Precambrian Rocks of Alaska

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CORRELATION OF PRECAMBRIAN ROCKS OF THE
UNITED STATES AND MEXICO

Edited by JACK E. HARRISON *and* ZELL E. PETERMAN

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Lithology, distribution, correlation, and isotope ages of exposed Precambrian rocks in Alaska

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ABSTRACT

Eleven widely separated areas in Alaska contain rocks of Precambrian or probable Precambrian age. The age assignment in five areas is based on radiometric dating; in the other six areas stratigraphic evidence is used to infer a Precambrian age. All known Alaskan Precambrian rocks are of Late Proterozoic age except those constituting the Kilbuck terrane of southwestern Alaska and an area in the Yukon-Tanana upland of eastern Alaska, which are Early Proterozoic, and the schist of the northeastern Kuskokwim Mountains in central Alaska, which is Middle and Late Proterozoic. No evidence exists at this time for the presence of rocks of Archean age in Alaska. The Tindir Group along the Yukon River in east-central Alaska, which is considered equivalent to parts of the Windermere, Belt, and Purcell Supergroups of Canada, is the only group of Precambrian rocks in Alaska that can be definitely related to Precambrian stratigraphic sections in other parts of the North American cordillera. The Neruokpuk Quartzite and underlying strata of northern Alaska are Precambrian on the basis of stratigraphic evidence. The Tindir(?) Group along the Porcupine River in east-central Alaska and low-grade metamorphic rocks in the Livengood–Crazy Mountains region of central Alaska are probably Precambrian, although their precise ages are not known.

Tectonomagmatic events in the interval 1,100 to 600 million years ago are recorded in schist of the Yukon-Koyukuk region in west-central Alaska and in gneiss on the Seward Peninsula. The Wales Group of the Alexander terrane of southeastern Alaska and the Kilbuck metamorphic terrane of southwestern Alaska are allochthonous and appear to belong to exotic terranes accreted to the North American craton during Phanerozoic time.

Although mineral deposits are known to occur in several areas of Precambrian rocks, many of these deposits were produced during Phanerozoic mineralization episodes. However, banded iron-formation within the Tindir Group of east-central Alaska and certain volcanogenic, stratabound base-metal deposits within the Wales Group in southeastern Alaska are believed to have been formed during the Precambrian era.

INTRODUCTION

The record of Precambrian history of Alaska is certainly more fragmentary and less well known than that of the remainder of the United States. Available data indicate that the Precambrian rocks of Alaska are of Proterozoic age; at this time there is no evidence for Archean rocks (older than 2,500 m.y. (million years)). Only a few Precambrian occurrences in Alaska can be correlated reasonably confidently with the Precambrian subdivisions or reference sections in Western North America. Some Precambrian rocks in Alaska have been interpreted as belonging to exotic terranes accreted to the North American craton during the Phanerozoic.

The distribution of Precambrian and possible Precambrian rocks in Alaska is shown on figure 1. Eleven areas in Alaska are classified as those including rocks of Precambrian age and those including rocks of probable Precambrian age (fig. 1, A–J; area D is divided into D_1 and D_2). Also shown is an area consisting mainly of medium- to high-grade metamorphic rocks; some workers believe that part of these rocks may be Precambrian in age (fig. 1, K). However, at present no unequivocal stratigraphic or isotopic evidence exists to support such an age assignment.

We briefly describe the geologic setting of these 11 different areas in Alaska, pointing out for each the stratigraphic or isotopic evidence for the occurrence and age of Precambrian rocks. A conceptual stratigraphic column for each area is given on the correlation chart (pl. 1). Discussion of the areas proceeds generally from

