosynclinal) part of the Franklinian geosyncline of the Canadian Arctic Islands much farther east, then the Skajit Limestone and perhaps the Hunt Fork Shale (both of Devonian age exposed in a belt south of the Neruokpuk) could be considered as western equivalents of the carbonate and shale belt (miogeosyncline) of the southern part of the Franklinian geosyncline. Argillites beneath Triassic rocks at the bottom of a bore hole at Point Barrow (Payne and others, 1951) may belong to the same belt of predominantly detrital rocks as the Neruokpuk farther east. Some of

(p. 73a follows)

the mafic intrusive rocks and related lavas and volcaniclastic sediments present in the northeastern Brooks Range are probably Devonian and others may be older (Reiser, 1970). Another belt of similar rocks with rare Devonian fossils and including a mafic dike of 370 m.y. near Mt. Doonerak forms a narrow belt along the axis of the Brooks Range (Brosgé and Reiser, 1964; 1965).

High magnetic anomalies along the Arctic slope of Alaska suggest that igneous rocks form part of the basement below the Mesozoic cover (Payne and others, 1951). These data can be interpreted as evidence of a lower Paleozoic geosyncline in northern Alaska (Churkin, 1969).

The thick chert-rich detrital rocks of Upper Devonian and in part Lower Mississippian age in the Brooks Range are thought to have been derived from a northern source (Brosgé and others, 1962). Farther east in northern Yukon and Northwest Territories, nonmarine sandstone and shale (Imperial Formation) passes southeastward into marine equivalents (Douglas and others, 1963). A similar belt of Upper Devonian detrital rocks, apparently derived from the northern part of the Franklinian geosyncline, occurs in the Canadian Arctic Archipelago as far east as Ellesmere Island (Thorsteinsson and Tozer, 1960; Trettin, 1967). In Chukotka and Wrangell Island on the opposite side of Alaska there are similar Upper Devonian(?) conglomerates. On Wrangell Island, these conglomerates seem to contain appreciable amounts of granitic and volcanic detritus (Bogdanov and Tilman, 1964; Tilman, 1964). Some geologists (Shatskiy, 1935; Eardley, 1948; Payne and others, 1951) 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. This speculation, in large part, led to the theory that the Arctic 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 (Carey, 1955; Tailleur and Brosgé, 1970). However, to judge from the mainly chert, quartz, and argillite detritus, its coarse grain size, the wedge-like shape of the sedimentary body, and its mainly nonmarine character, a shield source seems unlikely. Instead, it is the more highly deformed ~~and regionally~~

(p. 74a follows)

siliceous rocks of the Neruokpuk Formation and similar rocks of pre-late Devonian age in other parts of the Brooks Range and in bore holes along the Arctic Coast more likely were the sources of the detritus (Churkin, 1969). Absolute age determinations of granitic rocks around the margin of the Canada Basin part of the Arctic Ocean indicate that the intrusion of these rocks probably was related to the same mid-Paleozoic period of deformation and uplift that produced the wedge of Upper Devonian clastic deposits (Tailleur and others, 1967; Trettin, 1967; Churkin, 1969). Elsewhere in North America, at about the same time, clastic wedges were derived from uplifts in the Cordilleran (Roberts and others, 1958; Gabrielse and Wheeler, 1961) and Appalachian (Kay, 1947) geosynclines. Mid-Devonian time was thus one of widespread orogeny that marks major breaks in the early Paleozoic geosynclinal cycles.

Upper Paleozoic

Cordilleran geosyncline.--The Carboniferous and Permian rocks of southeastern Alaska closely parallel the earlier Paleozoic sequences of mainly detrital rocks interlayered with submarine lavas. Fortunately, subordinate amounts of limestone that are generally present are highly fossiliferous and provide a means of correlation. Unlike the earlier Paleozoic rocks, good Carboniferous and Permian sections similar to those in southeastern Alaska are known in the Wrangell Mountains and the eastern Alaska Range. Furthermore detrital and volcanic rock sequences of Late Paleozoic age cover a large area of southwestern Alaska that in the earlier Paleozoic received only carbonate rock (Cady and others, 1955).

The isolated exposure of Upper Paleozoic rocks at Cape Kekurnoi suggests that the detrital volcanic belt along the Pacific margin in southeastern Alaska continues west. These Upper Paleozoic rocks, associated with metamorphic rock complexes that may represent still older Paleozoic rocks, form the basement for the thick Mesozoic and, in places, Cenozoic sediments of the Alaska Peninsula (Burk, 1965). The Devonian and Mississippian pure dolomite-limestone section on St. Lawrence Island provides a northern limit to any extension of this belt across the Bering Shelf (fig. 17).

Figure 17 near here

The northern boundary of the detrital-volcanic facies that is here essentially equated with the northern limit of the Cordilleran geosyncline is located on the Alaska mainland somewhere between Seward Peninsula and the lower reaches of the Yukon. Farther east this boundary, although probably complicated by major faults, approximately follows the Yukon River (fig. 17). Along the northwest edge of the Yukon-Tanana Upland, in the center of Alaska, are the northernmost rocks of the Upper Paleozoic detrital-volcanic rock facies. Because of complex structure and scarcity of diagnostic fossils, the stratigraphy here is poorly known. It seems that Carboniferous and perhaps Permian is represented by a noncalcareous sedimentary sequence of mainly fine-grained detrital rocks with abundant chert. Basaltic and related gabbroic rocks that are associated with these sedimentary rocks as discussed earlier were found to in places intrusive into various parts of the Paleozoic section.

Yukon Shelf.--Northeast of the Yukon-Tanana area and across the Tintina trench, Carboniferous and Permian nonvolcanic rocks are known to underlie a large part of the Yukon-Porcupine Rivers area. The Carboniferous section here consists of thinly interbedded limestone, shale, and chert. Deep erosion below the base of the overlying Permian strata has, however, removed all but a small area of carboniferous rocks preserved in the vicinity of Calico Bluff. The Permian is a predominantly detrital facies of chert-pebble conglomerate, sandstone, siltstone, and argillaceous rocks. Limy interbeds occur from place to place, and locally these limestones reach thicknesses of several hundred feet (Tahkandit Limestone).

The conglomerate and sandstone of Permian age along the Yukon River, like the clastic rocks of Upper Devonian age, are made up mostly of chert and argillaceous rock fragments. Part of the detritus in the basal conglomerate of the Permian where it unconformably lies on rocks of Late Devonian age, is derived from reworking the older conglomerate, sandstone and argillite (Brabb and Churkin, 1967). Similar chert pebble conglomerate of questionable Permian age occurs farther north on Dave Lord Ridge just south of where the Porcupine River crosses the international boundary. As in the case of the clastic rocks of Upper Devonian age, the Permian detrital sediments in the interior of Alaska came from uplifts of siliceous sequences that bordered the area on the south and north.

Brooks "geosyncline" and related basins.--In the Brooks Range the Carboniferous sections are mainly limestone and dolomite with variable amounts of interbedded shale and chert (Brosgé and others, 1962). The considerably thinner Permian rocks are predominantly fine-grained detrital rocks and chert. The base of the Lisburne Group becomes progressively younger and more detrital into the northern parts of the Brooks Range. This northward transgression, plus the fact that the unconformably overlying Permian sandstones and conglomerates are also rich in chert detritus, suggests that in the late Paleozoic a source area existed north of the Brooks Range (Brosgé and others, 1962; Detterman, 1970). This may reflect renewed uplift of the ancestral Brooks geosynclinal belt that was providing sediment in the Upper Devonian and Mississippian (Churkin, 1969).

Mesozoic and Cenozoic tectonic events affecting Paleozoic rocks

The geologic conditions that prevailed throughout Paleozoic time in the southern half of Alaska seem to have continued on into early Mesozoic time. Triassic rocks in southeastern and southern Alaska, although separated in places from Paleozoic rocks by an unconformity, are characterized by basaltic submarine lavas and associated volcaniclastic rocks in a mainly detrital sedimentary sequence that continued the geosynclinal pattern established in the Paleozoic (Brew and others, 1966). Thin argillaceous limestones occur locally, but massive purer limestone and dolomite sequences like those in the Paleozoic are very rare. The only good example of a close parallel to the earlier Paleozoic carbonate development in southern and southeastern Alaska is the 2,000-foot-thick section of nearly pure limestone and dolomite (Chitistone and Nizina Limestones) in the Wrangell Mountains (Moffit, 1938; Armstrong and others, 1969). In the Kuskokwim region, the Gemuk Group ranging in age from Carboniferous to early Cretaceous (Hoare and Coonrad, 1961), is composed of siltstone, chert, mafic volcanic rocks, thin limestone and graywacke that seems to be a westward continuation of the stratigraphy in southeastern Alaska.

In the interior and northern parts of Alaska where Triassic rocks are known, they generally rest on Permian rocks with approximate structural conformity (Lathram, 1965; Detterman, 1970; Brabb and Churkin, 1969). The Triassic rocks of northern Alaska, composed of thin sequences of argillaceous sediments interbedded with minor limestone and chert parallel closely the Permian sedimentation pattern in the same area (Detterman, 1970).

In the Jurassic, and in places starting in the Cretaceous, began the development of a new pattern of high tectonic activity that lasted throughout most of the Mesozoic and in places continued through the Cenozoic. Where once the broad stratigraphic belts of the Paleozoic geosynclines and shelf existed, the rocks were deformed into a series of troughs and basins that were separated by uplifts (Payne, 1955; Gates and Gryc, 1963). The sediments that filled the depressions were dominantly detrital and were largely derived from nearby highlands composed of Paleozoic and Precambrian rocks (fig. 18). It was during

---

Figure 18 near here

---

these episodes of orogeny that vast tracts of Paleozoic and Precambrian rocks in the interior of Alaska and further south in the Alaska and Coast Ranges were severely deformed, altered by metamorphism, and in places ultimately granitized. The general pattern of basins and uplift in the Mesozoic, and to a lesser degree in the Tertiary, tends to be arcuate and follows, the trend of the Paleozoic stratigraphic belts (Payne, 1955). This parallelism shows the strong influence of the Precambrian and Paleozoic basement in controlling the tectonic features developed in the Mesozoic and Cenozoic.

Most of the post-Paleozoic sedimentary rocks of Alaska are largely impure sandstones of the graywacke type interbedded with dark argillaceous rocks and conglomerate. Furthermore, many of the post-Paleozoic sediments contain far more detrital feldspar than the rocks on which they lie. Notable examples are the Cretaceous strata of east-central Alaska where the amount of potassium feldspar detritus increases markedly in rocks of post middle Lower Cretaceous (Brabb, 1966). This suggests that the earlier Mesozoic intrusive rocks in the nearby Yukon-Tanana Upland (Wasserburg and others, 1963) were unroofed by late Mesozoic time. Another example is along the northern border of Matanuska basin where granitic intrusive rocks cut Lower Jurassic strata and furnished debris to form Upper Jurassic conglomerates (Gates and Gryc, 1963, p. 273). Thus the batholithic intrusions and their subsequent uplift, like the differentiation of Alaska into positive and negative areas, began in the Jurassic and continued intermittently through the late Mesozoic and into the Tertiary (cf. Reed and Lanphere, 1969). At the end of the Cretaceous and the beginning of the Tertiary, widespread orogenic movements affected large areas of Alaska. It was during this time that the thick late Mesozoic sequences of the Colville Basin were intensely folded and thrust-faulted northward (Gates and Gryc, 1963).

Alaska was essentially emergent by the end of the Cretaceous and has remained so up to the present time. In exception, Tertiary basins of marine deposition developed along the southern and northern borders of Alaska (fig. 18). The most significant of these was along the Gulf of Alaska where Eocene through Pliocene, mostly marine strata total at least 25,000 feet in thickness (Stoneley, 1967). In the interior of Alaska at various times during the Tertiary, local deformation formed scattered basins that were quickly filled by nonmarine coal-bearing sequences of claystone, sandstone, and conglomerate. Several of these continental deposits developed in narrow trenches that developed along major transcurrent fault zones--the Tintina (Brabb and Churkin, 1969) and the Kaltag fault zones (Patton and Hoare, 1968).

Deformation that produced uplift and erosion over much of Alaska during the Tertiary apparently intensified at the close of the Tertiary and continued into the Quaternary. This orogenic activity has resulted in the strong uplift that produced the present mountain ranges.

Along with the deformation, the Cenozoic orogenic events produced widely scattered terrestrial volcanic rocks and granitic intrusives. Tertiary granites, although not as extensive as those of the Mesozoic, are known from most of the geologic provinces of Alaska, but are rare or absent in east-central Alaska, the Brooks Range, and the Arctic coastal plain. The Aleutian volcanic arc and associated oceanic trench are prominent features of this high tectonic activity that started in the Cenozoic and continues into the present (Coats, 1956; Burk, 1965).

Major structural features of Paleozoic rocks

Alaska has experienced such penetrative folding, faulting, metamorphism, and intrusion during multiple episodes of Mesozoic and Cenozoic deformation that, as in other far more intensely studied parts of the North American Cordillera, any Paleozoic or older structures are generally very difficult to recognize. The structures that will receive attention here are first of all the major fold belts that indirectly reflect the trends and configurations of the older tectonic elements, such as basins, troughs, and stable areas. Secondly, some of the large-scale faults that may have displaced the Paleozoic stratigraphic belts and juxtaposed different rock types will be discussed.

Fold belts of Alaska and their extensions into Canada and Siberia.--Figure 19 shows the distribution of fold belts in Alaska and neighboring

Figure 19 near here

parts of Canada and Siberia. It is essentially a simplification of the Tectonic Map of North America (King, 1969) with a larger section of Asia added.

Fold belts on this map are differentiated by gross ages of regional deformation, metamorphism, and intrusion. Using these criteria to delineate fold belts, most of Alaska's structures were created during the Mesozoic as parts of the Cordilleran fold belt that lies along the western continental margin of North America.

The earliest deformational features within the Cordilleran fold belt, are the high grade schist and gneiss terranes across the center of Alaska stretching from Seward Peninsula into the Yukon-Tanana upland. Historically, these have been considered to be of Precambrian age. Numerous Mesozoic ages obtained by isotope dating of these schists and associated plutonic rocks, especially the Birch Creek Schist of east-central Alaska (Wasserburg and others, 1963) cast doubt on the Precambrian age of these structures. On the other hand, new isotopic dates on the metamorphic complexes in Seward Peninsula (Sainsbury, oral commun., 1970) and the Fairbanks area (Forbes, 1968) indicate Precambrian or at least earliest Paleozoic ages of deformation. Along the Pacific and the Arctic Ocean margins of the Cordilleran fold belt, there are in a number of places thick wedges of coarse clastic rocks associated with plutonic activity indicating orogenies within the Paleozoic geosynclines (fig. 13).

, The climactic orogenies of the Cordilleran fold belt, however, took place during the Mesozoic, and in many places, Cenozoic deformation continued and is responsible for much of the present mountainous topography within the original fold belts. High grade metamorphism in southeastern Alaska involving lower Paleozoic rocks (Brew and others, 1966) and lower grade metamorphism of pre Upper Devonian rocks in the northern Brooks Range (Reed, 1968) are other examples of these forerunners of the main Cordilleran orogeny. Thus, the Cordilleran fold belt arose from deformation and in part metamorphism and plutonism of several geosynclines, some of which took form in late Precambrian and early Paleozoic time, and others as late as Mesozoic time (King, 1969).

The Cordilleran fold belt north of the 49th parallel has a nearly constant width until it widens inland to form the MacKenzie Mountains in Northwest Territories. There it is sharply confined along its northeast margin, trends north along the Richardson Mountains of Yukon Territory, and turns westward across Alaska, widening out to the Bering and Chukchi Seas (fig. 19). Easternmost Siberia, separated from Alaska by these broad continental shelves, is part of the Chukotka fold belt of Mesozoic age (Yanshin, 1966). South of the Chukotka fold belt is the Circum-Pacific fold belt, mainly of Cenozoic age. It includes the islands surrounding the Sea of Okhotsk, Kamchatka, Koryak Mountains, and extends along the Aleutian Islands to the Gulf of Alaska. Thus we can see around the rim of the northern Pacific basin extensions of the fold belts of Alaska into the continent of Asia.

Another, though less obvous, correlation of Alaskan fold belts is around the rim of the Canada Basin part of the Arctic Ocean (fig. 19). This is the much older Circum-Arctic fold belt of Paleozoic age that is known in the Canadian Arctic Islands (Thorsteinsson and Tozer, 1960) and in the northeastern Brooks Range (Churkin, 1969). Farther west this fold belt is covered by the coastal plain deposits of northern Alaska. Boreholes along the Arctic coast of Alaska in places at rather shallow depths have penetrated steeply dipping, weakly metamorphosed rocks of pre-Upper Devonian age that probably belong to this same fold belt.

One of the most prominent structural features within the Cordilleran fold belt is the fold and thrust belt that starts along the east side of the Canadian Rocky Mountains and continues north into Yukon Territory where it turns west to make the Brooks Range in northern Alaska (fig. 20). Most of the rocks within this broad fold belt are

Figure 20 near here

Paleozoic carbonate rocks and shales, but rocks as old as Late Precambrian or as young as Tertiary are also involved. This remarkably continuous belt has several arcuate bends (Gabrielse, 1967; King, 1969). At the north end of the Rocky Mountains the relatively narrow (less than 100 miles wide) and fairly straight fold belt gives way to the Mackenzie Mountains (fig. 20, A), a broad series of arcuate ranges offset to the east into the Yukon Shelf. From the Mackenzie Mountains the fold belt turns gently west into the Wernecke-Ogilvie Mountains (fig. 20, B). At the west end of the Ogilvie Mountains near the Alaska-Yukon Territory boundary, the fold belt makes a sharp right-angle bend to form the north-south trending Nahoní Mountains (fig. 20, C). Farther north the Nahoni Mountains give way to the northeasterly trending Dave Lord Ridge fold structures (fig. 20, D). North of the Porcupine River the fold belt turns northwestward across the British Mountains in the northwest corner of Yukon Territory and crosses into Alaska to form the Brooks Range. The trend of the Brooks Range segment of the fold belt is essentially westerly for nearly 600 miles and in the Baird Mountains at the west end of the Brooks Range it bends south towards the Seward Peninsula, its northern margin making a sharp bend at Cape Lisburne where the folds and faults trend northward under the Chukchi Sea (cf. Tailleur and Brosgé, 1970).

The deep recess in the fold belt in northwestern Yukon Territory, where the structures from the Mackenzie Mountains and from the Brooks Range curve inward to form a sharp right angle, may be related to the structures of the Richardson Mountains located within the recess. The Richardson Mountains themselves are apparently a blocklike uplift of thick early Paleozoic and Mesozoic basinal deposits surrounded by the much thinner rocks of the Paleozoic Yukon Shelf (Jeletzky, 1962). At the time of the major folding in the region, the thick body of Paleozoic and Mesozoic sediments in the Richardson Basin possibly acted as a buffer that diverted the fold and fault trends in the thinner sections of the Yukon Shelf around its western and southern edge. Large-scale right lateral movement along the Porcupine lineament (Tailleur and Brosgé, 1970) a probable fault zone (Brosgé and Reiser, 1969) that may be an extension of the Kaltag Fault (Patton and Hoare, 1968) may also be responsible for the right angle bend in the fold belt near the Alaska-Yukon Territory boundary.

South of the Brooks Range, folds and thrust faults generally do not have the consistency of trend that they do in the Brooks Range and along the North Slope. The difficulty in distinguishing structural trends in southern Alaska is not that the rocks have escaped deformation but that multiple periods of deformation have created complex trends. The scarcity of good marker horizons in the thick eugeosynclinal sequences and multiple batholithic intrusions further complicate structural analyses.

Thrust faults involving early Paleozoic and Precambrian rocks have been recognized over a large part of Seward Peninsula (Sainsbury, 1969b). In the western Seward Peninsula unmetamorphosed carbonate rocks of Ordovician and Silurian age are imbricately thrust faulted and are in thrust fault contact with slates and faintly metamorphosed carbonate rocks of probable pre-Ordovician age (Sainsbury, 1969a, 1969b). Farther west, across the Bering Strait from Seward Peninsula, exposures along the sea cliffs of Chukotsk Peninsula reveal complicated imbrication of Ordovician and Silurian limestone with Devonian shales and other argillaceous, weakly metamorphosed rocks (Byalobzhevski, oral commun., 1967; Gnibidenko, 1969). The proximity of these similar stratigraphic and structural features suggests their correlation across the Bering Strait. As the stratigraphy of other structurally complicated areas of Paleozoic rock in Alaska is studied, more examples of important thrust faulting will become known. Preliminary results of regional mapping in the Terra Cotta Mountains area of the Alaska Range (Reed, oral commun., 1969) and in the Annette Island area of southeastern Alaska (Berg, 1970) indicate thrust faults involving Paleozoic rocks are important in these areas.

An important record of structural juxtaposition of widely different rock types has been reported from the White Mountains at the west end of the Yukon-Tanana Upland (Church and Durfee, 1961). Here, the Tolovana Limestone, consisting of a long and narrow outcrop belt of pure limestone and dolomite of Silurian and Devonian age is in contact with the Fossil Creek volcanics of Ordovician age, a unit characterized by siliceous sedimentary rocks and pillow basalt.

According to Church and Durfee (1961), the limestone is everywhere thrust faulted over the volcanic rocks. Instead, the massive limestone was found by myself in company with R. Chapman and F. Weber in 1968 to be accordant and, where best exposed, gradational over an interval of several feet into calcareous tuff. This interpretation of a strati-graphic contact agrees with the original interpretation of Mertie (1937b). This belt in the central part of Alaska, where carbonate rock sections are in close proximity and are partly interlayered with volcanic rocks and with fine grained siliceous rock facies, marks a zone transitional in facies with mainly limestones to the north and volcanic-siliceous sequences to the south. The structure within this belt and its relation to the carbonate facies on the one hand and metamorphic rocks on the other is however, quite complex, and large-scale faulting may be partly responsible for some of the abrupt changes in rock types.

The amount of lateral displacement on the various thrust faults in Alaska is poorly known and except for the instances discussed below is not recognized as displacing major stratigraphic belts.

Several periods of south to north overthrusting during the Cretaceous and Tertiary affected the area that is now the Brooks Range (Lathram, 1965; Porter, 1966; Tailleur and others, 1967). Because of the multiple thrusting of unknown displacement, it is difficult to reconstruct the original facies within the Paleozoic rocks of northern Alaska. In the western Brooks Range large-scale overthrusts are thought to have a cumulative northward displacement probably in excess of 150 miles (Tailleur and Snelson, 1968). Thus far, it has not been possible to accurately measure amounts of total displacement because of the imbricate nature of the faulting. On a single fault in the Chandalar area of the central Brooks Range 5 miles of horizontal displacement has been measured (Brosgé oral commun., 1968). Because scores of subparallel faults have been mapped, their aggregate displacement may be very substantial. Preliminary estimates of Paleozoic stratigraphic relations south to north across various parts of the Brooks Range have been made using palinspastic reconstruction across the multiple thrust sheets (Lathram, 1965; Tailleur and others, 1967).