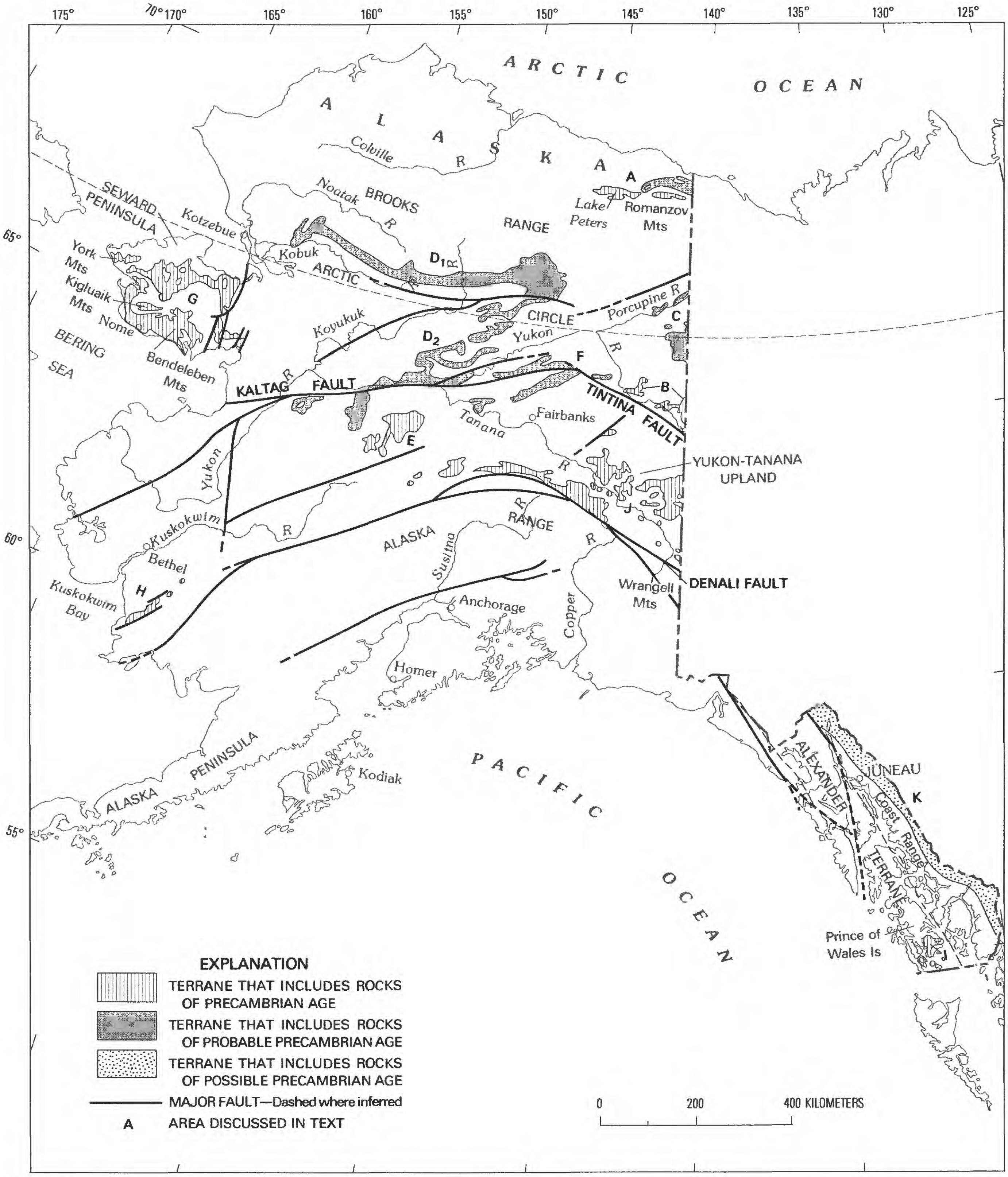

FIGURE 1.—Distribution of Precambrian, probable Precambrian, and possible Precambrian rocks in Alaska. A, northeastern Alaska; B, east-central Alaska (Yukon River region); C, east-central Alaska (Porcupine River region); D_1 and D_2, west-central Alaska (Yukon-Koyukuk region and southern Brooks Range); E, central Alaska (northeastern Kuskokwim Mountains); F, central Alaska (Livengood-Crazy Mountains region); G, Seward Peninsula; H, southwestern Alaska; I, southernmost southeastern Alaska; J, east-central Alaska (Yukon-Tanana upland); K, southeastern Alaska (Coast Range).

the interior of Alaska toward the continental margin. Several of the areas contain significant mineral deposits, which are described where appropriate. Also included is a discussion of the region that contains rocks of possible Precambrian age.

Previously published radiometric ages are cited as reported if these are referred to only in general terms. Ages discussed in more detail have been recalculated using decay constants and isotopic abundances recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger, 1977). Recalculated ages are indicated in the text.

ACKNOWLEDGMENTS

This review of the Precambrian of Alaska has drawn heavily upon the published literature, as well as upon the unpublished results of field studies by the authors and many of our colleagues in the U.S. Geological Survey. We particularly thank the following workers for generously offering their expertise and providing stimulating discussions about known and potential regions of Precambrian rocks in Alaska: D.A. Brew, W.P. Brosgé, R.M. Chapman, Michael Churkin, Jr., J.T. Dillon, H.L. Foster, G.E. Gehrels, J.M. Hoare, Travis Hudson, W.W. Patton, Jr., J.B. Saleeby, and D.L. Turner. We also thank C.C. Hawley and C.L. Sainsbury for the information they provided on the structure, stratigraphy, and economic geology of the Seward Peninsula. G.H. Eisbacher of the Geological Survey of Canada kindly reviewed the manuscript and made helpful general suggestions relative to the correlation of certain units across the Alaska-Yukon Territory boundary.

NORTHEASTERN ALASKA

A complex terrane of low-grade metamorphic rocks in northeastern Alaska unconformably underlies the Mississippian and Pennsylvanian Lisburne Group (fig. 1, pl. 1, A). Quartzite schist near Lake Peters was named the Neruokpuk Schist by Leffingwell (1919). Payne and others (1952) included other rocks within the Neruokpuk and renamed the unit the Neruokpuk Formation. Subsequent mapping resulted in the expansion of the Neruokpuk to include nearly all of the pre-Lisburne Paleozoic rocks in northeastern Alaska (Brosgé and others, 1962), although no fossils had been found in the formation up to that time. Fossils subsequently found in the Neruokpuk as defined by Brosgé and others (1962) indicate that it includes rocks of both Precambrian and Paleozoic age (Dutro and others, 1972). As a result of the most recent regional geologic studies in the northeastern Brooks Range, the Neruokpuk has been restricted to the usage of Leffingwell and renamed the Neruokpuk Quartzite (Reiser and others, 1978).