Longitudinal faults and topographic trenches.--In Alaska, as in more southern parts of the Cordilleran belt, there are a number of long fault zones which are frequently expressed topographically as trenches or valleys (fig. 20) Some of the more prominent faults and the way in which they affect Paleozoic rocks are discussed below.

The Tintina fault zone in east-central Alaska is marked by a narrow valley that parallels the Yukon River on its south side (Brabb and Churkin, 1965) and extends from Alaska southeastward across Yukon Territory to Liard plain which separates it from the Rocky Mountain Trench (Roddick, 1967). The Tintina fault zone effectively separates the unmetamorphosed Precambrian through Mesozoic stratigraphic succession on the north from the Birch Creek Schist--strongly metamorphosed, mainly siliceous sedimentary rocks and volcanics of probable Paleozoic and possible Precambrian age on the south. The granitic and ultramafic intrusions of Mesozoic age (except for the "Circle volcanics") cut metamorphic rocks south of the fault and do not extend north of the Tintina fault thus further contrasting the widely different geologic terranes on both sides of the fault. Thick sections of nonmarine, poorly consolidated sandstone, mudstone, conglomerate, and minor coal of Upper Cretaceous and Tertiary age are developed along the fault zone. Steep dips and faults cutting even the youngest Tertiary sediments along the trench-like valley indicate latest Tertiary and(or) Quaternary deformation. Large-scale lateral dislocation has been postulated along the fault. By matching an upper Precambrian quartzite-shale ("grit") unit north of the fault in Yukon Territory with a similar belt in the Yukon-Tanana Upland of east-central Alaska, a right-lateral offset of about 260 miles has been suggested (Roddick, 1967).

The north end of the Tintina fault is uncertain. It may continue straight into the Yukon Flats west of Circle or bend sharply westward parallel to the trend of the White and Crazy Mountains and then possibly connect up with the Kaltag fault that continues southwestward into Norton Sound (Patton and Hoare, 1968). Still another possible northern termination of the Tintina may be along a set of subparallel splays in the Livengood area where a number of through going faults (F. Weber, oral commun., 1969) may reflect the taking up of the substantial displacement postulated for the fault farther to the southeast.

The Kaltag fault controls the course of a long reach of the Yukon River and, like the Tintina, in places is marked by rift valleys and fault scarps that cut Tertiary and Quaternary deposits developed along it (Patton and Hoare, 1968). Seismic reflection profiles in the shallow Bering shelf reveal a sediment filled trough that is interpreted to be the seaward continuation of the Kaltag fault (Scholl and others, 1970). The major geologic trends in the area--the Yukon-Koyukuk Basin of Cretaceous age and a belt of metamorphic rocks of Paleozoic and Early Mesozoic age--have been displaced between 40-80 miles right laterally across the fault, and modern stream courses are offset up to 1.5 miles (Patton and Hoare, 1968). If the Kaltag and Tintina faults are differently trending segments of the same fault system, they have an arcuate trend nearly parallel to the Denali fault system farther south.

The Denali fault of southern Alaska is the longest throughgoing fault system in southern Alaska (St. Amand, 1957). The Denali fault is made up of different fairly straight segments that apparently interconnect at slight angles to give it an arcuate trend (Grantz, 1966). There are many subsidiary faults and strands, especially in its central part in the Alaska Range.

According to St. Amand (1957), the Denali fault system may have had 150 miles of right-lateral strike slip displacement since the start of the Pliocene. Because a number of geologic and topographic anomalies would result from this amount of displacement, Grantz (1966) suggested somewhat smaller and mainly older, Mesozoic movement with the amount of displacement across the fault varying from segment to segment. The Chatham Strait fault--a possible continuation of the Denali into southeastern Alaska separates regions of strongly contrasting geology (Twenhofel and Sainsbury, 1958; Lathram, 1964). About 120 miles of right-lateral separation is suggested by displacement of Paleozoic and Tertiary rocks on both sides of the fault (Lathram, 1964). In addition to this lateral displacement, several kilometers of vertical movement is assigned to the same fault (Loney and others, 1967). South of the Denali fault is another group of transcurrent faults that are more widely separated and seem to have different directions of displacement (fig. 20).

Correlation of the Paleozoic rocks around the edges of the Arctic and northern Pacific basins and sea floor spreading in the Arctic

Advocates of sea floor spreading and plate tectonics have established beyond reasonable doubt that the Atlantic Ocean has grown by sea floor spreading and that North America has drifted from Eurasia. In all the attempts to reconstruct how the drift has occurred, North America is considered a separate block from the Eurasian block and differential movement has been postulated between the two blocks (Blackett and others, 1965). The mid-Atlantic ridge and its northern extension across the Arctic Ocean is considered by many as the eastern boundary of North America (fig. 21). The position of

---

Figure 21 near here

---

the boundary separating North America from Eurasia in the Pacific realm is less certain but has been drawn between Chukotka and Alaska (Le Pichon, 1968). If drift has occurred across the northern Pacific, there should be some geological evidence of movement between the two continents in the Bering Sea region.

The Cenozoic geology of the Bering Sea area, recently summarized in the book "Bering Land Bridge" (Hopkins, 1967), indicates that there is a complex record of sea-level changes and intermittent land connections across the Bering Straits and that the North American and Eurasian continents appear to have been connected at least since the early Tertiary.

The geologic correlations of Mesozoic and older rocks and structures across the Bering and Chukchi Seas are less well known. Geophysical investigations, together with dredging in the Bering Sea, indicate that the acoustic basement represents in part a graywacke sequence of Cretaceous age and that, in places, gently deformed stratified sediments of late Tertiary age unconformably cover this basement (Scholl and others, 1966). No significant breaks in the Cenozoic and Mesozoic geologic trends have been reported to substantiate continental drift between North America and Eurasia where they come together in the northern Pacific.

However, if drift occurred, it is the pre-Mesozoic rocks and structures that should show the greatest displacement. A direct comparison of the pre-Mesozoic geology of Alaska with that of Chukotka will now be made in search for evidence of differential movement between the two continents.

Wrangell Island, connected by a bathymetric (Creager and McManus, 1965) and a gravity anomaly trend (Ostenso, 1968b) across the Chukchi Sea to Lisburne Peninsula, seems to represent a westward structural extension of the Brooks Range (Holmes and others, 1968; Grantz and others, 1970). The oldest fossiliferous rocks, of Mississippian age, occur in the central part of Wrangell Island as part of a thick sequence of marine sedimentary rocks (fig. 22). Nonmarine beds of chert-quartz

Figure 22 near here

conglomerate form the lower part of the sequence. The presence in the western Brooks Range of similar conglomerates of Late Devonian age in a stratigraphic section comparable to that in Wrangell Island has been noted (Bogdanov and Tilman, 1964). These conglomerates are part of a series of clastic wedge deposits that continued around the edge of the Canada Basin from the Soviet Arctic (Chukotka and Wrangell Island), across northern Alaska (Churkin, 1969), and then across the Canadian Arctic Islands at least as far as Ellesmere Island (Trettin, 1967).

Intrusive rocks on Wrangell Island include dikes and small plutonic bodies, mainly of granitic composition. They cut the Paleozoic section, but nowhere are they reported to affect the Triassic strata. The age of these rocks, supported by potassium-argon isotope dating, is thought to be late Paleozoic (fig. 22). Absolute age determinations of granitic rocks farther east around the margin of the Canada Basin indicate that the intrusion of these rocks probably was related to the same mid-Paleozoic orogeny that produced the wedge of Upper Devonian conglomerates and sandstones (Tailleur and others, 1967; Trettin, 1967; Churkin, 1969).

On Wrangell Island the Mississippian rocks, like the underlying Upper Devonian rocks, are very similar to, but thicker than, those in the Brooks Range. Permian and Triassic rocks, mainly clastics, unconformably overlie the Mississippian and again there is a similarity to the stratigraphy of the Brooks Range (fig. 22). In the Canadian Arctic Islands, an even thicker sequence of Carboniferous and younger rocks that lie unconformably on the older Paleozoic rocks of the Franklinian geosyncline form the Sverdrup Basin (Thorsteinsson and Tozer, 1960).

The rocks at the western tip of Seward Peninsula, being close to Chukotsk Peninsula, are important in testing the similarity of the geology of North America and Eurasia where the two continental land masses come together.

The basic elements of the geology of the Cape Dezhneva area, the easternmost tip of Chukotsk Peninsula and the land point nearest to Seward Peninsula, are shown on figure 23. There is a gneiss and

Figure 23 near here

amphibolite central dome that is surrounded progressively outward by marble and schist that is interlayered with partially recrystallized limestones. Shelly fossils in these limestones are of Ordovician, Silurian, Devonian, and Carboniferous age (Gnibidenko, 1969, p. 11-13). Granite and a syenite intrusion coupled by imbricate thrust faulting (Byalobzhevski, oral commun., 1967) complicate the structure. About 3 miles of schist and gneiss is reported by Gnibidenko to conformably underlie the limestone with Upper Ordovician fossils.

Directly across the narrow Bering Strait in Seward Peninsula, the west-trending Kigluaik Mountains expose, in their core, gneiss and biotite schists that have a well-defined domal structure (Collier and others, 1908, p. 67) (fig. 24). Overlying these high-grade metamorphic

---

Figure 24 near here

---

rocks are lower grade schists characterized by chlorite and muscovite, Marble is interlayered with the schist, especially in its upper part. Thin-bedded argillaceous limestone seems to overlie the schist and in turn is overlain to the north by a sequence of massive limestone containing Ordovician and Silurian fossils (Sainsbury, 1969a).

Sainsbury (written commun., 1970) has obtained a 750 m.y. date on gneiss in the Kigluiak Mountains using the Rb/Sr whole-rock method. According to Sainsbury, a dike cutting this same gneiss gives a 450 m.y. rubidium-strontium date.

On the other hand, dating of other metamorphic rocks and associated intrusives in the general area using the potassium-argon method indicates a Cretaceous metamorphic-plutonic event (Sainsbury, 1969a). In nearby Chukotsk Peninsula most of the dates on intrusive and metamorphic rocks are again Mesozoic, but a number of much older dates ranging from 1500 to 700 m.y. have been obtained on rocks in the same vicinity as those giving Mesozoic dates (Gnibidenko, 1969). Thus, there is a close correlation of stratigraphy and metamorphism in the oldest rocks across the Bering Strait (Churkin, 1970). There also appears to be a close correlation of thrust faulting (Sainsbury, 1969b) and plutonic activity (T. P. Miller, oral commun., 1970) across the straits.

A comparison of upper Paleozoic and lower Mesozoic stratigraphy between eastern Chukotka and Seward Peninsula is not possible because only isolated fragments of these rocks are available for comparison in Seward Peninsula. On St. Lawrence Island, however, in the middle of the Bering shelf, a rather complete Devonian through Triassic section has been reported by Patton and Dutro (1969). The section here closely resembles that of the western Brooks Range on the east and the Chukotsk Peninsula on the west (fig. 24).

On both sides of the Bering Straits, at about the same latitude but much further inland, are rather similar and much more complete sequences ranging in age from Precambrian to Triassic (fig. 24). In Alaska this is the section exposed in the Yukon-Porcupine Rivers area (Churkin and Brabb, 1967); in Siberia it is the section in the Kolmski massif (Bogdanov, 1963). These two relatively stable areas are mostly carbonate rock sections nearly surrounded by thicker, more terrigenous deposits.

In Chukotka, as in Alaska, the depth to the Mohorovicic discontinuity, except for some deep roots below high mountains, generally rises closer to the surface as the Arctic and Pacific Ocean basins are approached (Nikolaevskiy, 1964; Woollard and others, 1960). The preliminary inference that a trend of high crustal thickness across the center of Alaska connects with a comparable trend across the center of Chukotka suggests another correlation of the geology across the Bering Straits.

The close similarities between the geologic histories of the opposing edges of the Bering and Chukchi Seas imply that Alaska and Chukotka essentially have been connected since Paleozoic time and probably since the Precambrian. This conclusion is evaluated below in the light of the hypotheses of sea floor spreading and plate tectonics as they apply to the theory of continental drift and sea floor spreading in the Arctic.

The other possibility in reconstructing the relative movement between North America and Eurasia is that although a boundary between the two crustal blocks does not pass in the Bering Sea area--it may lie somewhere farther west in Siberia. A possible site for this boundary has been assumed to lie along the north-trending Verkhoyansk Mountains (Wilson, 1963; Heezen and Tharp, 1965; Morgan, 1968) (fig. 1). These mountains expose a Mesozoic fold belt that forms the east boundary of the Siberian Platform and separates its mainly Precambrian and Paleozoic rocks from the more intensely deformed rocks mainly of Mesozoic age in the Chukotka fold belt (Yanshin, 1966).

To test the Vehkhoyansk area as a possible boundary of movement between the North American and Eurasian blocks, the implication of the northern extension of the mid-Atlantic ridge being on trend with the Verkhoyansk fold belt as the two features approach each other in the Arctic has been briefly examined (Churkin, 1970).

The seismically and volcanically active mid-Atlantic ridge runs northwards as far as Iceland (Friend, 1967). North of Iceland the ridge runs between Greenland and Spitsbergen (Ostenso, 1968b) and with decreased seismicity (Sykes, 1965; Lazareva and Misharina, 1965) continues across the Eurasian Basin as the Nansen Cordillera (Gakkel Ridge) midway between the Lomonosov Ridge and the continental margin of Eurasia (Demenitskaya and Karasik, 1967) (fig. 25). Fault-plane

---

Figure 25 near here

---

solutions of earthquakes along this Arctic seismic zone show that the stress system on the Greenland end of the ridge is tensional as on the mid-Atlantic ridge while the Siberian end of the ridge is reported to be under compressional stress (Lazareva and Misharina, 1965; Scheidegger, 1966). The trend of earthquake epicenters continues into the Siberian mainland where it follows the Verkhoyansk and Cherski Mountains (Lazareva and Misharina, 1965). Judging by the tight folding and plutonic activity of Mesozoic age (Yanshin, 1966), and the occurrence of continental deposits of later Mesozoic and Tertiary age, this region has a long history of compression producing structures on trend with the northern extension of the mid-Atlantic ridge.

A marked decrease in amplitude of magnetic anomalies has also been observed over the Arctic extension of the mid-Atlantic ridge (Ostenso, 1968a). According to Ostenso, this northward attenuation of magnetic anomalies might imply that the Arctic extension of the mid-Atlantic ridge is under less tension.

These data are consistent with the concept that the Eurasian Basin part of the Arctic is a thin wedge-shaped opening that widens southward (cf. Harland, 1965). Thus the present day rotation of North America relative to Eurasia may be thought of as a wedge-like opening hinged north of the Verkhoyansk fold belt. The significance of the Verkhoyansk region representing either a plate boundary bringing together originally widely separated crustal blocks (cf. Wilson, 1963) or acting as the terminus of the mid-Atlantic rift system against the Eurasian continent and with no separation across it is a problem beyond the scope of this paper.

The pole of rotation for North America with respect to Eurasia has been independently determined to be 78° N, 102° E (using azimuths of fracture zones across the northern part of the mid-Atlantic ridge--LePichon, 1968) and 73° N, 96.5° E (using the best fit of Greenland to Europe--Bullard and others, 1965). These poles lie in the Soviet Arctic just southwest of the end of the Eurasian Basin. Considering all the inherent problems of estimating paleo-poles of continental drift, it is probably significant that the calculated poles of rotation are so near the apex of the Eurasian Basin-Northern Atlantic opening, again suggesting a hinge zone on one side of which there is tension and on the other compression.

As dating of magnetic anomalies in the Arctic has not been done, the spreading history in the Arctic is difficult to compare with the Atlantic. Spreading could have started in the central Atlantic and progressed northward along the mid-Atlantic ridge. Its trans-Arctic extension may be a very young feature in an embryonic state of development. Conversely, spreading in the Arctic may have started at the same time as in the central Atlantic but proceeded at a much slower rate.

Estimates of sea floor spreading in the North Atlantic indicate a rate of about 1 cm/year near Iceland (Vine, 1966). If this rate of spreading is extended back in time, then the volcanic rocks of southeastern Greenland and the equivalent volcanic rocks of Rockwall Bank off the coast of the British Isles, each located 600 km from the ridge and dated as 60 m.y. old, "may be related to the first rifting which was to become the Atlantic Ocean in this latitude" (Friend, 1967). If this 1,200 km of total separation has occurred on the Atlantic side of North America, there should be some dramatic expression of this drift bringing North America and Eurasia closer together assuming they were either separated across an originally larger Pacific basin or connected across the Bering-Chukchi continental seas.

There are in fact sharp bends in the structures of southern Alaska and Chukotka that have been interpreted as products of drift of North America relatively toward Eurasia (Grantz, 1968). These curved structures include the long faults in southern Alaska (fig. 20) and those in the Koryak Mountains of Chukotka. Mesozoic and older tectonic elements (figs. 1, 17, and 18) that are subparallel to these faults also reflect a bend in the stratigraphic belts of Alaska. Moreover the curved continental margin of the Bering Sea, Gulf of Alaska, and possibly the northward prolongation of the Chukchi shelf margin around the Chukchi Cap could also be products of this movement (fig. 20).

A complication of this simplified analysis of compressional bending in the Alaska-Chukotka region as a consequence of tensional opening of the Atlantic is that the strongly curved southern continental margins of Alaska and Chukotka and some of the subparallel trends in the stratigraphic and structural belts farther inland may be the result of thrusting of the Pacific floor against the continental margins of Alaska and Chukotka--a hypothesis supported by studies of magnetic anomalies in the Gulf of Alaska (Pitman and Hayes, 1968), faults and folds along the Gulf of Alaska (Stoneley, 1967) and in the Koryak Mountains of Chukotka (Bogdanov in Pieve, 1969), and land movements associated with the Alaska earthquake of 1964 (Plafker, 1969).

Finally, the geologic history around the margin of the Canada Basin together with geophysical data from the basin itself provide ways of answering questions concerning the age and origin of this part of the Arctic Ocean basin.

From the stratigraphic data presented earlier, there is evidence that an early Paleozoic geosyncline rimmed the Canada Basin. Starting in the Upper Devonian, uplifts in this geosyncline accompanied by granitic intrusion produced wedges of coarse clastic sediments that spread southward onto adjoining areas of Alaska, Canada, and Siberia. Interpretations of geophysical data indicate that the Canada Basin is floored by an oceanic crust (Oliver and others, 1955) and seems to have a "fossil" mid-oceanic ridge--the Alpha Cordillera (Vogt and Ostenso, in press). The Canada Basin would thus appear to be a true and probably very ancient ocean basin rimmed by a Paleozoic mobile belt (Churkin, 1969).

Another interpretation of the close similarity in geology between the Canadian Arctic Islands on the one hand and Alaska and Siberia on the other, is that the entire Arctic Ocean Basin was created by a single episode of large-scale rifting (Carey, 1955; cf. Tailleur and Brosgé, 1970).

If both the Canada and Eurasian basins were formed during a single period of rifting, it is difficult to explain the Lomonosov Ridge, a narrow, presumably nonvolcanic, submarine ridge that is oriented at right angles to the direction of rift but seems not to be offset (Eardley, 1948). A belt of deformed Paleozoic sialic rocks on the northern coast of Ellesmere Island (Trettin, 1969) and another in the New Siberian Islands (Bogdanov, 1963, fig. 66) have been found to line up with the submarine Lomonosov Ridge, supporting the view that the ridge is a continental outlier. Furthermore, both the Alpha (Vogt and Ostenso,,in press) and Nansen Cordillera (Demenitskaya and Karasik, 1967) 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 (fig. 25). 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 (fig. 25). The Eurasian basin has essentially straight continental margins that seem to match. The Canada Basin on the other hand has a rather straight margin along the Canadian Islands, but along its Alaskan-Siberian side has the Chukchi Cap, a large perhaps detached continental lobe (Hunkins and others, 1962) that has no counterpart along its Canadian side. The Eurasian basin contains the seismically active extension of the mid-Atlantic Ridge, whereas the Canada Basin, with its inactive Alpha Cordillera, probably is a much older depression.

References cited

Armstrong, A. K., 1970, Mississippian dolomites from Lisburne Group, Killik River, Mount Bupto region, Brooks Range, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 251-264.

________1970, Mississippian rugose corals, Peratrovich Formation, West Coast, Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Prof. Paper 534, 44 p.

Armstrong, A. K., MacKevett, E. M., Jr., and Silberling, N. J., 1969, The Chitistone and Nizina limestones of part of the southern Wrangell Mountains, Alaska—a preliminary report stressing carbonate petrography and depositional environment: U.S. Geol. Survey Prof. Paper 650D, p. D49-D62.

Armstrong, A. K., and Mamet, B. L., 1970, Biostratigraphy and dolomite porosity trends of the Lisburne Group, in Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. N1-N15.

Armstrong, A. K., Mamet, B. L., and Dutro, J. T., Jr., 1970, Foraminiferal zonation and carbonate facies of Carboniferous (Mississippian and Pennsylvanian) Lisburne Group, central and eastern Brooks Range, Arctic Alaska: Am. Assoc. Petroleum Geologists Bull., v. 54, p. 687-698.

Baadsgaard, H., Folinsbee, R. E., and Lipson, J., 1961, Caledonian or Acadian granites of the northern Yukon Territory, in Raasch, G. O., ed., Geology of the Arctic, V. 1: Toronto, Ontario, Univ. Toronto Press, p. 458-465.

Belyi, V. F., 1964, K voprosu o zhestkoi strukture vostochnoi Chukotki i Alyaske; Materyaly po geologii i poleznym iskopaemym Severo-Vostoka SSSR, Magadan, vyp. 17, p. 40-48.

Berg, H. C., 1970, Paleozoic plutonism and contrasting metamorphic terranes, Annette Island, Alaska: Geol. Soc. America Abstracts with Programs, v. 2, p. 70.

Blackett, P. M. S., Bullard, E., and Runcorn, S. K., (organizers), 1965, A symposium on continental drift: Royal Soc. London Philos. Trans., ser. A, v. 258, no. 1088, 323 p.

Bogdanov, N. A., 1963, Tektonicheskoe razvitie v Paleozoe Kolymskogo massiva i vostochnoi Arktiki [Tectonic development of the Kolyma massif and eastern Arctic in the Paleozoic]: Trudy, Geologicheskogo instituta Akademiya Nauk USSR, vyp. 99, Moscow, 235 p.