The Neruokpuk Quartzite is unconformably overlain in ascending sequence by a chert and phyllite unit, a calcareous siltstone and sandstone unit, a black phyllite and sandstone unit, and a volcanic and carbonate unit (fig. 2). Paleozoic echinoderm columnals have been found in the calcareous siltstone and sandstone unit, and trilobites of Early and Late Cambrian age have been found in limestone of the volcanic and carbonate unit. In addition to trilobites, poorly preserved articulate brachiopods occur in the upper part of the volcanic and carbonate unit. No fossils have been found in the Neruokpuk Quartzite or underlying strata (fig. 2). The only isotopic information bearing on the age of these rocks is a 439±13 m.y. K-Ar (potassium-argon) date (recalculated from Reiser, 1970) on hornblende from a postorogenic granitic intrusion on the upper Jago River, in the Romanzof Mountains of northern Alaska; this sets a minimum age of Late Ordovician for the quartzite. Thus, little doubt remains that the Neruokpuk Quartzite and underlying strata are Precambrian, but a more definite age assignment is not yet possible.

Mineral resources.—Although the Neruokpuk Quartzite and underlying units locally contain occurrences and geochemically anomalous amounts of lead, zinc, copper, tungsten, and molybdenum, these minerals appear to be spatially related to younger Phanerozoic granitic intrusions and therefore are not considered indicative of Precambrian metallogenesis. However, the area in which Precambrian rocks are known to occur is remote and has been covered only by reconnaissance geologic mapping; regional geochemical data are available for only a few widely scattered localities and total less than one-fourth of those considered necessary even for reconnaissance resource appraisal (Brosgé and Reiser, 1976). Furthermore, most of the area lies within the Arctic National Wildlife Range, which has been closed to prospecting for locatable minerals since 1960. Until the area is more completely studied, definitive assessment of the mineral resource potential of the Neruokpuk Quartzite and other Precambrian units is not possible.

EAST-CENTRAL ALASKA (YUKON RIVER REGION)

The sequence of Proterozoic rocks of east-central Alaska (fig. 1, pl. 1, B) is the only packet of Precambrian rocks in Alaska that can with little argument be correlated with the standard Precambrian subdivisions of Western North America. The Tindir Group, a thick

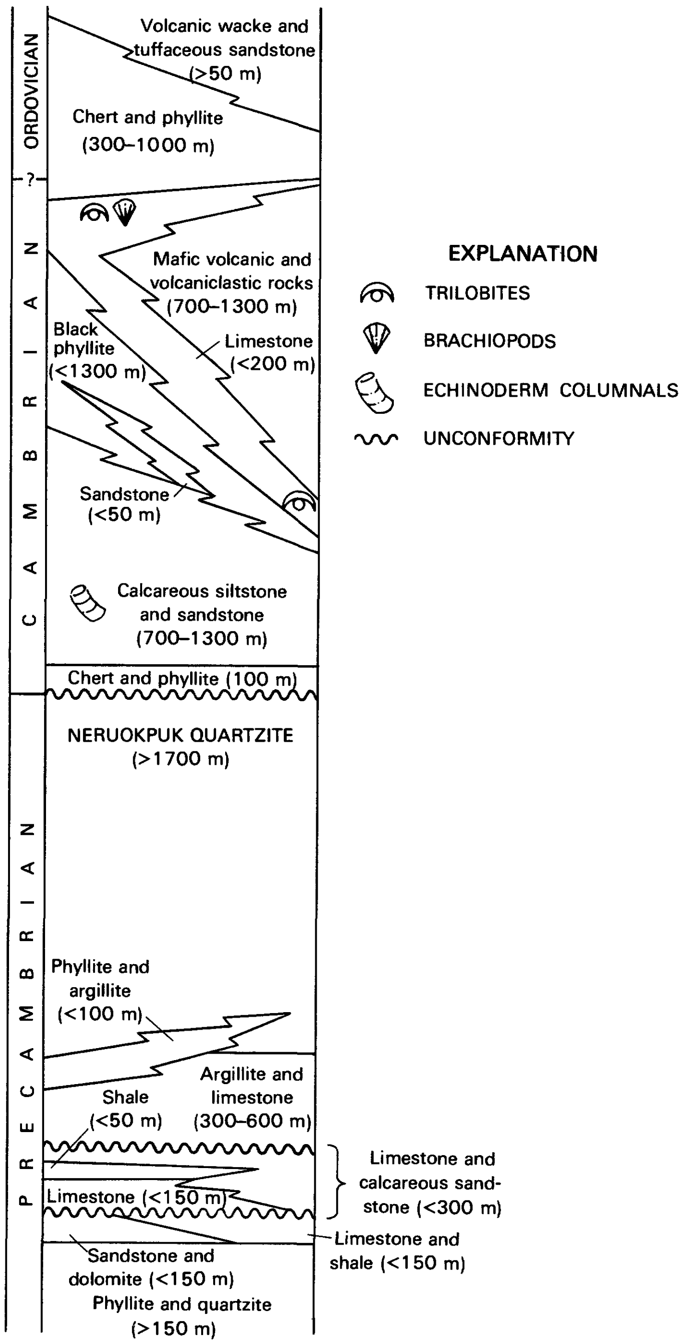

FIGURE 2.—Generalized stratigraphic relations among Precambrian and early Paleozoic rocks, northeastern Brooks Range, based on information from Reiser and others (1980). Base not exposed; younger rocks present at top of section but not shown.

sequence of unmetamorphosed stratified rocks that crop out along the Alaska-Yukon Territory boundary, was named by Cairnes (1914a, b) and subdivided into seven units by Mertie (1933). More recently, Brabb and Churkin (1965, 1969) divided the Tindir Group into five units, aggregating a thickness of more than 3,800 m (fig. 3). Both Mertie and Brabb and Churkin recognized an informal grouping of units into an upper and a lower Tindir. Young (1982) continued this informal division, but suggested that the two subdivisions, each as much as 2,000 m thick, merit separate group names. Young subdivided the Tindir Group into 11 units.

The lower Tindir Group consists mainly of carbonates and sandstones that were deposited in a shallow marine environment; a black shale unit is a deeper water deposit (Young, 1982). The lowest part of the upper Tindir consists of mafic pillow lavas and volcaniclastic rocks. Chemical data for the lavas indicate that most of the lavas are tholeiitic, though some are calc-alkaline (Young, 1982). Young described two units, consisting of purple mudstone, iron-formation, and diamictite, overlying the unit of igneous rock. These three units of Young were called the basalt and red beds unit by Brabb and Churkin (1965, 1969). The upper part of the upper Tindir shows rapid lateral facies variations. In general, these units consist of shales and turbidites to the west and shallow-water carbonates, sandstones, and shales to the east (Young, 1982).

The contact between the Tindir Group and overlying Lower Cambrian strata is accordant and appears to be conformable. However, the nature of this important contact has not been entirely resolved. Allison (1980) suggested that the boundary between the Tindir Group and the overlying Cambrian Funnel Creek and Jones Ridge Formations is transitional and that the base of the Cambrian may lie at the base of the basalt and red beds unit of Brabb and Churkin. This suggestion would place the upper part of the Tindir in the Cambrian, a view which (as discussed in following paragraphs) is not shared by many workers. Young (1982) pointed out that the contrast in depositional environments between the deeper water carbonates and shales of the upper part of the Tindir and the platform carbonates of the Jones Ridge Formation may indicate a stratigraphic break.

The oldest fossils known to occur above the Tindir are Early Cambrian archaeocyathids collected from the lower member of the Jones Ridge Limestone at a horizon about 150 m above its contact with the limestone unit of Brabb and Churkin, the highest unit of the Tindir Group. Early Cambrian trilobites occur in the Adams Argillite, more than 300 m above the top of the Tindir (Brabb, 1967). The base of the Tindir Group is not exposed.

The basalt and red beds unit of the Tindir Group (fig. 3) has been correlated with the Rapitan Group of the Windermere Supergroup in Yukon and Northwest Territories on the basis of their lithologic similarities (Gabrielse, 1967)—in particular, rhythmically bedded, siliceous iron-formation and diamictite of probable