Bogdanov, N. A., and Tilman, S. M., 1964, Obshchie cherty razvitiya paleozoiskikh struktur ostrova Vrangelya i zapadnoi chasti khrebta Bruksa (Alyaska) [Similarities in the development of the Paleozoic structures of Wrangell Island and the western part of the Brooks Range (Alaska), in Soveshchanie po Problem Tektoniki, Moscow, 1963, Skladchatye oblasti Evrazii: materialy]: Moskva, Nauka, p. 219-230.

Bowsher, A. L., and Dutro, J. T., Jr., 1957, The Paleozoic section in the Shainin Lake area, central Brooks Range, Alaska: U.S. Geol. Survey Prof. Paper 303-A, 1-39 p.

Brabb, E. E., 1967, Stratigraphy of the Cambrian and Ordovician rocks of east-central Alaska: U.S. Geol. Survey Prof. Paper 559-A, p. A1-A30.

Brabb, E. E., 1969, Six new Paleozoic and Mesozoic formations in east-central Alaska: U.S. Geol. Survey Bull. 1274-I, p. I1-I26.

Brabb, E. E., and Churkin, Michael, Jr., 1965, Preliminary geologic map of the Eagle D-1 quadrangle, east-central Alaska: U.S. Geol. Survey open-file map, scale 1:63,360.

________1967, Stratigraphic evidence for the Late Devonian age of the Nation River Formation, east-central Alaska in U.S. Geol. Survey Prof. Paper 575-D, p. D4-D15.

________1970, Geologic map of the Charley River quadrangle, east-central Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-573, scale 1:250,000.

Brabb, E. E., and Grant, R. E., Stratigraphy and paleontology of a revised type section for the Tahkandit Limestone (Permian) in east-central Alaska: U.S. Geol. Survey Prof. Paper 703 (in press).

Brew, D. A., 1968, The role of volcanism in post-Carboniferous tectonics of southeastern Alaska and nearby regions, North America: Internat. Geol. Cong., 23d, Prague 1968, v. 2, p. 107-121.

Brew, D. A., Loney, R. A., and Muffler, L. J. P., 1966, Tectonic history of southeastern Alaska in A symposium on tectonic history and mineral deposits of the western Cordillera in British Columbia and neighboring parts of the United States: Canadian Inst. Mining, spec. vol. no. 8, p. 149-170.

Brooks, A. H., 1911, The Mount McKinley region, Alaska, with descriptions of the igneous rocks and of the Bonnifield and Kantishna districts, by L. M. Prindle: U.S. Geol. Survey Prof. Paper 70, 234 p.

Brosgé, W. P., 1960, Metasedimentary rocks in the south-central Brooks Range, Alaska in Geological Survey Research 1960: U.S. Geol. Survey Prof. Paper 400-B, p. B351-B352.

Brosgé, W. P., Brabb, E. E., and King, E. R., 1970, Geological interpretation of reconnaissance aeromagnetic survey of northeastern Alaska: U.S. Geol. Survey Bull. 1271-F, p. F1-F14.

Brosgé, W. P., Dutro, J. T., Jr., Mangus, M. D., and Reiser, H. N., 1962, Paleozoic sequence in eastern Brooks Range, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 12, p. 2174-2198.

Brosgé, W. P., Lanphere, M. A., Reiser, H. N., and Chapman, R. M., 1969, Probable Permian age of the Rampart Group, central Alaska: U.S. Geol. Survey Bull. 1294-B, p. B1-B18.

Brosgé, W. P., and Reiser, H. N., 1964, Geologic map and section of the Chandalar quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-375, scale 1:250,000.

________ 1965, Preliminary geologic map of the Arctic quadrangle, Alaska: U.S. Geol. Survey open-file report.

________ 1969, Preliminary geologic map of the Coleen quadrangle, Alaska: U.S. Geol. Survey open-file report, scale 1:250,000.

Brosgé, W. P., Reiser, H. N., Dutro, J. T., Jr., and Churkin, Michael, Jr., 1966, Geologic map and stratigraphic sections, Porcupine River Canyon, Alaska: U.S. Geol. Survey open-file report, scale 1:63,360.

Brosgé, W. P., and Tailleur, I. L., 1970, Depositional history of northern Alaska, in Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, , p. D1-D17.

Brown, J. S., 1926, The Nixon Fork country, and silver-lead prospects near Ruby [Alaska]: U.S. Geol. Survey Bull. 783-D, p. 97-150.

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U.S. Geol. Survey Bull. 800, 398 p.

Bullard, Edward, Everett, J. E., and Smith, A. G., 1965, The fit of the continents around the Atlantic, in A symposium on continental drift: Royal Soc. London Philos. Trans., Ser. A., v. 258, no. 1088, p. 41-51.

Burk, C. A., 1965, Geology of the Alaska Peninsula--island arc and continental margin: Geol. Soc. America Mem. 99, 250 p.

Cady, W. M., Wallace, R. E., Hoare, J. M., and Webber, E. J., 1955, The central Kuskokwim region, Alaska: U.S. Geol. Survey Prof. Paper 268, 132 p.

Cairnes, D. D., 1914, The Yukon-Alaska international boundary, between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, 161 p.

Campbell, R. H., 1967, Areal geology in the vicinity of the Chariot site, Lisburne Peninsula, northwestern Alaska: U.S. Geol. Survey Prof. Paper 395, 71 p.

Carey, S. W., 1955, The orocline concept in geotectonics, Pt. I: Royal Soc. Tasmania Papers and Proc., v. 89, p. 255-288.

Church, R. E., and Durfee, M. C., 1961, Geology of the Fossil Creek area, White Mountains, Alaska: Alaska Univ., College, M.S. thesis, 96 p.

Churkin, Michael, Jr., 1966, Morphology and stratigraphic range of the phyllocarid crustacean Caryocaris from Alaska and the Great Basin: Palaeontology, v. 9, pt. 3, p. 371-380.

Churkin, Michael, Jr., 1969, Paleozoic tectonic history of the Arctic Basin north of Alaska: Science, v. 165, p. 549-555.

________1970, Fold belts of Alaska and Siberia and drift between North America and Asia, in Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. G1-G14.

________197_, Silurian and Devonian stratigraphy of Alaska and the Silurian-Devonian boundary: Internat. Symposium on the Silurian-Devonian boundary and the stratigraphy of the Lower and Middle Devonian, 3d, Leningrad, U.S.S.R., 1968. (In press)

Churkin, Michael, Jr., and Brabb, E. E., 1965a, Ordovician, Silurian, and Devonian biostratigraphy of east-central Alaska: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 2, p. 172-185.

________1965b, Occurrence and stratigraphic significance of Oldhamia, a Cambrian trace fossil in east-central Alaska, in Geological Survey research, 1965: U.S. Geol. Survey Prof. Paper 525-D, p. D120-D124.

________1967, Devonian rocks of the Yukon-Porcupine Rivers area and their tectonic relation to other Devonian sequences in Alaska, in Oswald, D. H., ed., International symposium on the Devonian system, Calgary, 1967, V. 2: Calgary, Alberta Soc. Petroleum Geologists, p. 227-258.

Churkin, Michael, Jr., and Carter, Claire, 1970, Earliest Silurian graptolites of Alaska and Nevada: U.S. Geol. Survey Prof. Paper 653, 51 p.

Churkin, Michael, Jr., Eberlein, G. D., Hueber, F. M., and Mamay, S. H., 1969, Lower Devonian land plants from graptolitic shale in southeastern Alaska: Palaeontology, v. 12, p. 559-573.

Churkin, Michael, Jr., Jaeger, Herman, and Eberlein, G. D., 1970, Lower Devonian graptolites from southeastern Alaska: Lethaia, v. 3, p. 183-202.

Churkin, Michael, Jr., and Kay, Marshall, 1967, Graptolite-bearing Ordovician siliceous and volcanic rocks, northern Independence Range, Nevada: Geol. Soc. America Bull., v. 78, no. 5, p. 651-668.

Churkin, Michael, Jr., and Langenheim, R. L., Jr., 1960, Silurian strata of the Klamath Mountains, California: Am. Jour. Sci., v. 258, no. 4, p. 258-273.

Coats, R. R., 1956, Geology of northern Adak Island, Alaska: U.S. Geol. Survey Bull. 1028-C, p. 45-67.

Collier, A. J., 1902, A reconnaissance of the northwestern portion of Seward Peninsula, Alaska: U.S. Geol. Survey Prof. Paper 2, 70 p.

Collier, A. J., Hess, F. L., Smith, P. S., and Brooks, A. H., 1908, The gold placers of parts of Seward Peninsula, Alaska, including the Nome, Council, Kougarok, Port Clarence, and Goodhope precincts: U.S. Geol. Survey Bull. 328, 343 p.

Collins, F. R., 1958, Test wells, Topagoruk area, Alaska, with a section on micropaleontology, by H. R. Bergquist: U.S. Geol. Survey Prof. Paper 305-D, p. 265-316.

Creager, J. S., and McManus, D. A., 1965, Pleistocene drainage patterns on the floor of the Chukchi Sea: Marine Geology, v. 3, no. 4, p. 279-290.

Danner, W. R., 1966, Limestone resources of western Washington: Washington Div. Mines and Geology Bull. 52, 474 p.

Demenitskaya, R. M., and Karasik, A. M., 1967, Rift system of the Arctic Ocean [abs.]: Internat. Union Geodesy and Geophysics, 14th General Assembly, Switzerland 1967, v. 8, Upper Mantle Committee.

Detterman, R. L., 1970, Sedimentary history of the Sadlerochit and Shublik Formations in northeastern Alaska, in Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. 01-013.

Douglas, R. J. W., Norris, D. K., Thorsteinsson, R., and Tozer, E. T., 1963, Geology and petroleum potentialities of northern Canada: Canada Geol. Survey Paper 63-31, 28 p.

Dutro, J. T., Jr., 1956, Annotated bibliography of Alaskan Paleozoic paleontology: U.S. Geol. Survey Bull. 1021-H, p. 253-287.

_______1970, Pre-Carboniferous carbonate rocks, northeastern Alaska, in Adkinson, W. L., and Brosgé, M. M., eds, Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. M1-M7.

Dutro, J. T., Jr., and Douglass, R. C., 1961, Pennsylvanian rocks in southeastern Alaska: U.S. Geol. Survey Prof. Paper 424-B, p. B239-B241.

Dutro, J. T., Jr., and Payne, T. G., 1957, Geologic map of Alaska: U.S. Geol. Survey, scale 1:2,500,000.

Eakin, H. M., 1918, The Cosna-Nowitna region, Alaska: U.S. Geol. Survey Bull. 667, 54 p.

Eardley, A. J., 1961, History of geologic thought on the origin of the Arctic Basin, v. 1: Toronto, Ontario, Univ. Toronto Press, p. 607-621.

Eberlein, G. D., and Churkin, Michael, Jr., 1970, Paleozoic stratigraphy in the northwest coastal area of Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Bull. 1284, 67 p.

Egiazarov, B. Kh., and others, 1965, Geologiya i poleznye iskopaemye Koryakskogo nagor'ya (Geology and mineral resources of the Koryak Upland): Trudy Naychno--Issled. Inst. Geol. Arktiki, Leningrad, v. 148, 3#2 p.

Forbes, R. B., Pilkington, H. D., and Hawkins, D. B., 1968, Gold gradients and anomalies in the Pedro Dome-Cleary Summit area, Fairbanks district, Alaska: U.S. Geol. Survey open-file report, 43 p.

Foster, H. L., 1969, Reconnaissance geology of the Eagle A-1 and A-2 quadrangles, Alaska: U.S. Geol. Survey Bull. 1271-G, p. G1-G30.

Foster, R. L., 1967, Tectonic inclusions from a serpentinite, east-central Alaska: U.S. Geol. Survey Prof. Paper 575-D, p. D120-D122.

Friend, P. F., 1967, The growth of the north Atlantic Ocean by the spreading of its floor: Polar Rec., v. 13, p. 579-588.

Gabrielse, H., 1967, Tectonic evolution of the northern Canadian Cordillera: Canadian Jour. Earth Sci., v. 4, no. 2, p. 271-298.

Gabrielse, H., and Wheeler, J. O., 1961, Tectonic framework of southern Yukon and northwestern British Columbia: Canada Geol. Survey Paper 60-24, 37 p.

Gates, G. O., and Gryc, George, 1963, Structure and tectonic history of Alaska, in Childs, O. E., and Beebe, B. W., eds., The backbone of the Americas--tectonic history from pole to pole, a symposium: Am. Assoc. Petroleum Geologists Mem. 2, p. 264-277.

Gnibidenko, G. S., 1969, Metamorficheskie kompleksy v stryktyrakh severozapadnogo sektora tikhookeanskogo poyaca [Metamorphic complexes in the structures of the northwestern sector of the circum-pacific belt]: Akademiya Nauk, USSR Siberskoe otdeleniye, Nauka, Moscow, 134 p.

Grantz, Arthur, 1966, Strike-slip faults in Alaska: U.S. Geol. Survey open-file report, 82 p.

________ 1968, Strike-slip faults in Alaska [abs.]: Geol. Soc. America and Assoc. Socs. Ann. Mtg., Mexico City 1968, Program, p. 117.

Grantz, Arthur, Wolf, S. C., Breslau, Lloyd, Johnson, T. C., and Hanna, W. F., 1970, Geology of the Chukchi Sea as determined by acoustic and magnetic profiling, in Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. F1-F28.

Gryc, George, Dutro, J. T., Jr., Brosgé, W. P., and Churkin, Michael, Jr., 1967, Devonian of Alaska, in Oswald, D. H., ed., International symposium on the Devonian system, Calgary, 1967, V. 1: Calgary, Alberta Soc. Petroleum Geologists, p. 703-716.

Hanson, B. M., 1957, Middle Permian limestone on Pacific side of Alaska Peninsula: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, p. 2376-2378.

Harland, W. B., 1965, Discussion on the tectonic evolution of the Arctic-north Atlantic region: Royal Soc. London Philos. Trans., Ser. A, v. 258, no. 1088, p. 59-75.

Heezen, B. C., and Tharp, M., 1965, Tectonic fabric of the Atlantic and Indian Oceans and continental drift: Royal Soc. London Philos. Trans., Ser. A, v. 258, no. 1088, p. 90-106.

Hoare, J. M., 1961, Geology and tectonic setting of lower Kuskokwim-Bristol Bay region, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 594-611.

Hoare, J. M., and Coonrad, W. L., 1961, Geologic map of Goodnews quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-339, scale 1:250,000.

Holmes, M. L., Creager, J. S., and McManus, D. A., 1968, Structure and history of the Chukchi basin [abs.]: Geol. Soc. America and Assoc. Socs. Ann. Mtg., Mexico City 1968, p. 141.

Hopkins, D. M., ed., 1967, Bering land bridge: Stanford, Calif., Stanford University Press, 495 p.

Hunkins, Kenneth, Herron, Thomas, Kutschale, Henry, and Peter, George, 1962, Geophysical studies of the Chukchi cap, Arctic Ocean: Jour. Geophys. Research, v. 67, no. 1, p. 235-247.

Irwin, W. P., 1966, Geology of the Klamath Mountains province, in Bailey, E. H., ed., Geology of northern California: California Div. Mines and Geology Bull. 190, p. 19-38.

Jackson, D. E., and Lenz, A. C., 1962, Zonation of Ordovician and Silurian graptolites of northern Yukon, Canada: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 1, p. 30-45.

Jeletzky, J. A., 1962, Pre-Cretaceous Richardson Mountains trough--its place in the tectonic framework of Arctic Canada and its bearing on some geosynclinal concepts: Royal Soc. Canada Trans., 3d ser., v. 56, sec. 3, pt. 1, p. 55-84.

Kay, Marshall, 1947, North American geosynclines: Geol. Soc. America Mem. 48, 143 p.

Kindle, E. M., 1908, Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., v. 19, p. 315-338.

King, P. B., compiler, 1969, Tectonic map of North America: U.S. Geol. Survey, scale 1:5,000,000.

Kirk, E., 1918, Paleozoic glaciation in southeastern Alaska: Am. Jour. Sci., v. 46, p. 511-515.

Kirk, Edwin, and Amsden, T. W., 1952, Upper Silurian brachiopods from southeastern Alaska: U.S. Geol. Survey Prof. Paper 233-C, p. 53-66.

Kobayashi, T., 1935, The Briscoia fauna of the late Upper Cambrian in Alaska, with descriptions of a few Upper Cambrian trilobites from Montana and Nevada: Japanese Jour. Geology and Geography, v. 12, nos. 3-4, p. 39-57.

Krasniy, L. I., ed., 1966, Geologicheskoe stroenie Severo-Zapadnoi chasti tikhookeanskogo podvizhnogo poyasa [Geological structure of the northwestern part of the Pacific mobile belt]: Ministerstvo geologii SSSR, Vses. Nauchino-issled. Geol. Inst., Nedra, Moscow, 516 p.

Lanphere, M. A., 1965, Age of Ordovician and Devonian mafic rocks in northern Alaska, in Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525A, p. A101-A102.

Lanphere, M. A., MacKevett, E. M., Jr., and Stern, T. W., 1964, Potassium-argon and lead-alpha ages of plutonic rocks, Bokan Mountain area, Alaska: Science, v. 145, no. 3633, p. 705-707.

Lathram, E. H., 1964, Apparent right-lateral separation on Chatham Strait fault, southeastern Alaska: Geol. Soc. America Bull., v. 75, no. 3, p. 249-251.

_______1965, Preliminary geologic map of northern Alaska: U.S. Geol. Survey open-file map, scale 1:1,000,000.

Lazareva, A. P., and Misharina, L. A., 1965, Stresses in earthquake foci in the Arctic seismic belt: Akad. Nauk SSSR Isvestiya, Physics of the Solid Earth (in translation) 1965, no. 2, p. 84-87.

LePichon, Xavier, 1968, Sea-floor spreading and continental drift: Jour. Geophys. Research, v. 73, p. 3661-3697.

Loney, R. A., 1964, Stratigraphy and petrography of the Pybus-Gambier area, Admiralty Island, Alaska: U.S. Geol. Survey Bull. 1178, 103 p.

Loney, R. A., Brew, D. A., and Lanphere, M. A., 1967, Post-Paleozoic radiometric ages and their relevance to fault movements, northern southeastern Alaska: Geol. Soc. America Bull., v. 78, p. 511-526.

Loney, R. A., Condon, W. H., and Dutro, J. T., Jr., 1963, Geology of the Freshwater Bay area, Chichagof Island, Alaska: U.S. Geol. Survey Bull. 1108-C, p. C1-C54.

Martin, L. J., 1961, Tectonic framework of northern Canada, in Raasch, G. O., ed., Geology of the Arctic, V. 1: Toronto, Ontario, Univ. Toronto Press, p. 442-457.

Mendenhall, W. C., 1905, Geology of the central Copper River region, Alaska: U.S. Geol. Survey Prof. Paper 41, 133 p.

Mertie, J. B., Jr., 1930a, Geology of the Eagle-Circle district, Alaska: U.S. Geol. Survey Bull. 816, 168 p.

_______1930b, Mountain building in Alaska: Am. Jour. Sci., 5th ser., v. 20, p. 101-124.

_______1933, The Tatonduk-Nation district: U.S. Geol. Survey Bull. 836-E, p. 347-443.

_______1937a, The Kaiyuh Hills: U.S. Geol. Survey Bull. 868-D, p. 145-178.

_______1937b, The Yukon-Tanana region, Alaska: U.S. Geol. Survey Bull. 872, 276 p.

Mertie, J. B., Jr., 1938, The Nushagak district, Alaska: U.S. Geol. Survey Bull. 903, 96 p.

Moffit, F. H., 1913, Geology of the Nome and Grand Central quadrangles, Alaska: U.S. Geol. Survey Bull. 533, 140 p.

______1938, Geology of the Chitina Valley and adjacent area, Alaska: U.S. Geol. Survey Bull. 894, 137 p.

______1954, Geology of the eastern part of the Alaska Range and adjacent area: U.S. Geol. Survey Bull. 989-D, p. 63-218.

Morgan, W. J., 1968, Rises, trenches, great faults and crustal blocks: Jour. Geophys. Research, v. 73, p. 1959-1982.

Muffler, L. J. P., 1967, Stratigraphy of the Keku Islets and neighboring parts of Kuiu and Kupreanof Islands, southeastern Alaska: U.S. Geol. Survey Bull. 1241-C, p. C1-C52.

Nikolaevskiy, A. A., 1964, Sovremyenyi relef poverkhonsti mohorovichicha po geofisicheskim dannym [Present-day relief along the Mohorivicic discontinuity based on geophysical data], in Tektonika i glubinnoe stroenie severo-vostoka SSSR: Akad. Nauk SSSR Sibirsk. Otdeleniye Severo-Vostoch. Kompleks. Nauchno-Issled. Inst. Trudy, Vyp. 11, p. 131-149.

Norford, B. S., 1964, Reconnaissance of the Ordovician and Silurian rocks of northern Yukon Territory: Canada Geol. Survey Paper 63-39, 139 p.

Obradovich, J. D., and Peterman, Z. E., 1968, Geochronology of the Belt Series, Montana: Canadian Jour. Earth Sci., v. 5, p. 737-747.

Oliver, J. E., Ewing, W. M., and Press, Frank, 1955, Crustal structure of the Arctic regions from the L_g phase: Geol. Soc. America Bull., v. 66, no. 9, p. 1063-1074.

Ostenso, N. A., 1968a, Geophysical studies in the Greenland Sea: Geol. Soc. America Bull., v. 79, no. 1, p. 107-132.

_______1968b, A gravity survey of the Chukchi Sea region, and its bearing on westward extension of structures in northern Alaska: Geol. Soc. America Bull., v. 79, p. 241-254.

Ovenshine, A. T., Eberlein, G. D., and Churkin, Michael, Jr., 1969, Paleotectonic significance of Silurian-Devonian clastic wedge, southeastern Alaska [abs.]: Geol. Soc. America, Cordilleran Sec., Program, p. 50.

Ovenshine, A. T., and Webster, G. D., 1970, Age and stratigraphy of the Heceta Limestone in northern Sea Otter Sound, southeastern Alaska, in Geological Survey research 1970: U.S. Geol. Survey Prof. Paper 700-C, p. C170-C174.

Palmer, A. R., 1968, Cambrian trilobites of east-central Alaska: U.S. Geol. Survey Prof. Paper 559-B, p. B1-B115.

Patton, W. W., Jr., 1957, A new upper Paleozoic formation, central Brooks Range, Alaska: U.S. Geol. Survey Prof. Paper 303-B, p. 41-45.

Patton, W. W., Jr., and Dutro, J. T., Jr., 1969, Preliminary report on the Paleozoic and Mesozoic sedimentary sequence on St. Lawrence Island, Alaska: U.S. Geol. Survey Prof. Paper 650-D, p. D138-D143.

Patton, W. W., Jr., and Hoare, J. M., 1968, The Kaltag fault, west-central Alaska, in Geological Survey research, 1968: U.S. Geol. Survey Prof. Paper 600-D, p. D147-D153.

Patton, W. W., Jr., and Tailleur, I. L., 1964, Geology of the Killik-Itkillik region, Alaska: U.S. Geol. Survey Prof. Paper 303-G, p. 409-500.

Payne, T. G., 1955, compiler, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-84, scale 1:5,000,000.

Payne, T. G., and others, 1951, Geology of the Arctic slope of Alaska: U.S. Geol. Survey Oil and Gas Inv. Map OM-126, scale 1:1,000,000 [1952].

Peive, A. V., 1969, Okeanicheskaya kora geologicheskogo proshologo [Oceanic crust in the geologic past]: Geotektonika, no. 4, p. 5-23.

Petocz, R. G., 1970, Biostratigraphy and Lower Permian fusulinidae of the upper Delta River area, east-central Alaska Range: Geol. Soc. America, Spec. Paper 130, 94 p.

Péwé, T. L., Wahrhaftig, Clyde, and Weber, Florence, 1966, Geologic map of the Fairbanks quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-455, scale 1:250,000.

Pitman, W. C., III, and Hayes, D. E., 1968, Sea-floor spreading in the Gulf of Alaska: Jour. Geophys. Research, v. 73, p. 6571-6580.

Plafker, George, 1969, Tectonics of the March 27, 1964, Alaska earthquake: U.S. Geol. Survey Prof. Paper 543-I, 74 p.

Porter, S. C., 1966, Stratigraphy and deformation of Paleozoic section at Anaktuvuk Pass, central Brooks Range, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 952-980.

Reed, B. L., 1968, Geology of the Lake Peters area, northeastern Brooks Range, Alaska: U.S. Geol. Survey Bull. 1236, 132 p.

Reed, B. L., and Lanphere, M. A., 1969, Age and chemistry of Mesozoic and Tertiary plutonic rocks in south-central Alaska: Geol. Soc. America Bull., v. 80, p. 23-44.

Reiser, H. N., 1970, Northeastern Brooks Range--a surface expression of the Prudhoe Bay section, in Adkison, W. L., and Brosgè, M. M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. K1-K10.

Rickwood, F. K., 1970, The Prudhoe Bay field, in Adkison, W. L., and Brosgè, M. M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. L1-L11.

Roberts, R. J., Hotz, P. E., Gilluly, James, and Ferguson, H. G., 1958, Paleozoic rocks of north-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 12, p. 2813-2857.

Roddick, J. A., 1967, Tintina Trench: Jour. Geology, v. 75, no. 1 p. 23-32.

Ross, C. P., 1933, Mineral deposits near the West Fork of the Chulitna River, Alaska: U.S. Geol. Survey Bull. 849-E, p. 289-333.

Rossman, D. L., 1963, Geology of the eastern part of the Mount Fairweather quadrangle, Glacier Bay, Alaska: U.S. Geol. Survey Bull. 1121-K, p. K1-K57.

Rowett, C. L., 1969, Upper Paleozoic stratigraphy and corals from east-central Alaska Range, Alaska: Arctic Inst. North America Tech. Paper no. 23, 120 p.

Sable, E. G., 1965, Geology of the Romanzof Mountains, Brooks Range, northeastern Alaska: U.S. Geol. Survey open-file report, 218 p.

Sable, E. G., and Dutro, J. T., Jr., 1961, New Devonian and Mississippian formations in DeLong Mountains, northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 585-593.

Sainsbury, C. L., 1961, Geology of part of the Craig C-2 quadrangle and adjoining areas, Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Bull. 1058-H, p. 299-362.

______1965, Previously undescribed Middle(?) Ordovician, Devonian(?), and Cretaceous(?) rocks, White Mountain area, near McGrath, Alaska, in Geological Survey research, 1965: U.S. Geol. Survey Prof. Paper 525-C, p. C91-C95.

______1969a, Geology and ore deposits of the central York Mountains, western Seward Peninsula, Alaska: U.S. Geol. Survey Bull. 1287, 101 p.

______1969b, The A. J. Collier Thrust Belt of the Seward Peninsula, Alaska: Geol. Soc. America Bull., v. 80, p. 2595-2596.

St. Amand, Pierre, 1957, Geological and geophysical synthesis of the tectonics of portions of British Columbia, the Yukon Territory, and Alaska: Geol. Soc. America Bull., v. 68, no. 10, p. 1343-1370.

Scheidegger, A. E., 1966, Tectonics of the Arctic seismic belt in the light of fault-plane solutions of earthquakes: Seismol. Soc. America Bull., v. 56, p. 241-245.

Scholl, D. W., Buffington, E. C., and Hopkins, D. M., 1966, Exposure of basement rock on the continental slope of the Bering Sea: Science, v. 153, p. 992-994.

Scholl, D. W., Greene, H. G., Marlow, M. S., Addicott, W. O., Adey, W. H., Evitt, W. R., Mamay, S. H., and Pierce, R. L., 197_, Eocene age of "Paleozoic(?)" Adak site, Aleutian Islands: Geol. Soc. America Bull. (In press).

Scholl, D. W., Marlow, M. S., Creager, J. S., Holmes, M. L., Wolf, S. C., and Cooper, A. K., 1970, A search for the seaward extension of the Kaltag fault beneath the Bering Sea: Geol. Soc. America, Abstracts with Programs, v. 2, p. 141-142.

Schuchert, Charles, 1910, Paleogeography of North America: Geol. Soc. America Bull., v. 20, p. 427-606.

Shatskiy, N. S., 1935, O tektonike Arktiki [On the tectonics of the Arctic], in U.S.S.R. Glavnoe upravlenie Severnogo morskogo puti, Geologo-Razvedochnaia Konferentisiia, 1st, Moskva, 1935: Geologiia i poleznye iskopaemye Sovera SSSR Trudy, v. 1, Geologiia, p. 149-168. GLAVESEVMORPUTI.

Smith, J. G., and MacKevett, E. M., Jr., 1970, Skolai Group in the McCarthy B-4, C-4, and C-5 quadrangles, Wrangell Mountains, Alaska: U.S. Geol. Survey Bull. 1274-Q, 26 p.

Smith, P. S., 1939, Areal geology of Alaska: U.S. Geol. Survey Prof. Paper 192, 100 p.

Smith, P. S., and Eakin, H. M., 1911, A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U.S. Geol. Survey Bull. 449, 146 p.

Spurr, J. E., 1898, Geology of the Yukon gold district, Alaska: U.S. Geol. Survey 18th Ann. Rept., pt. 3, p. 87-392.

Steidtmann, Edward, and Cathcart, S. H., 1922, Geology of the York tin deposits, Alaska: U.S. Geol. Survey Bull. 733, 130 p.

Stoneley, Robert, 1967, The structural development of the Gulf of Alaska sedimentary province in southern Alaska: Geol. Soc. London Quart. Jour., v. 123, p. 25-57.

Sykes, L. R., 1965, The seismicity of the Arctic: Seismol. Soc. America Bull., v. 55, no. 2, p. 501-518.

Tailleur, I. L., and Brosgé, W. P., 1970, Tectonic history of northern Alaska, in Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the Geological Seminar on the North Slope of Alaska: Los Angeles, Pacific Sec., Am. Assoc. Petroleum Geologists, p. E1-E19.

Tailleur, I. L., Brosgé, W. P., and Reiser, H. N., 1967, Palinspastic analysis of Devonian rocks in northwestern Alaska, in Oswald, D. H., ed., International symposium on the Devonian system, Calgary, 1967, V. 2: Calgary, Alberta Soc. Petroleum Geologists, p. 1345-1361.

Tailleur, I. L., Kent, B. H., Jr., and Reiser, H. N., 1966, Outcrop/ geologic maps of the Nuka-Etivluk region, northern Alaska: U.S. Geol. Survey open-file maps, scale 1:63,360.

Tailleur, I. L., and Sable, E. G., 1963, Nuka Formation of late Mississippian to late Permian age, new formation in northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 4, p. 632-642.

Tailleur, I. L., and Snelson, Sigmund, 1968, Large-scale thrusting in northwestern Alaska possibly related to rifting of the Arctic Ocean [abs.]: Geol. Soc. America and Assoc. Socs. Ann. Mtg., Tucson, Ariz., 1968, Program, p. 120.

Thorsteinsson, R., and Tozer, E. T., 1960, Summary account of structural history of the Canadian Arctic Archipelago since Precambrian time: Canada Geol. Survey Paper 60-7, 25 p.

Tilman, S. M., 1962, Tektonika i istoriya razvitiya severovostochnogo Prikolym'ya [Tectonics and the history of the development of northeastern Kolym region]: Trudy SVKNII (Sev. Vost. Komplek. Nauchno-Issled. Inst.), vyp. 1, Magadan, 190 p.

Trettin, H. P., 1967, Devonian of the Franklinian eugeosyncline, _in_ Oswald, D. H., ed., International symposium on the Devonian system, Calgary, 1967, V. 1: Calgary, Alberta Soc. Petroleum Geologists, p. 693-701.

______ 1969, A Paleozoic-Tertiary fold belt in northernmost Ellesmere Island aligned with the Lomonosov Ridge: Geol. Soc. America Bull., v. 80, p. 143-148.

Twenhofel, W. S., and Sainsbury, C. L., 1958, Fault patterns in southeastern Alaska: Geol. Soc. America Bull., v. 69, no. 11 p. 1431-1442.

Vine, F. J., 1966, Spreading of the ocean floor--new evidence: Science, v. 154, p. 1405-1415.

Vogt, P. R., and Ostenso, N. A., 197_, The Alpha cordillera and ocean floor spreading in the Arctic: (In press).

Wahrhaftig, Clyde, 1968, Schists of the central Alaska Range: U.S. Geol. Survey Bull. 1254-E, p. E1-E22.

Wanless, R. D., Stevens, R. D., Lachance, G. R., and Rimsaite, R. Y. H., 1965, Age determinations and geologic studies, Pt. 1, Isotopic ages, Rept. 5: Canada Geol. Survey Paper 64-17, 126 p.

Wasserburg, G. J., Eberlein, G. D., and Lanphere, M. A., 1963, Age of the Birch Creek Schist and some batholithic intrusions in Alaska [abs.]: Geol. Soc. America Spec. Paper 73, p. 258-259.

Wilson, J. T., 1963, Hypothesis of earth's behavior: Nature, v. 198, p. 925-929.

Woollard, G. P., Ostenso, N. A., and Thiel, E., 1960, Gravity anomalies, crustal structure, and geology in Alaska: Jour. Geophys. Research, v. 65, no. 3, p. 1021-1037.

Yanshin, A. L., ed., 1966, Tectonic map of Eurasia: Geol. Inst. of the Academy of Sciences, U.S.S.R., scale 1:5,000,000.

Yates, R. G., Becraft, G. E., Campbell, A. B., and Pearson, R. C., 1966, Tectonic framework of northeastern Washington, northern Idaho, and northwestern Montana, in A symposium on the tectonic history and mineral deposits of the western Cordillera, Vancouver, B. C., 1964: Canadian Inst. Mining and Metallurgy, Spec. V. 8, p. 47-59.

Ziegler, P. A., 1969, The development of sedimentary basins in western and Arctic Canada: Alberta, Canada, Alberta Soc. Petroleum Geologists.

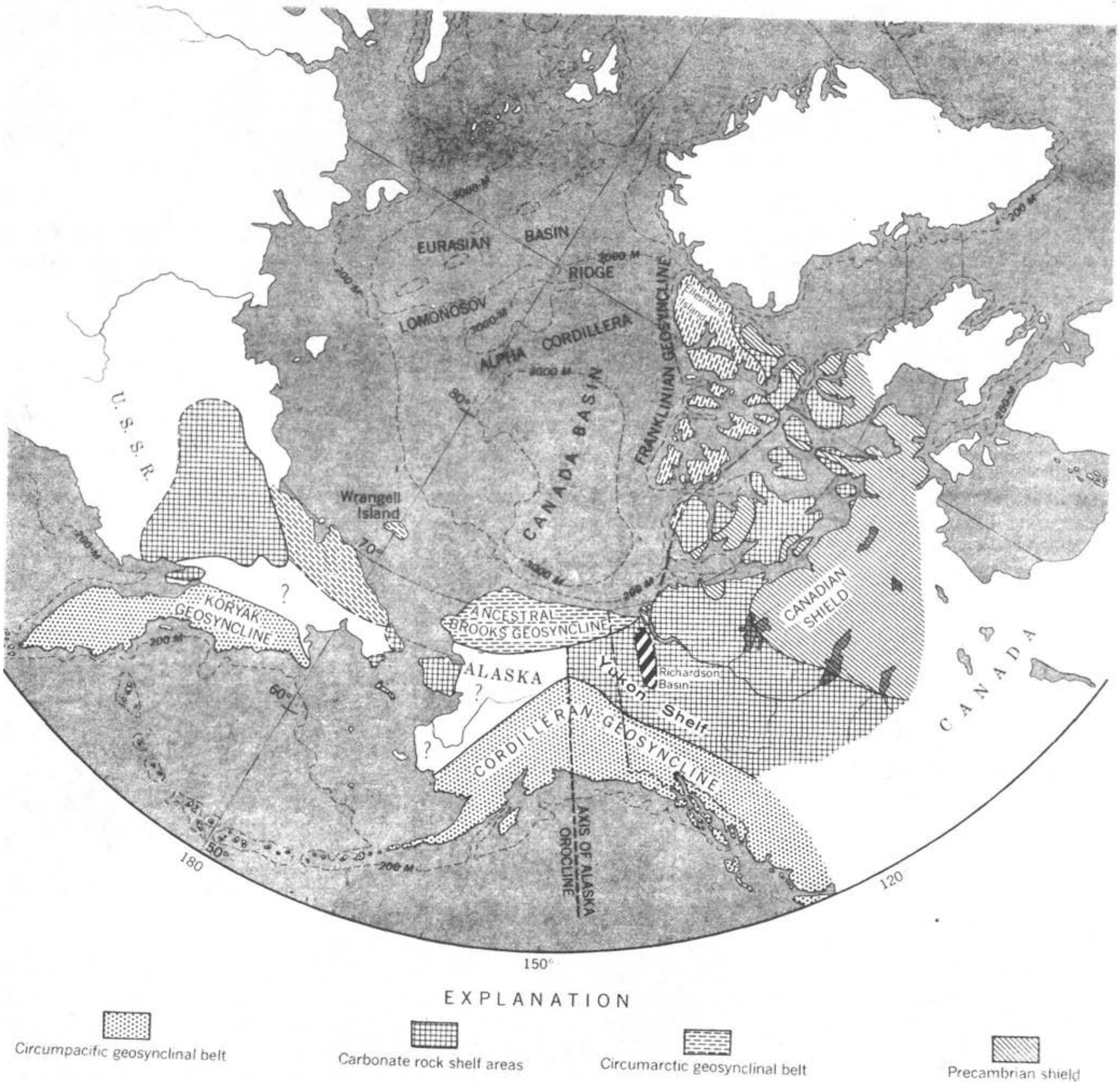


Fig. Tectonic framework of lower Paleozoic (Cambrian-middle Devon) sedimentation.

Figure 2. Precambrian rocks and metamorphic complexes that may include Precambrian strata.

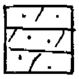
EXPLANATION

Definitely Precambrian


Predominantly dolomite, limestone, and shale


Canadian shield

Probably Precambrian


Predominantly quartzite and dolomite

Metamorphic rocks, age uncertain but may include Precambrian strata


Predominantly schist; minor gneiss and marble

1. Charley River Area
   Tindir Group - Mertie, 1933; Brabb and Churkin, 1969

2. Porcupine River
   "Tindir Group" - Kindle, 1908; Brosgé and others, 1966

3. Eastern Brooks Range
   Neruokpuk Formation - Brosgé and others, 1962; Reiser, 1970

4. Yukon-Tanana Upland
   Birch Creek Schist - Mertie, 1930
   474 $\pm$ 35 m.y. K/A - Forbes and others, 1968

5. Seward Peninsula
   Slates in York Mtns. and Kigluiak
   Schist - Moffit, 1913; Sainsbury, 1969
   750 m.y. Rb/Sr whole rock date on gneiss; 450 m.y. Rb/Sr whole rock date on dike - Sainsbury, written commun., 1970

6. Alexander Archipelago
   Wales Group - Buddington and Chapin, 1929

7. Lower Kuskokwim Region
   Gneiss and schist overlain by unmetamorphosed Devonian limestone - Hoare and Coonrad, 1961

8. Chukotsk Peninsula
   Gneiss mantled by schist 1587-722 m.y. K/A - Gnibidenko, 1969

Argillite in bottom of Simpson well 592 $\pm$ 18 m.y. K/A whole rock date (M. Lanphere <u>in</u> Brosgé, 1970).

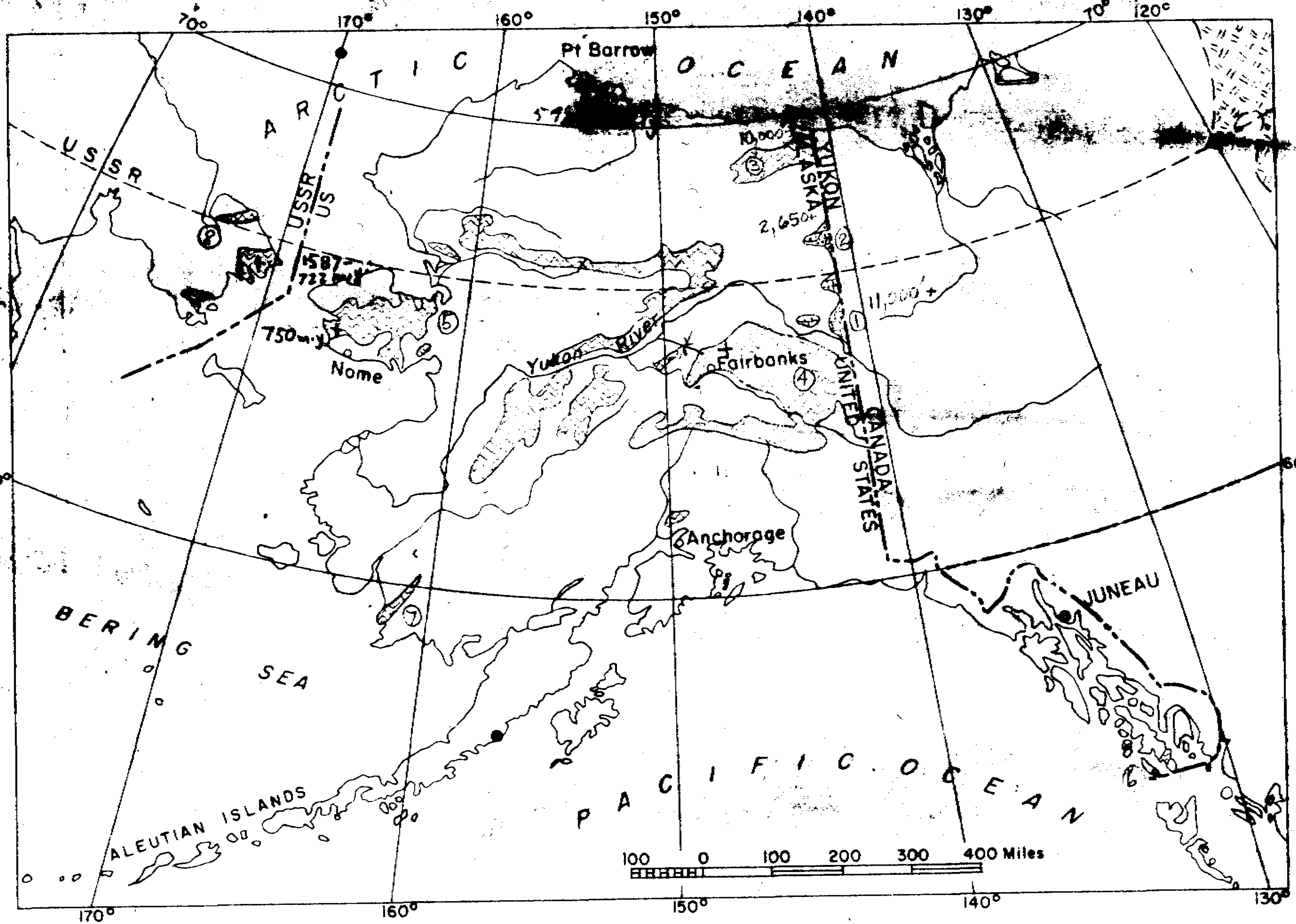
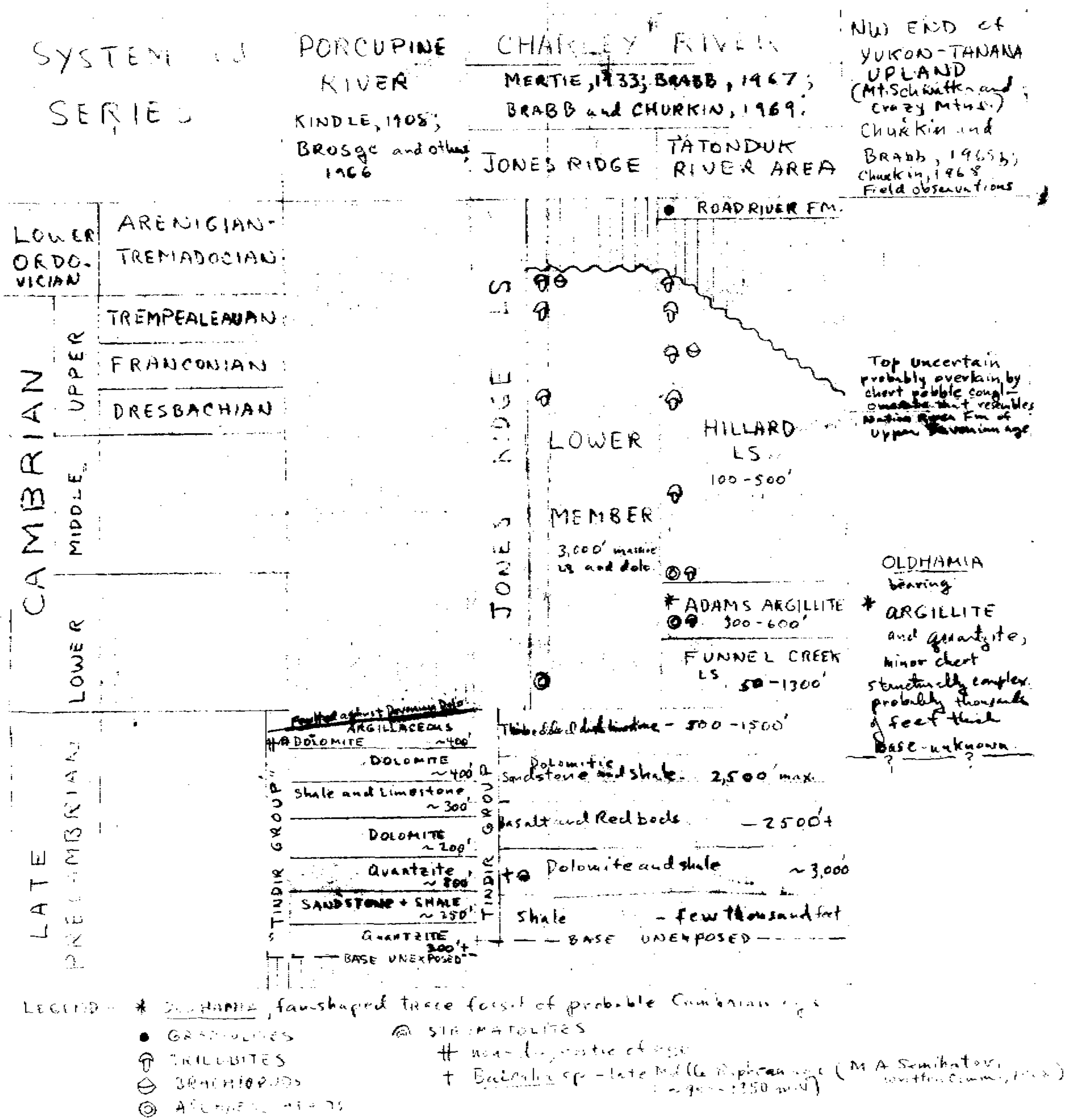


Figure 2. Precambrian rocks and metamorphic complexes that may include Precambrian strata.