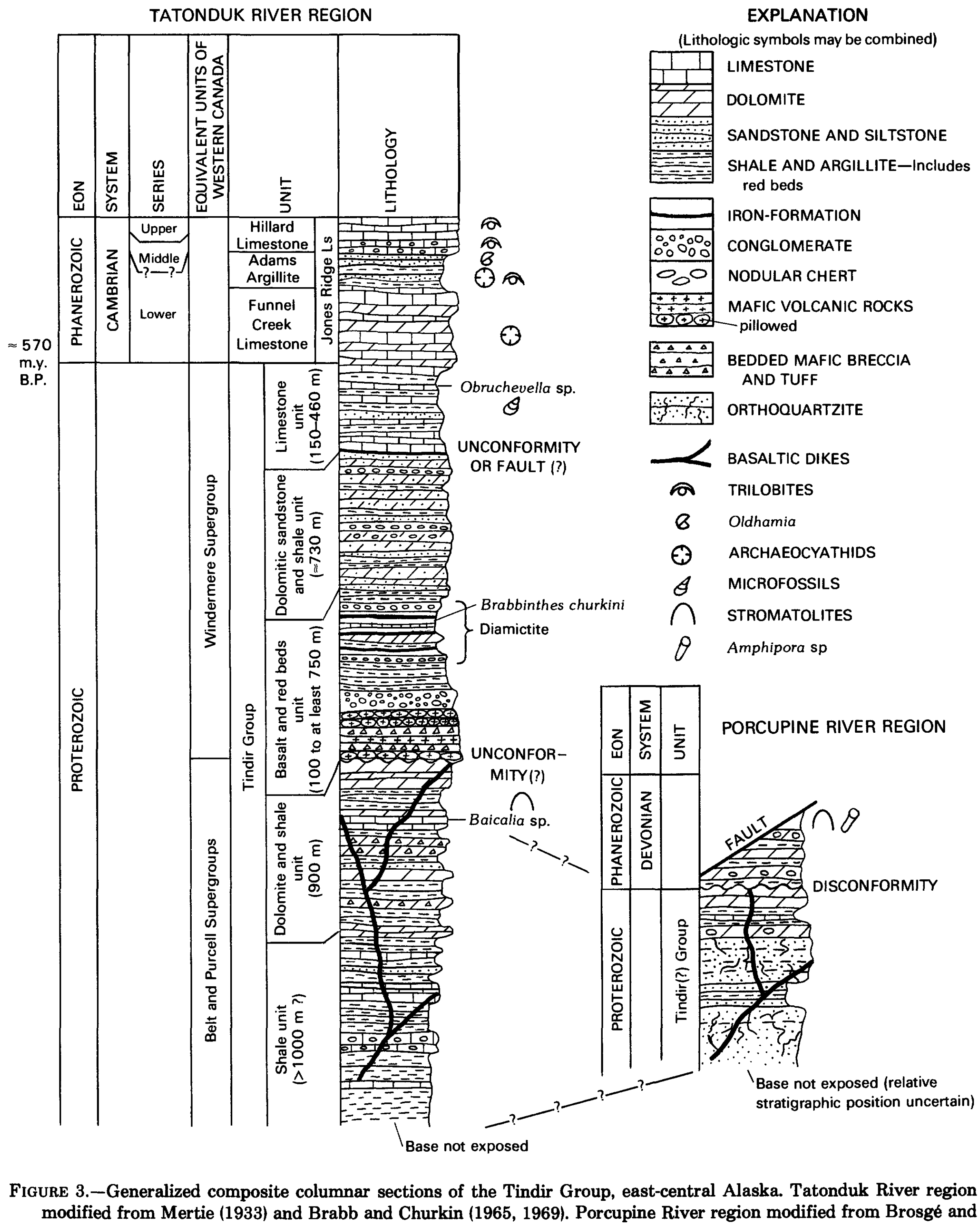

FIGURE 3.—Generalized composite columnar sections of the Tindir Group, east-central Alaska. Tatonduk River region modified from Mertie (1933) and Brabb and Churkin (1965, 1969). Porcupine River region modified from Brosgé and others (1966).

glaciogenic origin. Most geologists consider that the Rapitan Group is part of the Windermere Supergroup (Gabrielse, 1972, and oral commun., 1976; Eisbacher, 1978), and on this basis that the upper part of the Tindir Group is equivalent to the Windermere Supergroup of Proterozoic age.

A major unconformity at the base of the basalt and red beds unit (Kline, 1977) separates the two lower units of the Tindir Group as defined by Brabb and Churkin (1965, 1969) from its three upper units. The lower part of the Tindir Group lithologically resembles the Belt Supergroup, although direct biostratigraphic correlation has not been possible (Churkin, 1973). The Belt Supergroup and the Purcell Supergroup of Western Canada are generally considered correlative; on this basis the lower part of the Tindir Group is probably equivalent to the Belt and Purcell Supergroups.

Attempts to measure an isotopic age on the Tindir Group have so far been unsuccessful. Fossil collections have been reported from three units of the Tindir Group—the dolomite and shale, the basalt and red beds, and the limestone units of Brabb and Churkin (1965, 1969). Well-preserved stromatolites from the dolomite and shale unit have been identified as *Baicalia* sp. by M. A. Semikhatov (written commun., 1976). This stromatolite assemblage in Siberia is characteristic of the middle Riphean, with an estimated age of about 1,000 m.y.—an age based on a time scale developed by Russian workers from glauconite analyses. Thus, on the basis of fossil evidence, the lower part of the Tindir Group appears to be equivalent to parts of the Belt and Purcell Supergroups.

The microscopic fossil *Brabbinthes churkini* Allison, which Allison (1975) considered to be a Precambrian flatworm, reportedly occurs in siliceous shale of the basalt and red beds unit of the Tindir Group. Cloud and others (1976), however, questioned both the age and affinities of this fossil; they suggested that the *Brabbinthes* locality may not be in the Tindir because pillow basalts and red beds typical of the basalt and red beds unit are not present. They also proposed that other structures associated with *Brabbinthes* are sponge spicules, and that *Brabbinthes* may be the fortuitous cross section of a hexactinellid spicule instead of a flatworm. Although the oldest known hexactinellids are of Early Cambrian age, a late Precambrian assignment for some hexactinellids cannot completely be eliminated. Thus, *Brabbinthes* does not seem to provide a definitive time point for the Precambrian of Alaska.

Kline (1977) reported the occurrence of a distinctive spiral microfossil, *Obruchevella*, some 150 m below the top of the limestone unit of the Tindir Group. *Obruchevella* occurs in the Tommotian (earliest Cambrian) strata of eastern Siberia, and on this basis Kline suggested that the upper three units of the Tindir Group as defined by Brabb and Churkin (1965, 1969) should be assigned a Cambrian age. M. A. Semikhatov (oral commun., 1976), however, stated that *Obruchevella* also occurs in Vendian (=Terminal Riphean=Ediacarian) (late Precambrian) strata of one area of Siberia as well as in the Tommotian rocks. Subdivision of the Tindir and assignment of part of it to the Cambrian have also been advocated by Payne and Allison (1978) without reference to Kline's earlier suggestion, but they did not specify which part or parts or their evidence for reassignment. At present Kline's view that the upper part of the Tindir is Cambrian is not shared by many workers, most of whom consider the Tindir Group to be entirely of Precambrian age.

Mineral resources.—Low-grade, banded siliceous hematitic red beds (banded iron-formation) of sedimentary origin comprise about 550 m of interbedded reddish-brown shale, argillite, jasper, tuff, and minor dolomite and conglomerate (in part diamictite) in the upper part of the basalt and red beds unit of the Tindir Group. Hematite occurs in discrete beds from a few millimeters to 2.5 cm thick as a replacement mineral of volcanic fragments and as hematitic argillaceous cement. A basal pebble to boulder conglomerate 120–245 m thick has a hematitic matrix. The hematitic red beds are best exposed along the Tatonduk River, about 27 km north of Eagle, Alaska, and 5 km west of the International Boundary with Canada.

Reconnaissance chip sampling over a stratigraphic interval of nearly 243 m by the U.S. Bureau of Mines in 1962 yielded assays ranging from 4.73 to 24.7 percent soluble iron[1] (Kimball, 1969). Sampling of intervals 40.5 m and 61 m thick that were judged in the field to have the highest iron content showed 20.10 and 21.85 percent soluble iron, respectively. One 2-cm-thick slaty bed assayed 33.4 percent soluble iron, the highest assay obtained. The iron is present as extremely fine grained earthy hematite with only a trace of magnetite and is not amenable to simple magnetic or gravity concentration.