Fig. 3. COLUMNAR sections of Late [illegible] and Cambrian rocks in east central Alaska



revised Sept 1970

Figure 4, Cambrian rocks.

EXPLANATION

Definite Cambrian

Predominantly limestone and dolomite

1. Charley River Area
   Hillard Limestone, Adams Argillite and Funnel Creek Limestone; Brabb, 1967

Probable Cambrian based on Oldhamia, (fan-shaped trace fossil, Churkin & Brabb, 1965b)

Argillite and quartzite

2 Nation River area

3 Crazy Mountains

4 Mount Schwatka

Nonfossiliferous strata of possible Cambrian age below known Ordovician

5 Argillaceous and dolomitic limestone below Ordovician limestone (Sainsbury, 1969a)

6 Argillite and platy limestone below Lower Ordovician graptolitic shale (Churkin, Reed, and Kerr, 1969 field data).

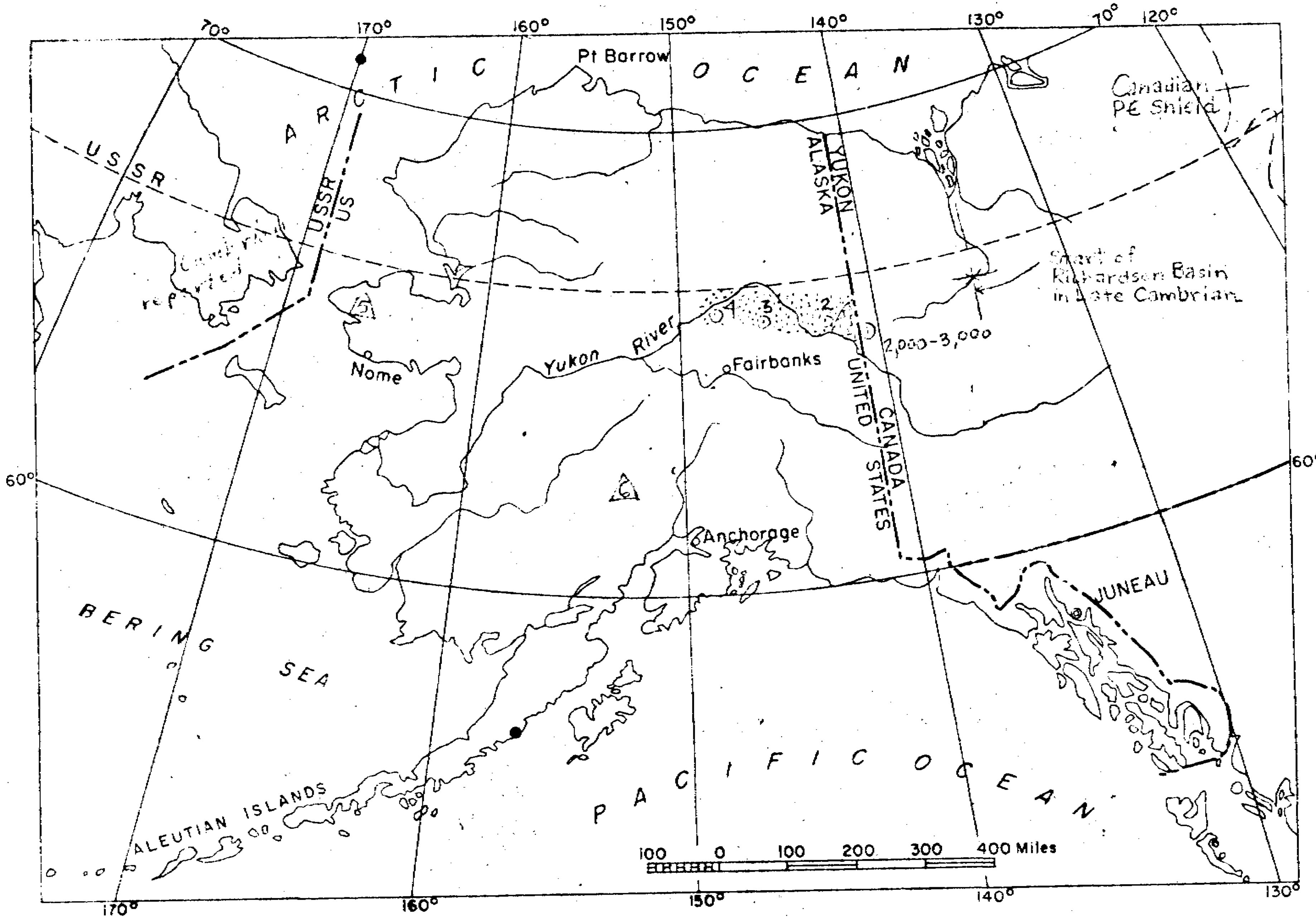


Figure 4. Cambrian rocks

Figure 5. Ordovician rocks.

EXPLANATION

Predominantly limestone and dolomite

Graptolitic shale and chert

Volcanic-bearing, graywacke, shale and chert assemblage

1. Seward Peninsula
   Port Clarence Limestone- Steidtmann and Cathcart, 1922; Sainsbury, 1969a..

2. Upper Kuskokwim River
   Eakin, 1918; Brown, 1926.

3. Alaska Range-
   Tatina Group; Brooks, 1911; Terra Cotta Mountain sequence-Churkin, Reed, and Kerr, 1969 field observations

4. White Mountain Area
   Sainsbury, 1965

5. Porcupine River
   Kindle, 1908; Cairnes, 1914 (Brosgé and others, 1966)

6. Charley River Area-
   Road River Formation, Jones Ridge limestone; Churkin and Brabb, 1965A; Brabb, 1967.

7. Livengood Area
   Fossil Creek volcanics; Mertie, 1937; shelly fossils reported to be in uppermost Fossil Creek volcanics can be interpreted as coming from basal part of overlying Tolovana Limestone (Churkin, 1968 field observations)

8. Alexander Archipelago
   Point Descon Formation; Buddington and Chapin, 1929; Brew and others, 1966; Eberlein and Churkin, in press.

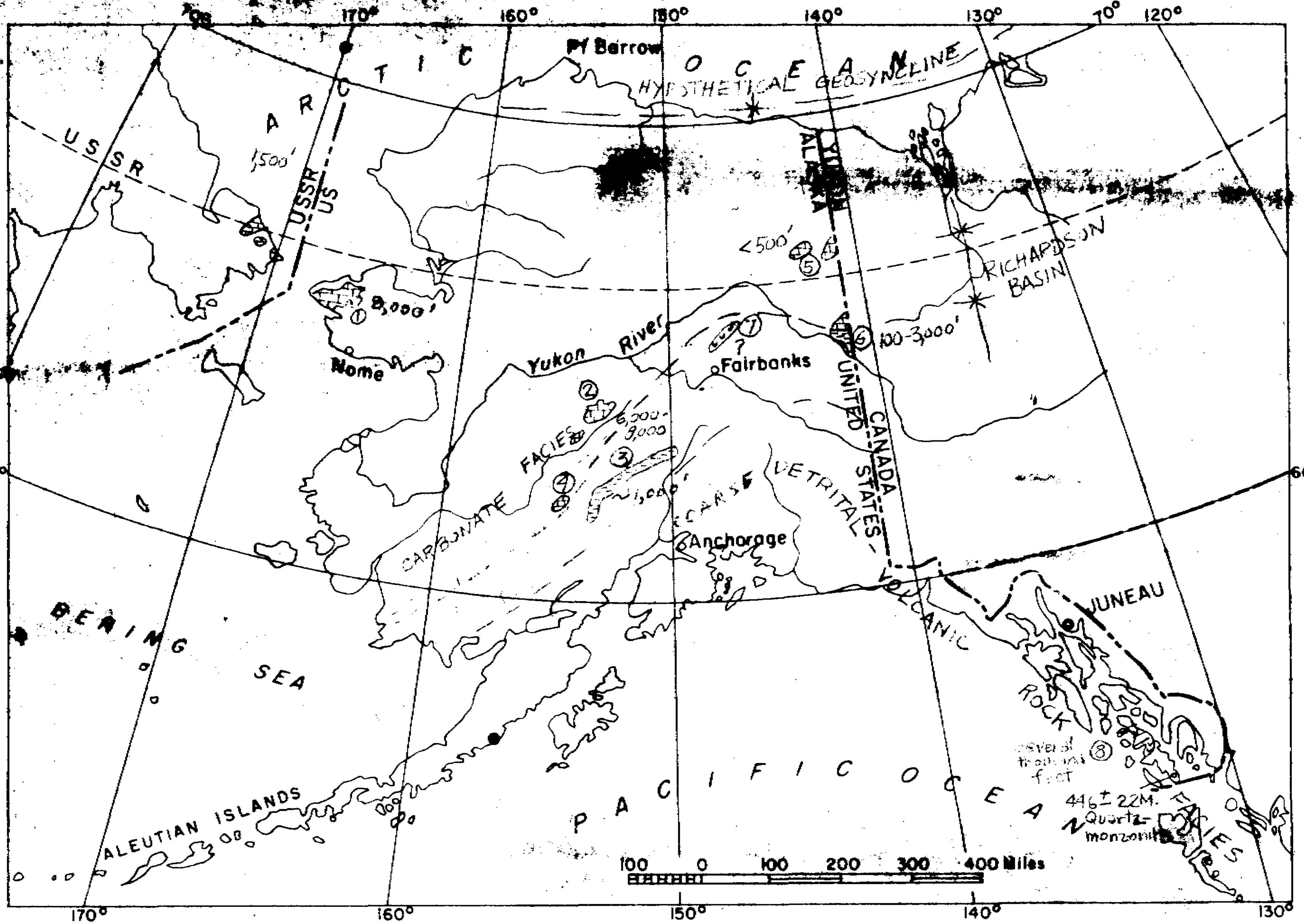
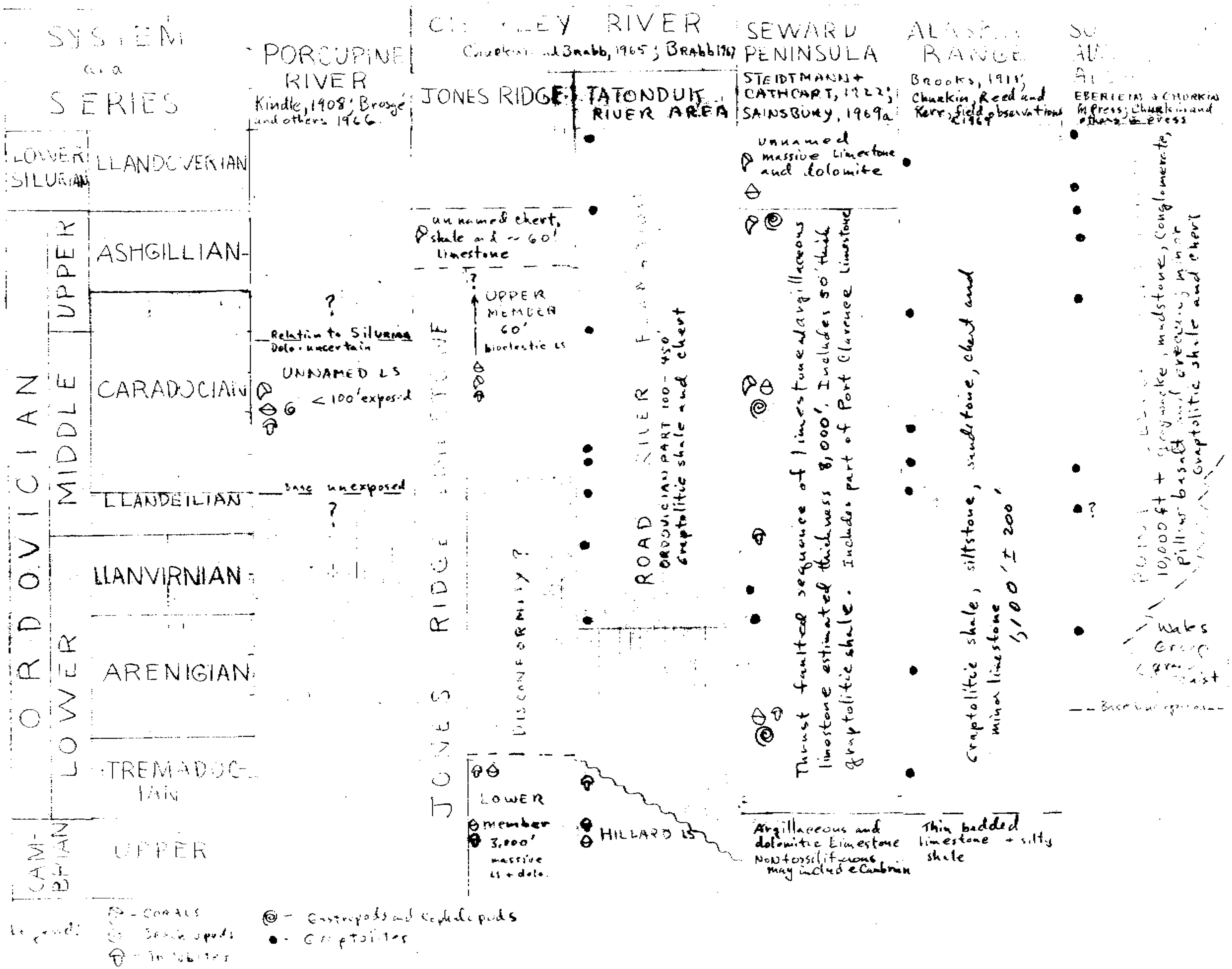


Figure 5. Ordovician Rocks

Revised Sept 1970

Fig. 6— CORRELATION CHART of Ordovician rocks.



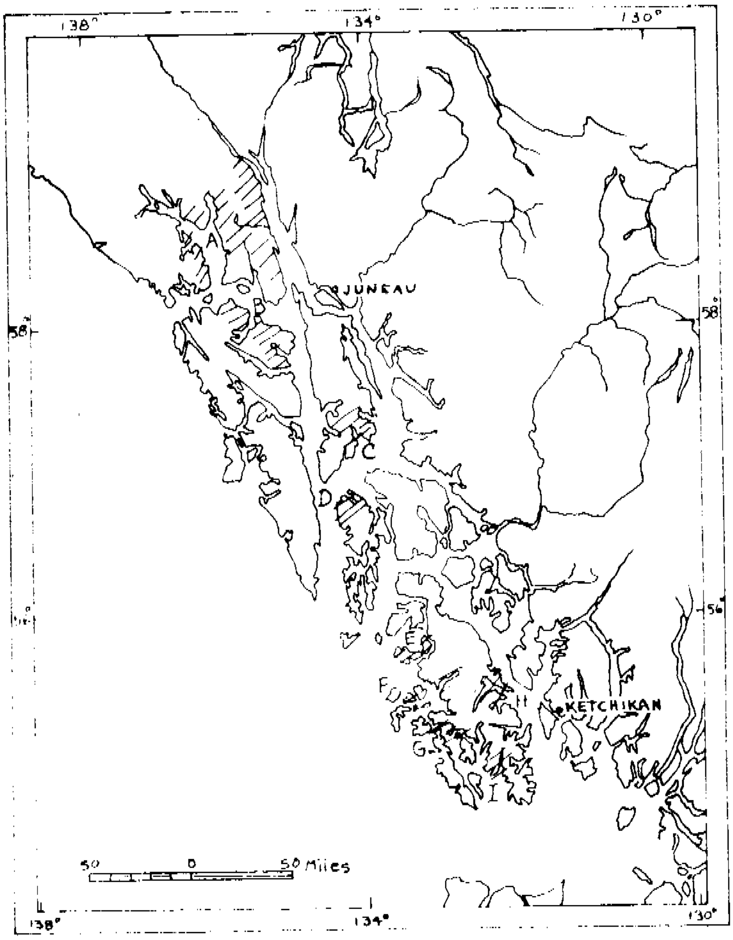


Fig. 9 - Index map of southeastern Alaska

Churkin 10/9/70

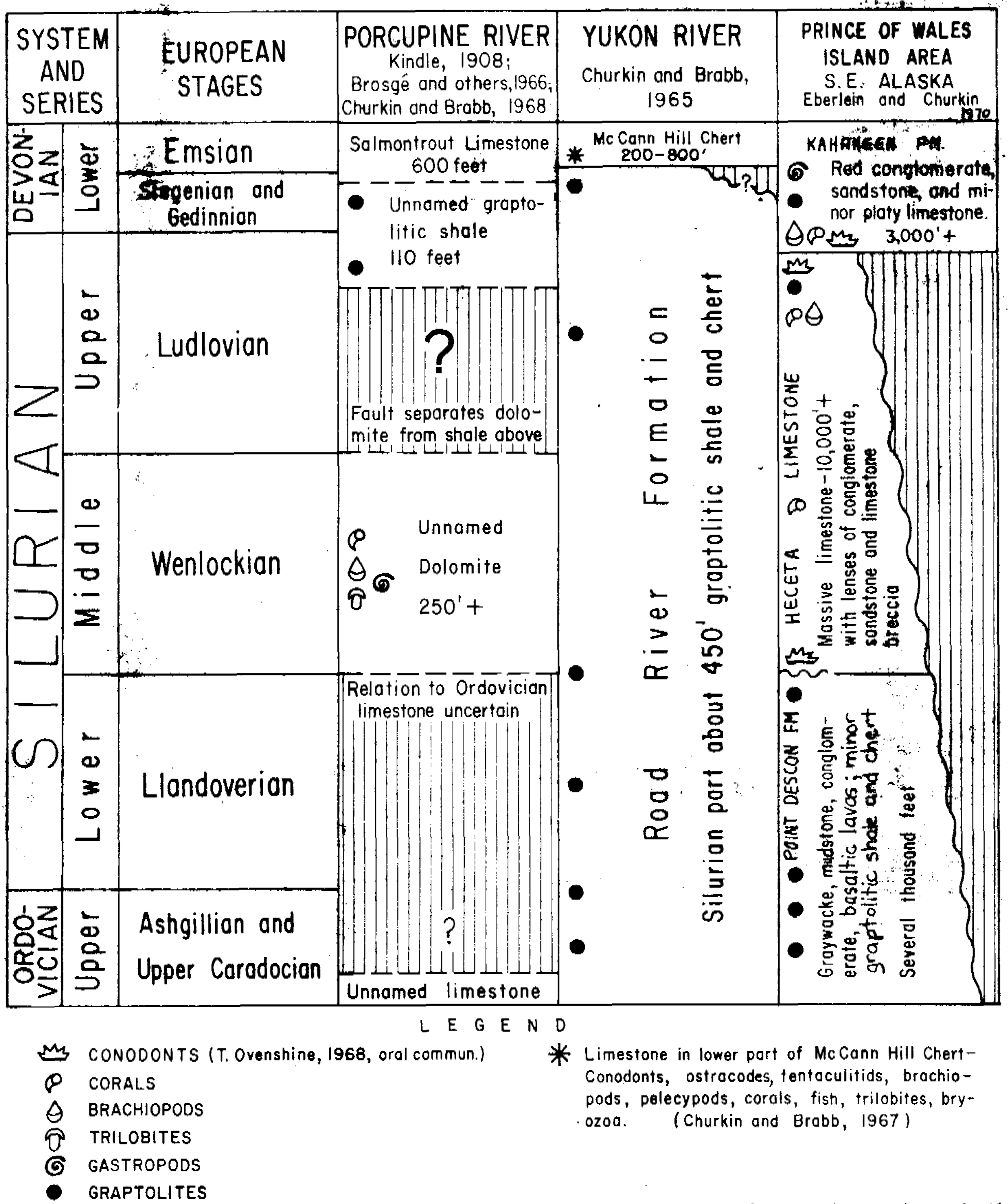


Figure 8. Correlation chart of Silurian rocks.

Figure 7. Silurian rocks

EXPLANATION

Mainly dolomite and limestone

Non-volcanic shale and chert

Volcanic rock, graywacke, conglomerate, shale and chert assemblage; thick limestone occurrences indicated by pattern

1. Livengood area
   Tolovana limestone (in part) - Mertie, 1937; Church and Durfee, 1961; Péwé and others, 1966

2. Porcupine River
   Kindle, 1908; Churkin and Brabb, 1967

3. Charley River area
   Road River Formation (upper part) - Churkin and Brabb, 1965

4. Upper Kuskokwim River
   Brown, 1926

5. Kuskokwim River
   Holitna Group (in part) - Cady and others, 1955

6. Alaska Range (Terra Cotta Mtn. sequence)
   Churkin, Reed, and Kerr, 1969 field data

7. York Mountains
   Sainsbury, 1969a

7a. Northeastern Baird Mountains
   Thrust slice of Skajit Limestone - Tailleur and others, 1967, p. 1352

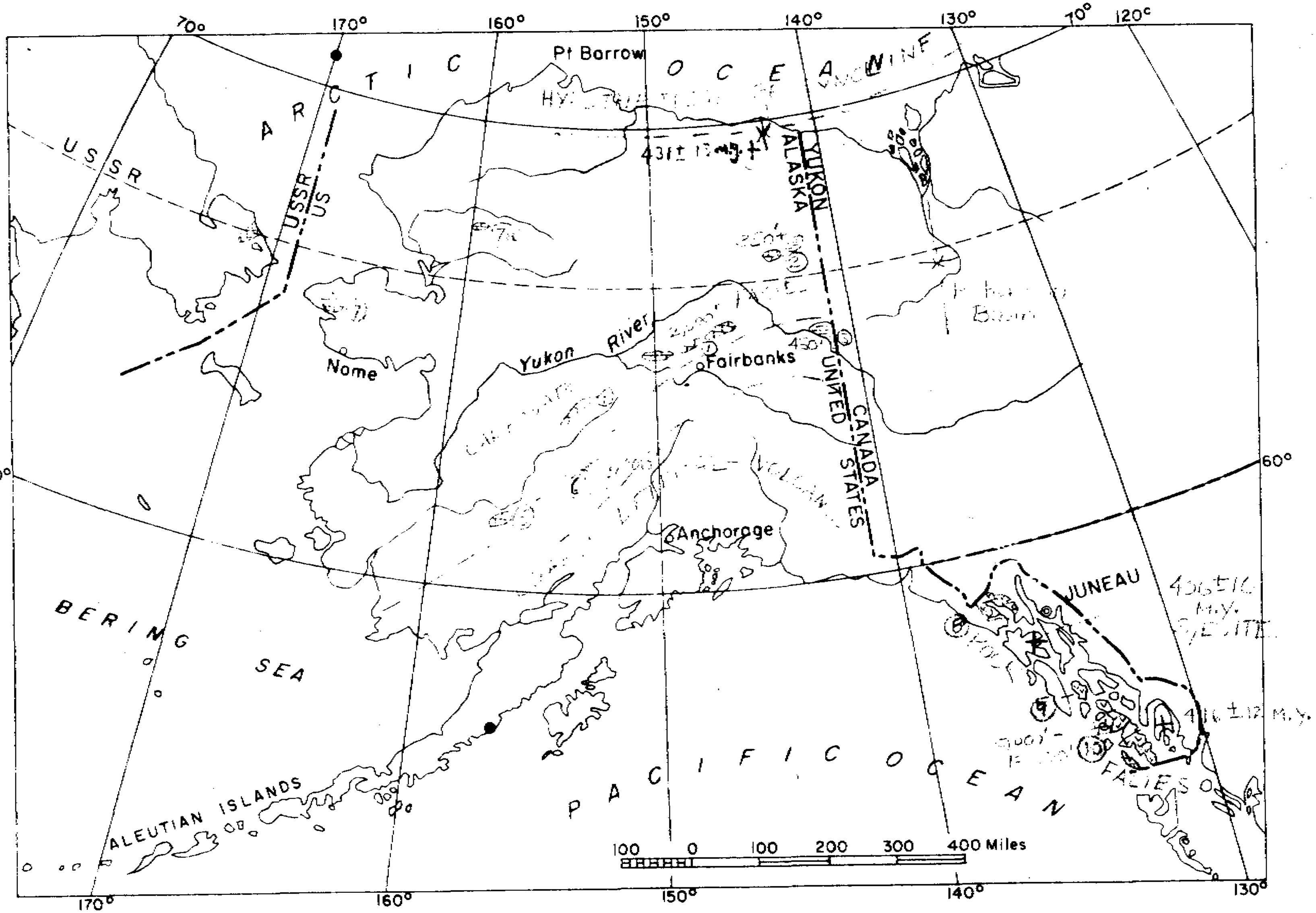
8. Glacier Bay
   Willoughby Limestone; Tidal Formation; Pyramid Peak limestone and Rendu Formation - Rossman, 1963

9. Kosciusko Island
   Bay of Pillars Formation; Kuiu limestone - Muffler, 1967

10. Prince of Wales Island area
   Buddington and Chapin, 1929; Brew and others, 1966
   Point Descon Formation; Heceta Limestone; Karheen Formation - Eberlein and Churkin, 1970

Radiometric dates

431 Romanzof granite satellitic intrusion (Reiser, 1970)
406 Tenakee area, Chichagof Island (Lanphere and others, 1965)
416 Annette Island (Berg, 1970)



[illegible] 7. [illegible] ocks

EXPLANATION

Mainly limestone and dolomite

Nonvolcanic shale and chert

Volcanic-bearing graywacke, conglomerate, shale and chert assemblage. [illegible] includes very thick limestone [illegible]

Figure 11. Devonian rocks--excludes coarse terrigenous rocks of Upper Devonian and Mississippian age (Nation River, Kanayut, and Kekituk Formations (cf. Gryc and others, 1967).

SOURCES OF DATA

1. Porcupine River
   Salmontrout Limestone (Churkin and Brabb, 1967; Brosgè and others, 1966).
2. Jones Ridge area
   Thick limestone below McCann Hill Chert (Churkin and Brabb, 1965).
3. Western and Central Brooks Range
   Skajit Limestone, unnamed limestone and siltstone, and Hunt Fork Shale (Brosgè and others, 1962; Sable and Dutro, 1961; Bowsher and Dutro, 1957; Tailleur and others, 1967; Chapman and others, 1964).

3a. Sadlerochit-Shublik Mountains and vicinity
   Nanook Limestone and Katakturuk dolomite (Dutro, 1970).

3b. Northeastern Brooks Range
   Neruokpuk Formation (questionable Devonian age) (Brosgè and others, 1962; Sable, 1965; Reed, 1969; Reiser, 1970).

4. White Mountains
   (Sainsbury, 1965).
5. Central Kuskokwim River
   Holitna Group (upper part) (Cady and others, 1955).
6. Seward Peninsula
   (Revised after Smith and Eakin, 1911, and earlier workers).
7. Topagoruk test well
   500'+ chert pebble conglomerate and shale (Collins, 1958).

7a. Charley River area
   Upper part of Road River Formation, McCann Hill Chert (Churkin and Brabb, 1965; 1967).

8. Livengood area
   Tolovana Limestone (upper part) (Péwè and others, 1966; Church and Durfee, 1961).
9. Yukon River
   Woodchopper Volcanics (Mertie, 1930; Brabb and Churkin, 1969).
10. East Alaska Range
    (Moffit, 1954).
11. Central Alaska Range
    Limestone overlying Tonzona Group (Brooks, 1911); Limestone in vicinity of Farewell, Alaska (B. Reed, oral commun., 1968).
12. Upper Kuskokwim River
    (Revised after Smith and Eakin, 1911).
13. Lower Kuskokwim River
    (Hoare and Coonrad, 1961; Hoare, 1961).
14. Glacier Bay
    Black Cap Limestone (Rossman, 1963).
15. Chichagof Island
    Freshwater Bay Formation, Cedar Cove Formation, Kennel Creek Limestone. (Loney and others, 1963).
16. Admiralty Island - Keku Strait
    Hood Bay Formation, Cambier Bay Formation (Loney, 1964; Muffler, 1967).
17. Prince of Wales Island
    Wadleigh Limestone, Coronados Volcanics and Port Refugio Formation (Eberlein and Churkin, 1970).
18. Chukotsk Peninsula
    (Krasny, 1964; Gnibidenko, 1969).

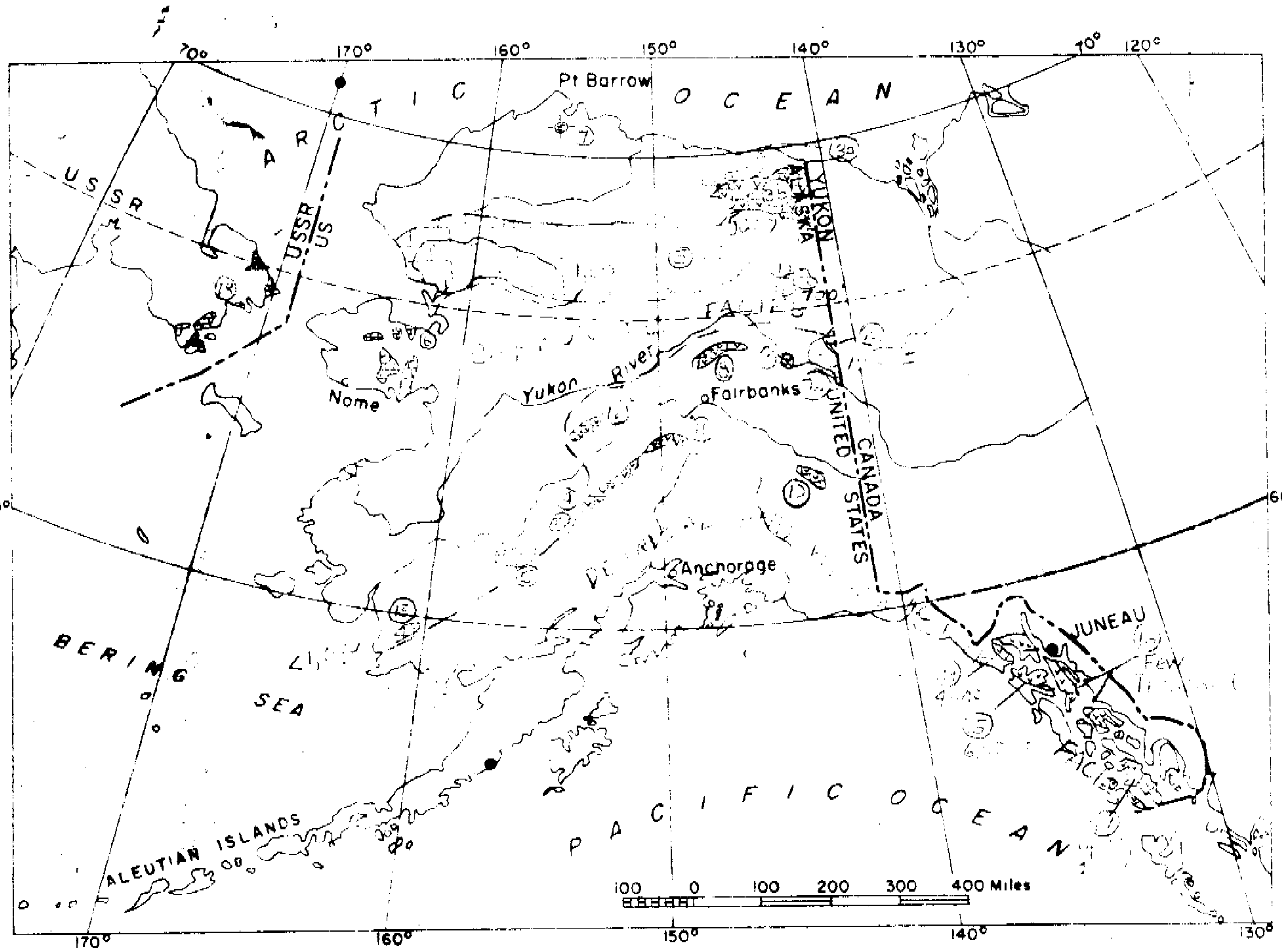


Figure 11. Devonian rocks — excludes coarse terrigenous rocks of Upper Devonian and Mississippian age (Nation River, Kanayut and Kekituk Formations) (cf. Grye and others, [illegible]).

EXPLANATION

Mainly limestone and dolomite. In the Brooks Range upper part includes shale and sandstone

Limestone in mainly siliceous detrital-volcanic terranes of uncertain age

Mainly shale and chert, [illegible] sandstone

Volcanic-rich, graywacke, conglomerate, shale and chert [illegible]. Locally includes thick limestone.

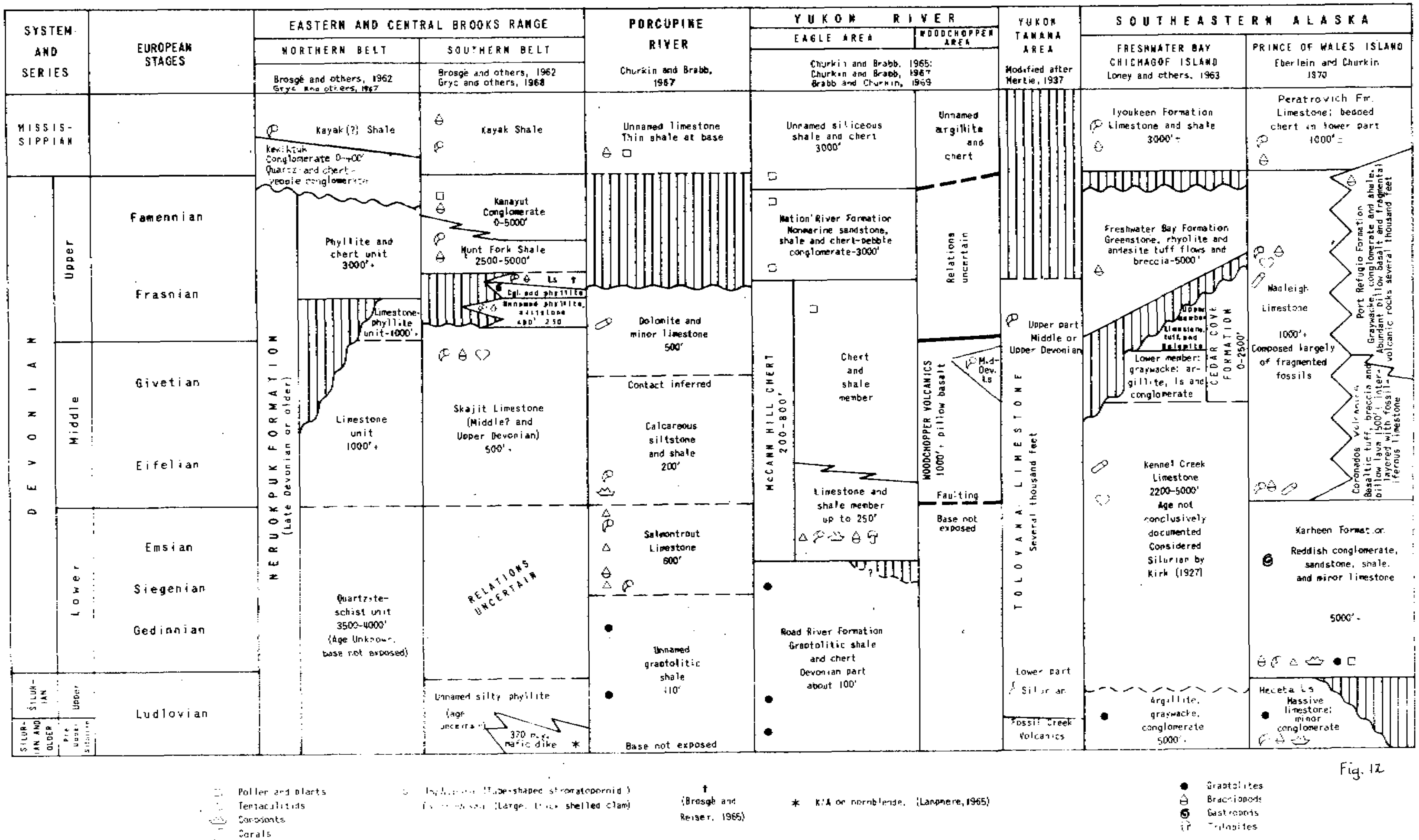


Fig. 12

Figure 12. Correlation chart of Devonian rocks.

EXPLANATION

Upper Devonian and, in NE Brooks Range, lower Mississippian [illegible]

Lower Devonian and may include some Upper Silurian

Major sources of coarse detritus

+ Granitic intrusions with absolute age in millions of years

✱ Graywacke, conglomerate and shale. (F. Webber, oral commun., 1960)

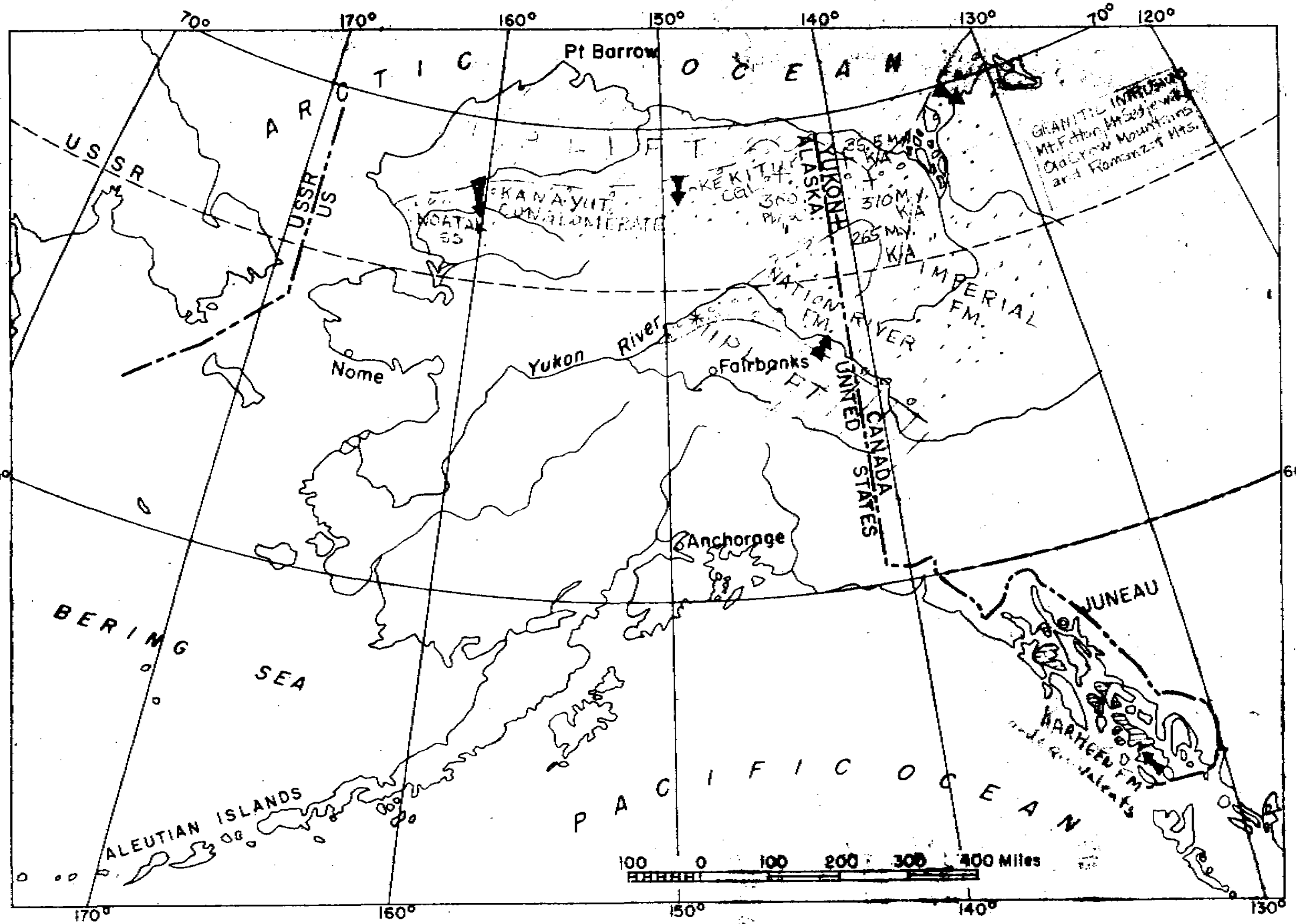


Figure 13. Devonian coarse terrigenous rocks. (including early Mississippian Kekiktuk conglomerate)

Figure 14. Carboniferous rocks

LEGEND

Mainly limestone, minor shale, sandstone, and chert

Limestone, shale, and sandstone

Limestone, graywacke, conglomerate, shale, and chert in sequence with volcanic rocks

1. Lake Peters
   Kayak Shale, Lisburne Group (Brosgė and others, 1962).
2. Shainin Lake
   Kayak Shale, Lisburne Group (Bowsher and Dutro, 1957; Patton and Tailleur, 1964).
3. DeLong Mountains
   Lisburne Group (Sable and Dutro, 1961).
4. Lisburne Peninsula
   Lisburne Group (Campbell, 1967).
5. Topagoruk test well
   Red beds of uncertain age (Collins, 1958).

5a. Prudhoe Bay oil field
   Kayak Formation and Lisburne Group (Rickwood, 1970).

6. Cape Mountain
   Steidtmann and Cathcart, 1922; Sainsbury, oral commun., 1969).
7. St. Lawrence Island
   Lisburne(?) Limestone underlain by Devonian dolomite (W. Patton and Dutro, 1969).
8. Kaiyuh Hills
   Nonfossiliferous volcanic rock (Mertie, 1937a).
9. Livengood-Yukon River area
   Livengood Chert (Mertie, 1937b).
10. Porcupine River
   (Brosgė and others, 1966).
11. Eagle area
   Calico Bluff Formation, Ford Lake Shale (Brabb and Churkin, 1967).
12. Central Alaska Range
   Totatlanika Schist (Pėwė and others, 1966).
13. Eastern Alaska Range
   Rainbow Mountain Sequence (Rowett, 1969).
   Chisna Formation (Moffit, 1954).
14. Chitina Valley
   Strelna Formation and Klutina Group (Moffit, 1938).
15. Kuskokwim River
   Gemuk Group (Lower non-fossiliferous part) (Cady and others, 1955).
16. Nushagak District
   Non-fossiliferous siliceous rocks below Permian limestone (Mertie, 1938).
17. Chichagof Island
   Iyoukeen Formation (Loney and others, 1963).
18. Kuiu Strait area
   Saginaw Bay Formation (Muffler, 1967).
19. Craig area
   Peratrovich Formation, Klawak Formation, Ladrones Limestone (Eberlein and Churkin, 1970).
20. Northeast U.S.S.R.
   (Krasny, 1964).