The beds sampled by the U.S. Bureau of Mines have an exposed area of about 10 km², but the unit containing banded iron-formation has been traced northward in discontinuous exposures for at least 48 km. Accordingly, speculative and hypothetical resources could amount to several billion tons or more (Eberlein and Menzie, 1978). Also, if the postulated correlation of the basalt and red beds unit with the Rapitan Group is correct, appropriate facies of parts of the Tindir Group that underlie the Rapitan might contain potentially copper-bearing basinal strata similar to those of the Redstone copper belt, District of Mackenzie, Northwest Territories, Canada. Careful examination of such facies would appear warranted.

[1] Iron dissolved by digestion in a heated 1:1 solution of HCl.

Recent company exploratory activity in the upper Yukon River region of Alaska adjacent to the Canadian border has led to the discovery of several so-called stratabound(?) zinc-lead deposits of the Mississippi Valley type. At least one of these is reportedly in an area underlain by carbonaceous shale with minor interbeds of quartzite, limestone, and dolomite in the lowest member of the Tindir Group (shale unit of Brabb and Churkin, 1969). Because of company confidentiality, information on the nature and extent of this reported occurrence is not currently available for publication. However, this occurrence may be analogous to conformable lead-zinc massive sulfide deposits in Late Proterozoic rocks northeast of Watson Lake and north of the Nadaleen River, Yukon Territory.

EAST-CENTRAL ALASKA (PORCUPINE RIVER REGION)

Along the Porcupine River, approximately 250 km north of the section of the Tindir Group exposed in the upper Yukon River region, is a section of quartzite and dolomite that Cairnes (1914a, b) included in the Tindir Group (fig. 1, pl. 1, C). The section is about 800 m thick and, like parts of the Tindir at its type locality, contains essentially unmetamorphosed units that appear to have been deposited in a high-energy, shallow-water, possibly intertidal environment (fig. 3). The base of the section is covered; the top is overlain by thin-bedded argillaceous dolomite grading upward into Devonian gray dolomite and nodular chert containing stromatolites and *Amphipora* (Brosgé and others, 1966; Brosgé and Reiser, 1969; W. P. Brosgé, oral commun. 1978). Churkin (1973) concluded that, despite lithologic similarities between the Yukon and Porcupine sections, available data do not permit the two sections to be correlated with confidence. On the basis of more recent mapping, Gary Kline (oral commun., 1976) suggested that rocks of the Porcupine River section probably correlate with the lower part of the Tindir along the Yukon River and are thus equivalent to the Purcell Group.

WEST-CENTRAL ALASKA (YUKON-KOYUKUK REGION AND SOUTHERN BROOKS RANGE)

A belt of low-grade schist that rims the Yukon-Koyukuk region (fig. 1, pl. 1, D_1 and D_2) probably includes Precambrian rocks, although unequivocal stratigraphic evidence is lacking and radiometric evidence in the southern and western Brooks Range is compromised by Mesozoic tectonic and thermal events. The belt is a structurally complex, polymetamorphic terrane of pelitic, calcareous, and graphitic schist, amphibolite, felsic to mafic metavolcanic rocks, and minor marble that were metamorphosed under conditions of the greenschist, epidote-amphibolite, and blueschist facies. Limiting evidence on the age of the terrane is given by fossiliferous late(?) Middle Permian rocks that overlie the schist in the central and eastern parts of the belt (Brosgé and Pessel, 1977), and by graptolite-bearing Lower Ordovician rocks in the western part of the belt (Tailleur and Carter, 1975). However, the schist units exposed at these two widely separated localities may not belong to the same sequence. Poorly preserved, recrystallized fossils have been collected recently from discontinuous marble beds associated with the schist belt in the Ambler district. Tentative identification of the faunas suggests a Middle Devonian to Early Mississippian age (Smith and others, 1978). Together with their interpretation of lead-isotope data from overlying stratiform volcanogenic base-metal massive sulfide deposits, Smith and others took this as evidence for a middle Paleozoic depositional age of part of the schist belt.

Turner and others (1978) reported 76 K-Ar mineral ages on 47 metamorphic and igneous rocks from the southwestern Brooks Range. Most of the data are muscovite and biotite ages ranging from 136 to 86 m.y. They interpreted these results to indicate a Cretaceous thermal event caused by intrusion of a series of granitic plutons into the metamorphic terrane in the southern part of the range. However, this interpretation must be modified on the basis of U-Pb (uranium-lead) ages of zircon from some granitic rocks and metavolcanic rocks of the schist belt reported by Dillon and others (1979, 1980). Eight zircon fractions from five samples of volcanic and plutonic rock have slightly discordant U-Pb ages that define a discordia line that intersects the concordia curve at ages of 365 ± 15 m.y. and 6 ± 120 m.y. Zircons from two other plutons yielded Late Proterozoic U-Pb ages. Some of these zircons have rounded cores that may be inherited xenocrysts. The discordant U-Pb data do not define a well-constrained discordia line. The data and the presence of inherited zircon cores permit assigning either a mid-Paleozoic or a Proterozoic age to these zircons. Dillon and others (1980) preferred the Proterozoic age. Consequently, Dillon and others (1979, 1980) asserted that many southern Brooks Range volcanic and plutonic rocks are Middle Devonian in age and may be cogenetic, that the poorly constrained lower intercept with the concordia curve reflects a Cretaceous metamorphic event which caused lead loss from the zircons, and that the Late Proterozoic ages are evidence for the presence of old basement in the Brooks Range.