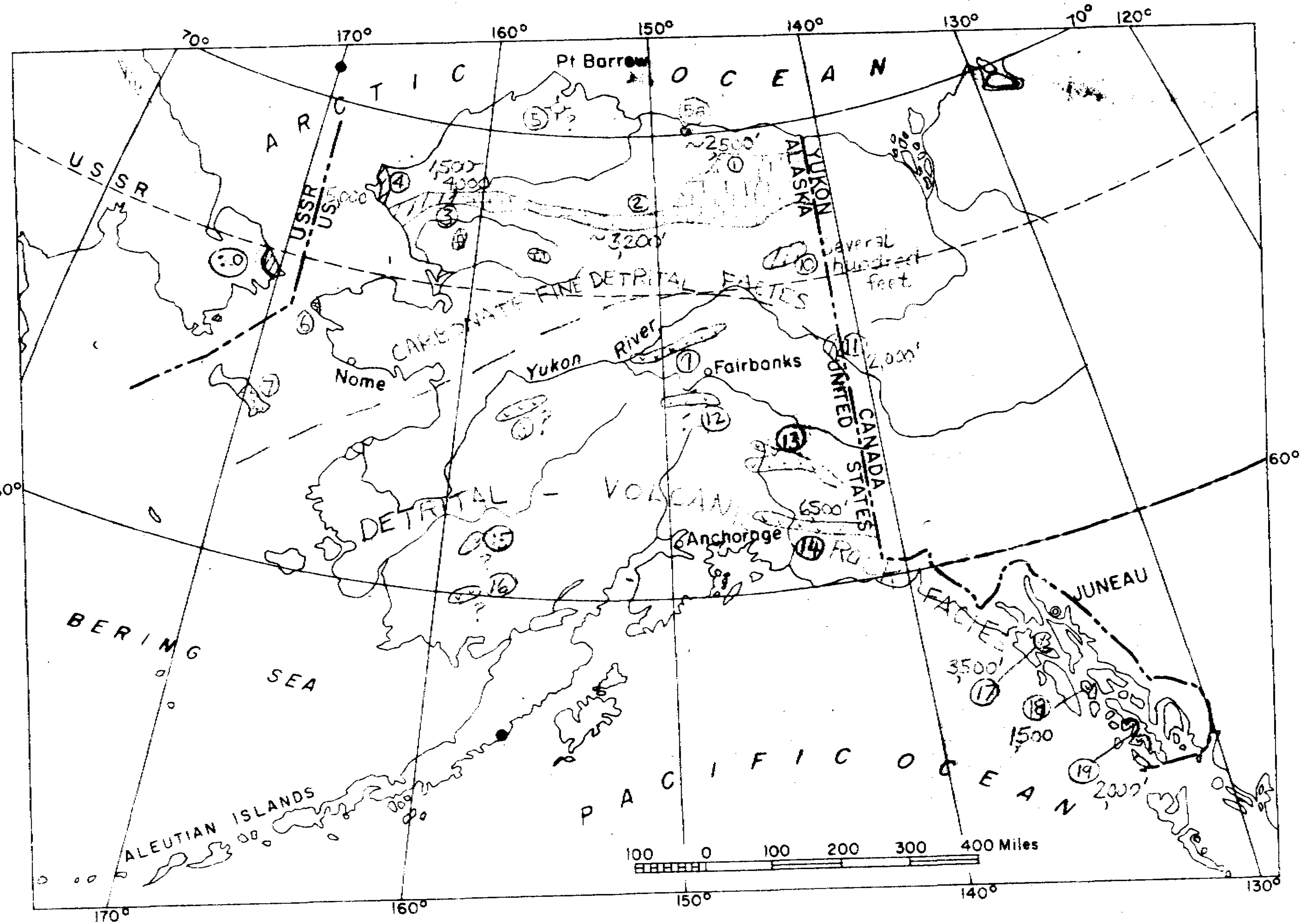


FIGURE 14 - CAR[illegible]

Figure 16. Permian rocks

LEGEND

Mainly Limestone

Sandstone, siltstone, shale, chert, and, in places, chert pebble conglomerate

Basaltic lavas, volcaniclastic rocks, graywacke, conglomerate, shale, chert, and minor limestone

1. Topagoruk test well
   Includes some chert pebble conglomerate (Collins, 1958).

1a. Prudhoe Bay oil field
   Sadlerochit Formation (Rickwood, 1970).

2. Lake Peters
   Sadlerochit Formation (Brosgė and others, 1962; Detterman, 1970).

3. Shainin Lake
   Siksikpuk Formation (Bowsher and Dutro, 1957; Patton and Tailleur, 1964).

3a. Nuka Ridge
   Nuka Ridge Formation, arkosic sandstone and limestone (Tailleur and Sable, 1963).

4. Lisburne Peninsula
   Siksikpuk Formation (Campbell, 1967).

5. Porcupine River
   (Brosgė and others, 1966).

6. Eagle area
   Tahkandit Limestone (Brabb and Churkin, 1969).

7. Yukon River
   Step Conglomerate (Brabb and Churkin, 1969).

7a. West edge of Yukon Flats
   Rampart Volcanics of questionable Permian age (Brosgė and others, 1969).

8. Susitna River area
   (Ross, 1933).

9. Eastern Alaska Range
   Mankomen Formation (Moffit, 1954; D. Richter, written commun., 1968; Rowett, 1969).

10. East Wrangell Mountains
   Skolai Group (Moffit, 1938; Smith and MacKevett, 1970).

11. Lower Yukon River
   Permian fossil bearing limestone (500'-1000') overlain conformably by 4500' of greenstone (Smith, 1939).

12. Nushagak area
   Permian limestone overlain conformably by tuff (Mertie, 1938).

13. Goodnews Bay district
   Permian limestone interlayered and grades into fine grained siliceous sedimentary rocks and volcanic rocks (Smith, 1939; Hoare, 1961).

14. Cape Kekurnoi area
   Permian limestone associated with volcanics (Hanson, 1957).

15. Chilkat Range
   Limestone and graywacke (Lathram and others, 1959).

16. Chichagof Island
   Goon Dip Greenstone (Loney and others, 1963).

17. Admiralty Island
   Cannery Formation and Pybus Dolomite (Loney, 1964).

18. Keku Strait area
   Cannery, Halleck, and Pybus Formations (Muffler, 1967).

19. Chukotka, NE USSR
   (Krasny, 1964).

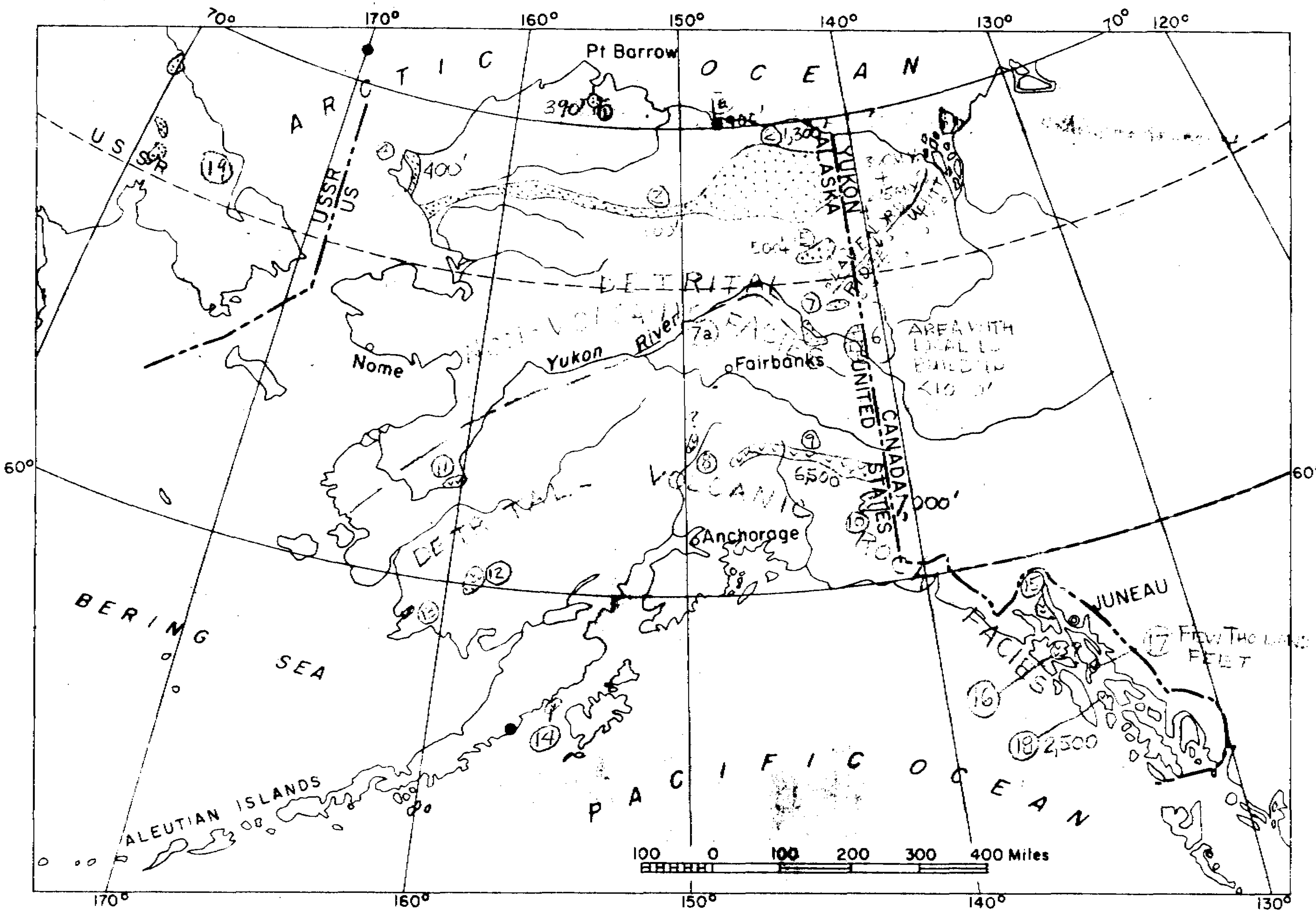


FIGURE 16 PERMIAN ROCKS

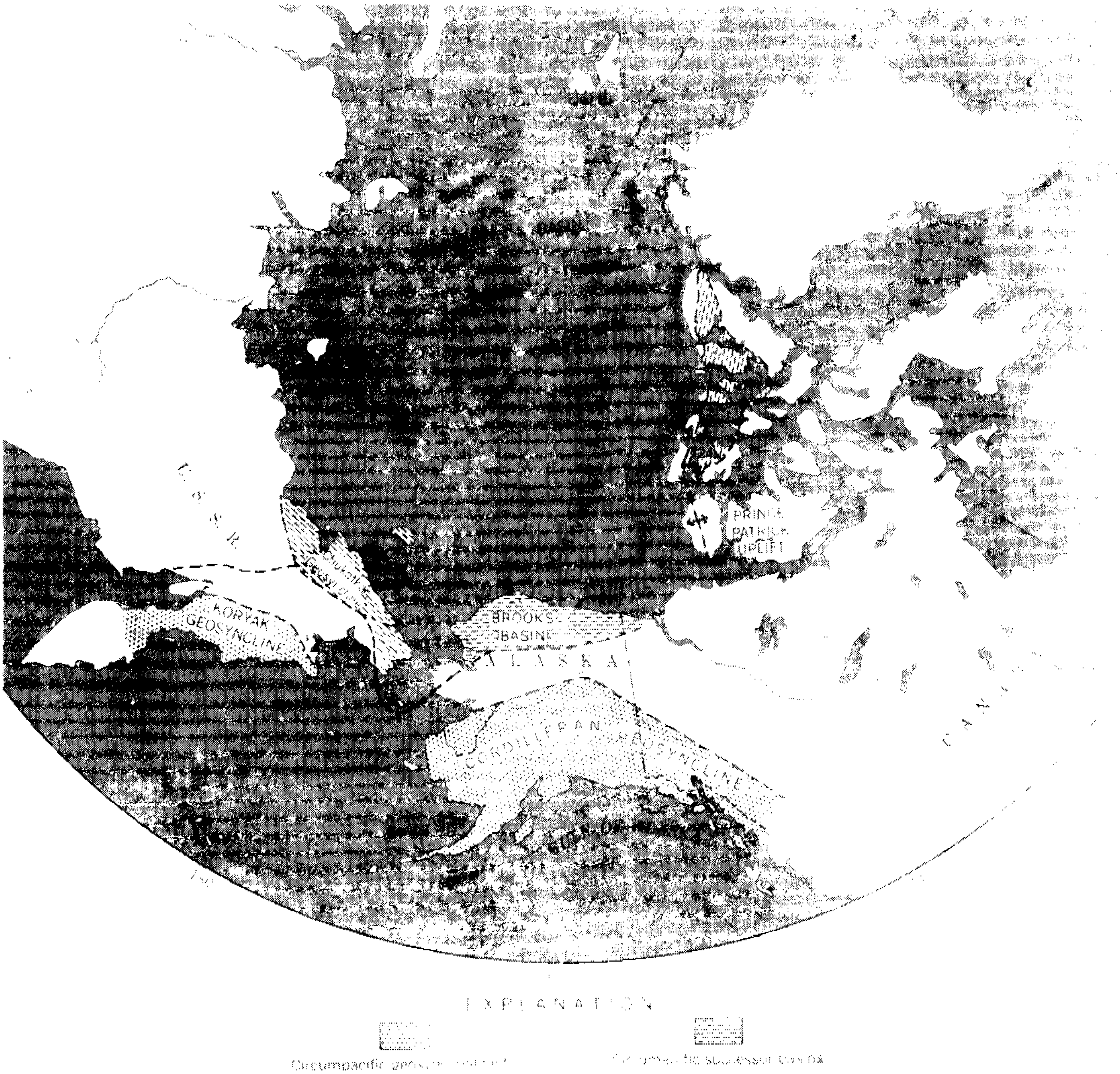


Figure 17. Tectonic framework of Carboniferous and Permian sedimentation.

Figure 18. Late Mesozoic and Tertiary tectonic features (modified after Payne, 1955; Gates and Gryc, 1963)

EXPLANATION

Tertiary basins and troughs of detrital sedimentation. Mostly non-marine

M Marine

Terrestrial volcanic rocks

Late Mesozoic, mainly Cretaceous basins and troughs of thick detrital sedimentation

Areas of Mesozoic and in part Tertiary uplift and erosion. Arrows indicate direction of sediment transport

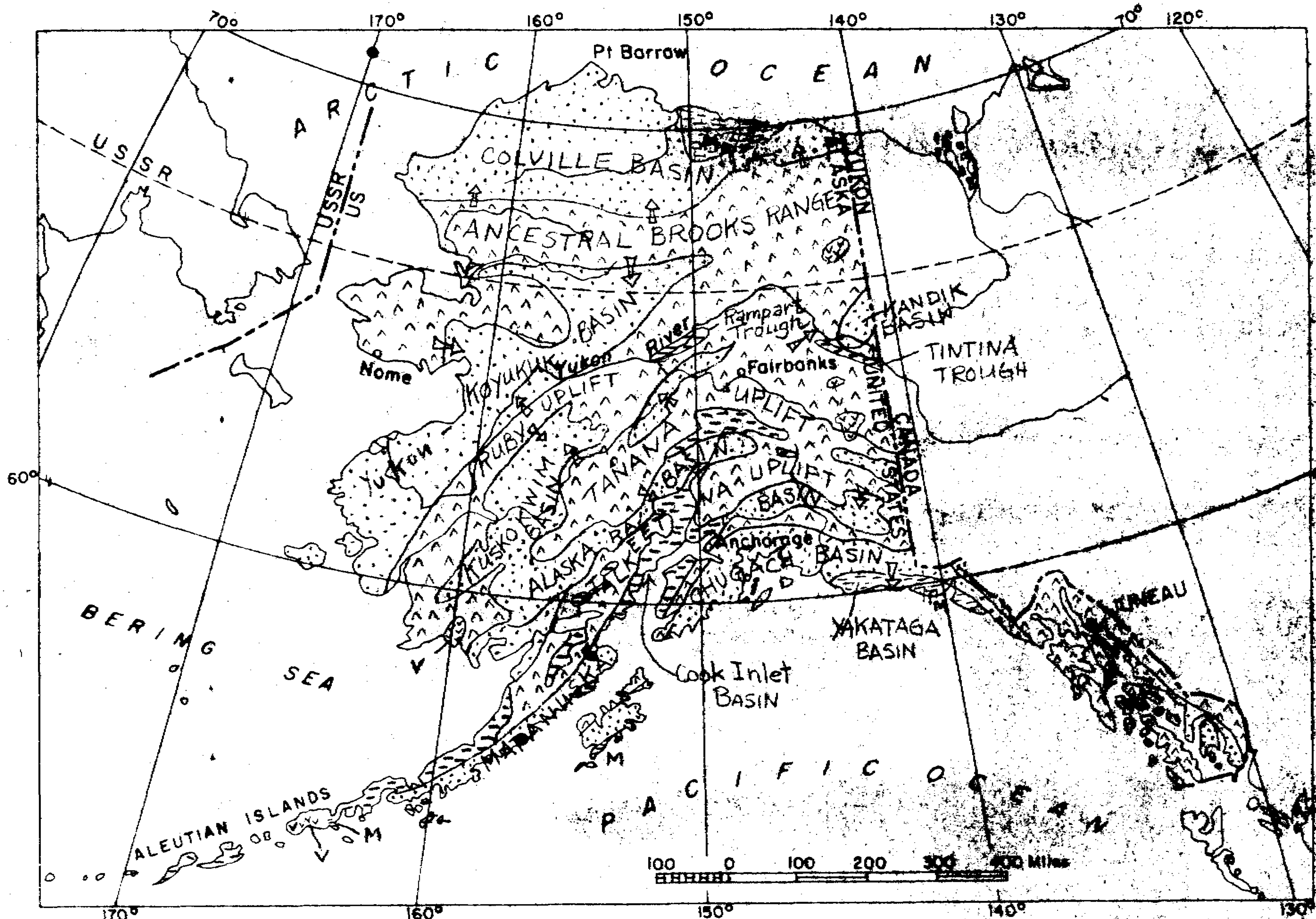


Figure 18 - Late Mesozoic and Tertiary tectonic features (M... after Payne, 1955; Gates and Gryc, 1963)

chunkin 9/10/

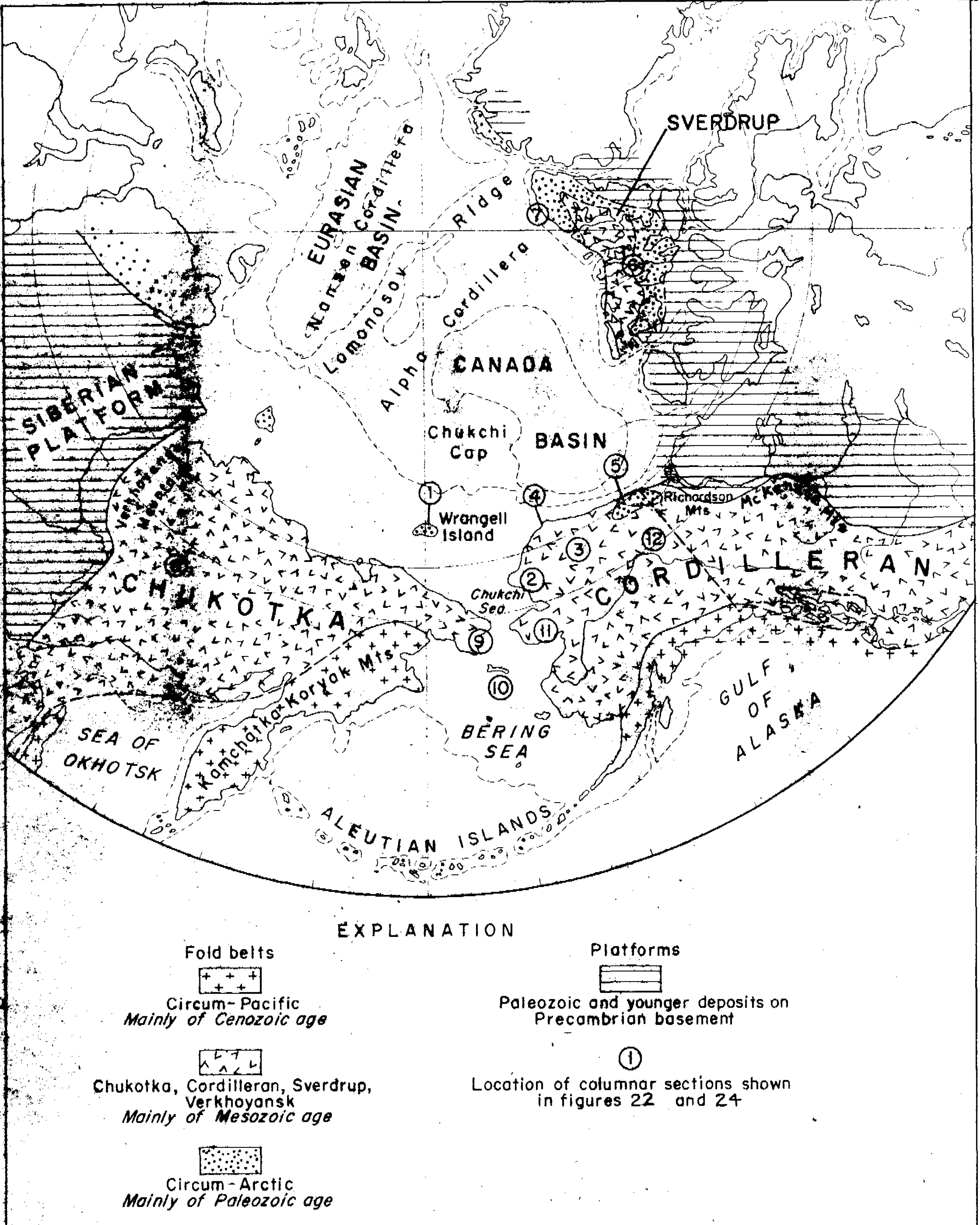


Figure 19.--Major fold belts around the northern Pacific and the Canada Basin portion of the Arctic Ocean

Figure 20.--Major structural features of northern Circum-Pacific and adjacent parts of the Arctic (after King, 1969; Yanshin, 1966).