Evidence for a pre-Cretaceous metamorphic history is given by a number of mineral ages older than about 140 m.y. Turner and others (1978) suggested that seven K-Ar ages ranging from 756 to 587 m.y. indicate late Precambrian metamorphism; the mean and standard deviation of these ages are 657±60 m.y. The distribution of these possible Precambrian rocks is not well known, and the precise age of metamorphism is not well established. Turner and others (1978) interpreted glaucophane ages ranging from 2,600 to 1,300 m.y. as anomalously old owing to the presence of inherited argon and thus of no geologic significance.

In a subsequent report, Turner and others (1979), using the same data and much of the same commentary as in the earlier publication, presented substantially the same conclusions, but were more positive about the presence of a late Precambrian basement in the southern Brooks Range that is correlative with a basement of late Precambrian age and compatible lithology in the North Slope region. Citing Drummond (1974) and I.L. Tailleur (oral commun., 1977), they stated (p. 1803) that "cores from wells that penetrate greenschist facies basement at Prudhoe Bay have yielded similar Late Precambrian to Early Cambrian K-Ar ages" and concluded that a reasonable structural interpretation of those ages and their own Brooks Range data is that most of the Brooks Range may be underlain by a late Precambrian basement complex. However, such an interpretation is not supported by paleontologic and lithologic data, and even the K-Ar dates can be explained in other ways. The "basement" penetrated by the wells at Prudhoe Bay is not greenschist, but rather black siliceous argillitic shale that contains *Monograptus spiralis*, a late Llandoverian graptolite, and Middle Ordovician to Silurian chitinozoans (Carter and Laufeld, 1975). Carter and Laufeld also reported Ordovician and Silurian (Caradocian through Ashgillian) chitinozoans from cores in similar basement rocks in South Barrow test wells, proving that the basement rocks of the Barrow arch are of approximately the same early Paleozoic age, at least over the 325 km between Prudhoe Bay and Point Barrow. These same authors pointed out that although three of the chitinozoan samples show a state of preservation implying that the rocks had been heated to more than 180 °C, one sample (South Barrow 1, core 38) is essentially unaltered. Thus, paleontologic data indicate that the oldest rocks penetrated by the North Slope wells in question are not Precambrian or Early Cambrian, but rather are Ordovician and Silurian. A K-Ar age of 592±8 m.y. was reported by one of us (Lanphere, 1965) for mica from basement argillite in a well at Simpson, about 80 km southeast of Point Barrow, Alaska; the mica quite probably is detrital.

In our opinion the K-Ar data suggest a minimum age of about 650 m.y. for a Precambrian metamorphic event in the southern Brooks Range. Field evidence suggests that the schist belt and closely associated Paleozoic rocks of the southern Brooks Range may be a structural mixture of units of several ages, ranging from Ordovician to as young as Mississippian and probably including metamorphosed Precambrian strata. Correlation with the basement rocks of the Barrow arch on the North Slope is not substantiated by existing paleontologic and lithologic evidence.

The schist belt of the Ruby geanticline (fig. 1, pl. 1, D_2), referred to as the Ruby terrane by Jones and others (1981), lies along the southern margin of the Yukon-Koyukuk region. There is no direct evidence to determine the age of these low-grade metamorphic rocks, which are lithologically similar to and adjoin (though separated by a fault from) rocks of the schist belt of the southern Brooks Range. The schist of the Ruby geanticline may also correlate with similar schists in the northeastern Kuskokwim Mountains (fig. 1, pl. 1, E). Fossils from carbonate rocks intercalated with schist of the Ruby terrane suggest that the protoliths of the metasedimentary rocks are Paleozoic; however, the possibility that some of the protoliths are Precambrian cannot be ruled out (Dillon and others, 1985).

Mineral resources.—The belt of low-grade pelitic and calcareous schist with associated amphibolite that borders the northern and southeastern parts of the northern Yukon-Koyukuk Cretaceous province contains a wide variety of generally unproductive lode deposits and placers that collectively have produced over 400,000 troy oz of gold, as well as byproduct silver and a little platinum. However, no evidence links any known deposits or occurrences to a Precambrian origin. During the past decade the schist belt of the southern Brooks Range has been the target of an intensive company exploratory activity, and numerous stratiform base-metal sulfide deposits have been discovered, distributed over a linear distance of about 160 km. These deposits appear to be localized within a stratigraphic interval of felsic to intermediate volcanic rocks about 900 m thick. Although rocks of Precambrian age may possibly be involved in this interval, as previously noted, Smith and others (1978) cited evidence that led them to favor a middle Paleozoic age for the massive sulfide deposits and enclosing strata.

CENTRAL ALASKA (NORTHEASTERN KUSKOKWIM MOUNTAINS)

Low-grade pelitic schist and quartzite with subordinate interbedded amphibolite, as well as calc schist similar to that bordering the Yukon–Koyukuk basin, rim the northeast apex of the Cretaceous Kuskokwim basin in central Alaska about 120 km north of the settlement of Medfra (fig. 1, pl. 1, E). These metamorphic rocks, part of the Nixon Fork terrane of Jones and others (1981), are overlain by unmetamorphosed Ordovician through Devonian shelf carbonates and younger terrigenous sedimentary rocks (Patton and others, 1980).