Structural elements:

1. Denali-Farewell-Holitna Fault System
2. Chatham Strait Fault
3. Tintina Trench
4. Rocky Mountain Trench
5. Chugach-St. Elias-Fairweather Fault System
6. Kaltag Fault
7. Brooks Range - British Mountains thrust and fold belt
8. Richardson Mountains fold belt
9. Nahoni-Ogilvie-Wernecke Mountains fold belt
10. Mackenzie Mountains thrust and fold belt
11. Koryak thrust and fold belt
12. Verhoyansk fold belt

Generalized trend of folds

Transcurrent fault arrows show inferred movement

Thrust fault barbs on upthrown side

Arcuate trends in continental margins

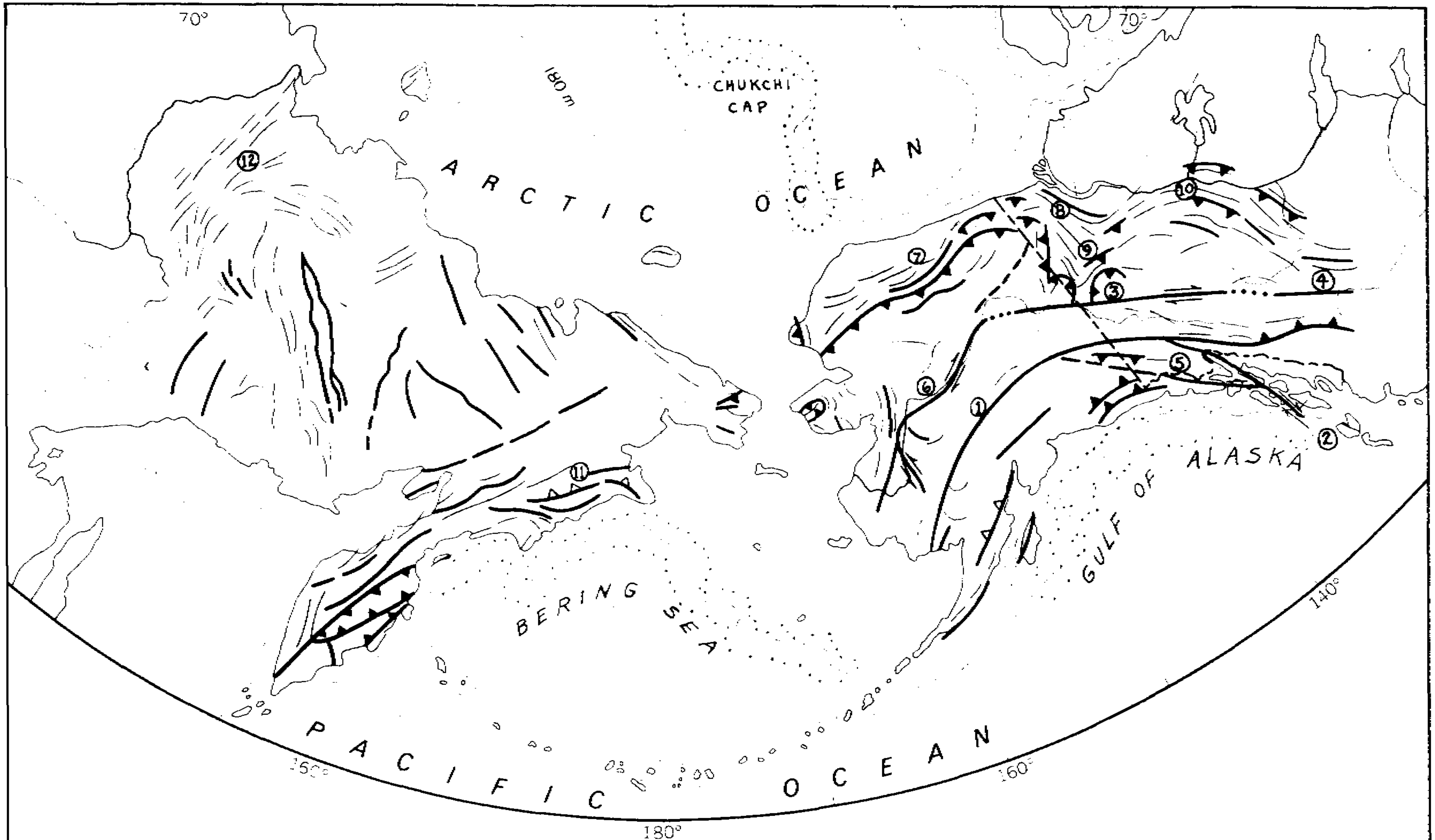

70°
180m
CHUKCHI
CAP
ARCTIC OCEAN
70°
BERING SEA
GULF OF ALASKA
140°
PACIFIC OCEAN
160°
180°

Figure 20

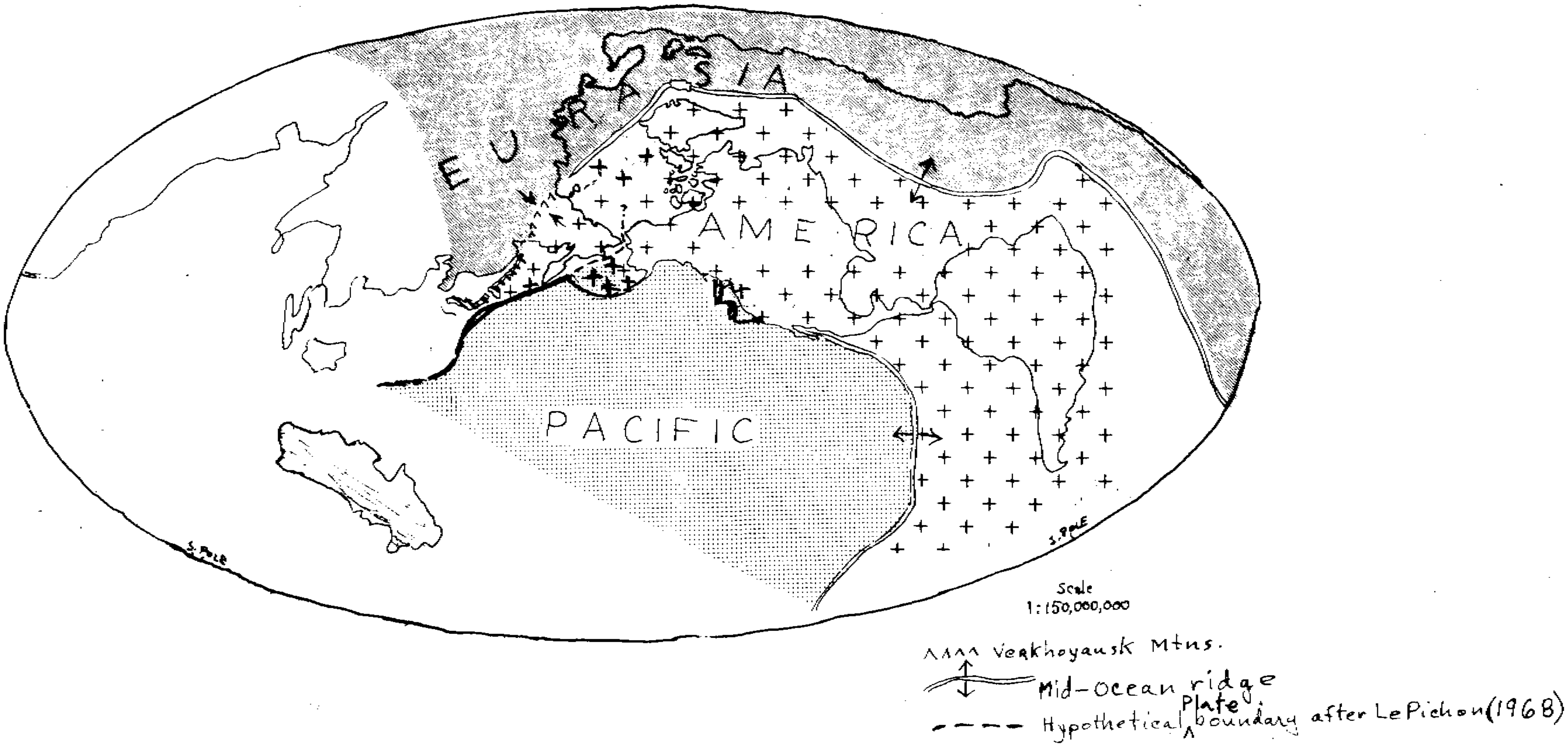


Figure 21. Boundaries of the major crustal plates in the northern hemisphere.

Churkin, 1970

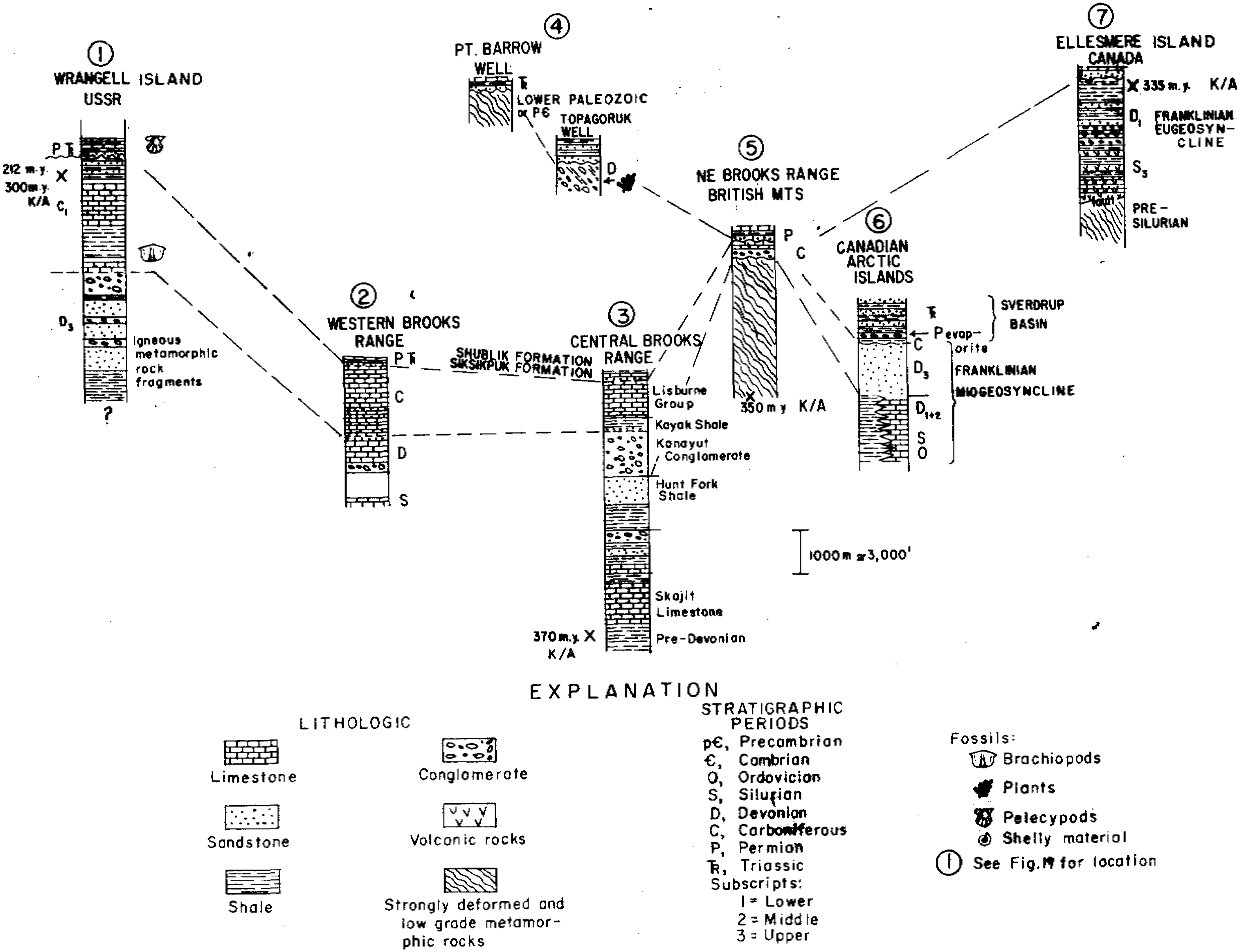


Figure 22. Correlation of the Paleozoic stratigraphy around the Canada Basin,

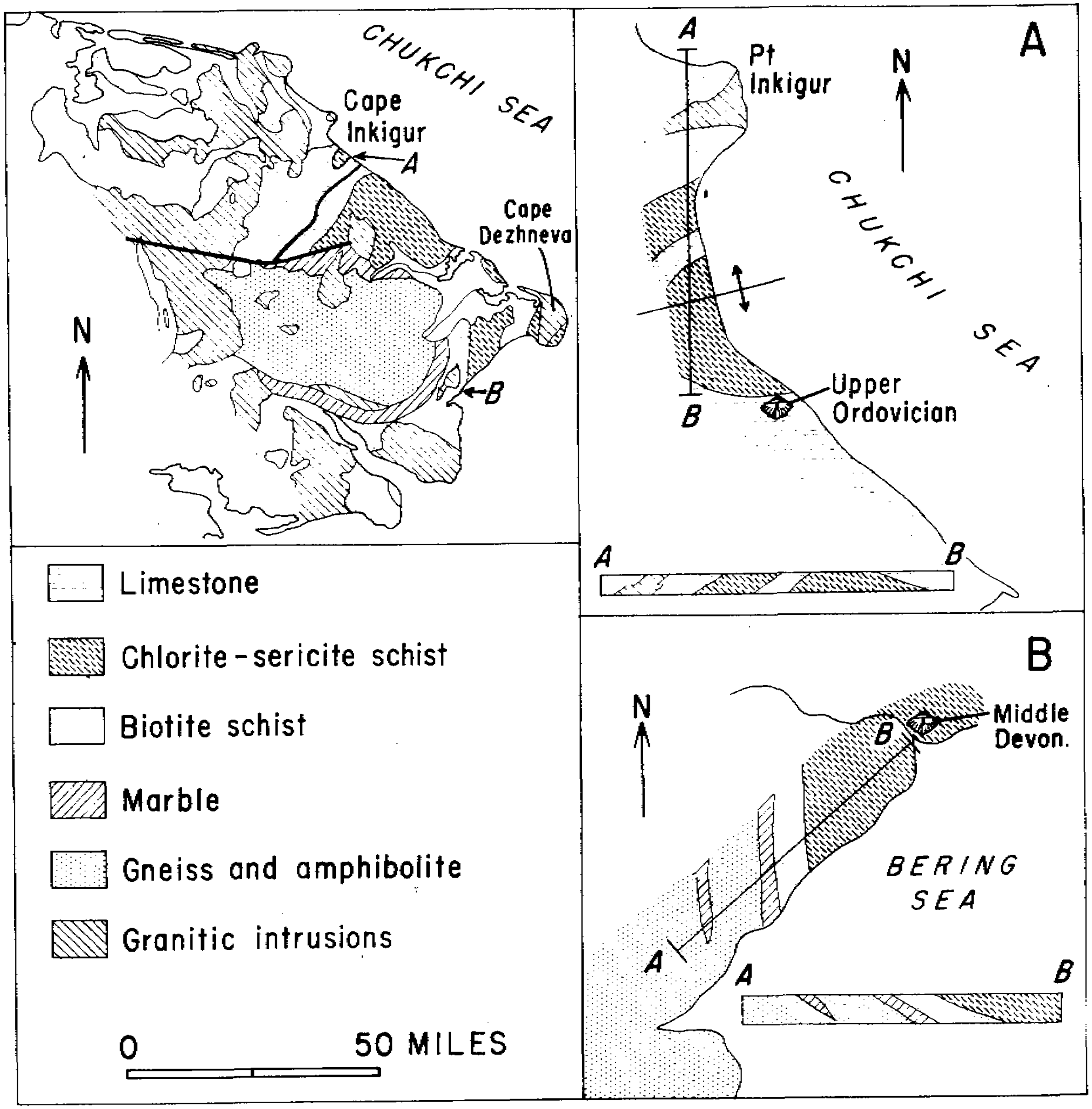


Figure 23. Geologic map and sections of the eastern part of the Chukotsk Peninsula, U.S.S.R. (after Gnibidenko, 1969)

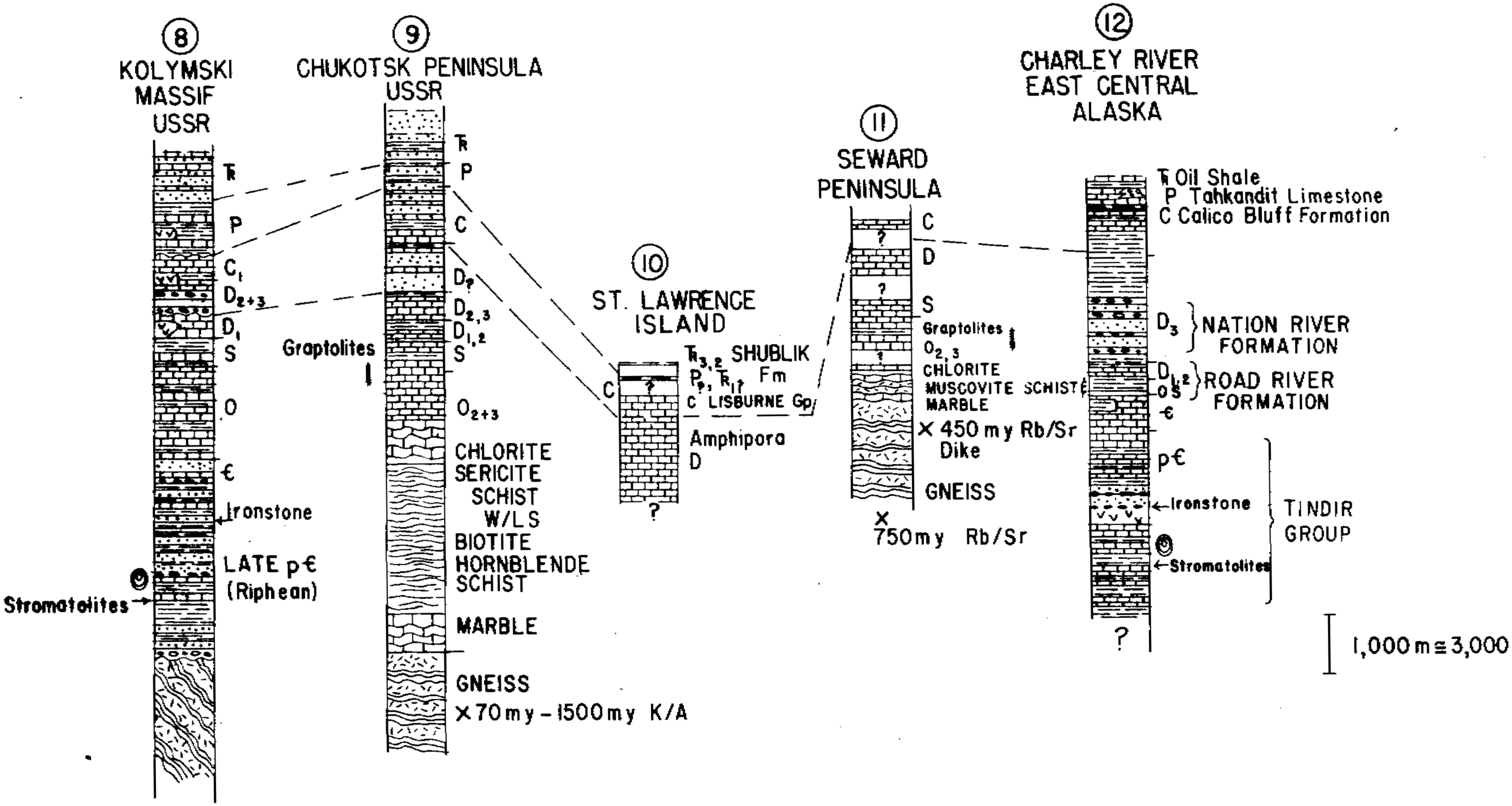


Figure 24. Correlation of Precambrian and Paleozoic rocks across the central parts of Chukotka and Alaska

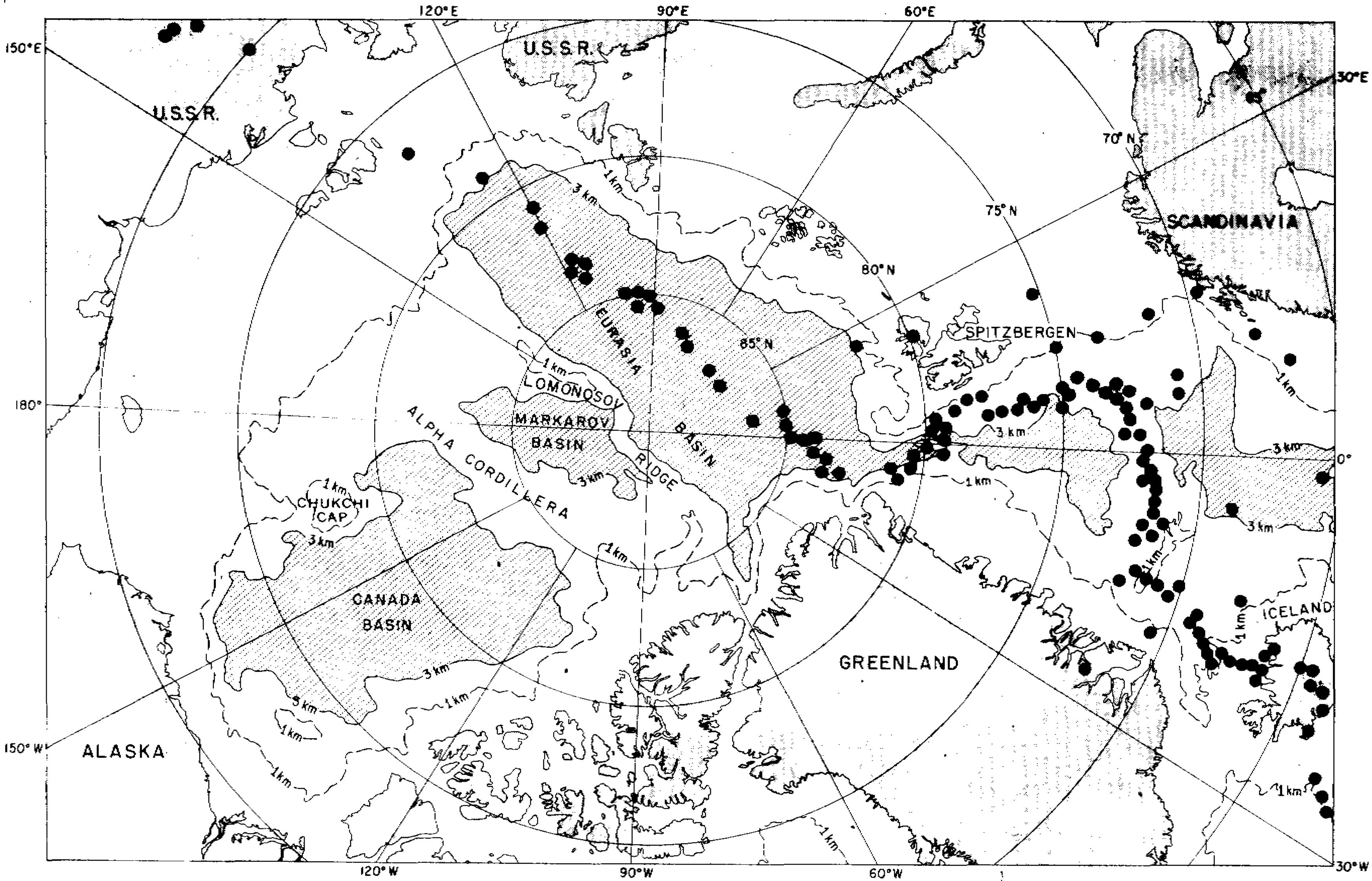


Figure 25. Bathymetric map of the Arctic Ocean showing earthquake epicenters, (after Sykes, 1965)