Patton and Dutro (1979) reported that the schist on a tributary of Meadow Creek is unconformably overlain by basal polymictic conglomerate containing large angular clasts of schist and abundant Permian fossils, leaving no doubt that the schist is pre-Permian. The conglomerate also rests unconformably on unmetamorphosed carbonate rocks of Early Ordovician, possibly Late Cambrian, through Permian age; these in turn also overlie the schist. Patton also reported that elsewhere the same lower Paleozoic platform carbonate rocks rest on quartzite, siltstone, and grit similar to rocks in the Livengood district and in the Crazy Mountains that contain the fan-shaped trace fossil *Oldhamia*, of probable Early Cambrian age (Churkin and Brabb, 1965).

Preliminary radiometric evidence for a Precambrian age of the low-grade schist terrane has been obtained by Silberman and others (1979) from an area about 125 km southeast of Ruby, Alaska. These workers reported that biotite phenocrysts from a sheared metamorphosed quartz diorite pluton that cuts the schist give a K-Ar mineral age of 921 m.y. Muscovite from recrystallized mylonite along the border of the intrusive gives an age of 663 m.y. Three other samples from the schist yield muscovite and muscovite-chlorite ages between 514 and 296 m.y., presumably reflecting argon loss. Dillon and others (1985) reported an additional K-Ar age of 697 m.y. for white mica from a metamorphic rock in the Nixon Fork terrane. The stratigraphic and K-Ar data, although not unequivocal, indicate that at least some of the metamorphic rocks in the region are as old as Precambrian.

Uranium-lead zircon ages (Dillon and others, 1985) show that Proterozoic rocks of two different ages are present in the Nixon Fork terrane. Zircons from metavolcanic rocks in the southern part of the terrane have discordant U-Pb ages that lie on a discordia chord that has an upper intercept with concordia (Wetherill, 1956) of 850±30 m.y. and a lower intercept of 73±10 m.y. Zircons from metaplutonic rocks in the northern part of the terrane have discordant U-Pb ages that lie on a chord with upper and lower concordia intercepts of 1,265±50 m.y. and 390±40 m.y., respectively. The U-Pb data document two different igneous events of Proterozoic age in the Nixon Fork terrane followed by regional metamorphic events, which caused lead loss from zircon, during the Paleozoic and Mesozoic. These different histories suggest that the Nixon Fork terrane may be an amalgamation of different Precambrian terranes.

CENTRAL ALASKA (LIVENGOOD–CRAZY MOUNTAINS REGION)

A sequence of quartzose grit, maroon and green slate, argillite, and phyllite crops out north and northeast of Fairbanks, Alaska, in what is known as the Livengood region (fig. 1, pl. 1, F). Many workers have considered part of this sequence to be of probable Precambrian age, although no direct evidence has been found for the presence of Precambrian rocks.

Mertie (1937) divided this structurally complex sequence into five lithologic units, with unit A the youngest and unit E the oldest. Unit A is overlain by volcanic rocks of Middle Ordovician age. Unit E is distinguished with difficulty from the underlying Birch Creek Schist, a unit which is discussed in the section, "East-central Alaska (Yukon-Tanana upland)." The only fossils found in this assemblage were collected from the upper part of unit B by Eliot Blackwelder in 1915. Brachiopods and trilobites from this collection were judged to be of Early Ordovician age by Edwin Kirk and E. O. Ulrich, but to be of Late Cambrian age by L. D. Burling (Mertie, 1937, p. 73). Reevaluation of taxa from the Blackwelder collection has confirmed the Early Ordovician age assignment (M. E. Taylor and A. J. Rowell, written commun., 1972). This age assignment was also confirmed by examination of conodonts present in the collection (J. W. Huddle, written commun., 1972; John Repetski, written commun., 1976). The contact between units B and C is not exposed and may be structural. Recent reconnaissance geologic mapping has demonstrated that units C, D, and E are at least partially traceable into the Mount Schwatka–Crazy Mountains region, where they appear to underlie phyllitic shale and quartzite containing the trace fossil *Oldhamia* of probable Early Cambrian age (R. M. Chapman, oral commun., 1978). Units C, D, and E also are lithologically similar to and may correlate with rocks assigned to the Windermere Supergroup (Late Proterozoic) in the Yukon crystalline terrane and the Omineca crystalline belt of Canada (Templeman-Kluit, 1976).

Mertie (1937) considered units C, D, and E to be of Precambrian age, an opinion that is not inconsistent with later observations. However, on strictly stratigraphic grounds, the lower three units of the assemblage can be assigned only an age of pre-Early

Ordovician; a Precambrian age for at least part of the sequence is permissible but not proved.

SEWARD PENINSULA

The oldest fossiliferous rocks of the Seward Peninsula are carbonate rocks of Early Ordovician age (Sainsbury, 1969). These rocks and the overlying thick section of Paleozoic carbonate rocks were deposited on an assemblage of sedimentary, igneous, and low- to high-grade metamorphic rocks that most workers have considered to be at least partly Precambrian (fig. 1, pl. 1, G). However, complex structural geology involving large-scale thrusting has made it difficult to establish the age of the pre-Ordovician rocks by standard stratigraphic methods.

Sainsbury (1969) and Sainsbury and others (1971) have reviewed the nomenclature of pre-Ordovician rocks of the Seward Peninsula. On the basis of his detailed fieldwork during the 1960's, Sainsbury has suggested extensive revisions to the stratigraphy of older rocks of the Seward Peninsula. In the York Mountains Sainsbury (1969) found that the slate of the York region (Collier, 1902, p. 48) is transitional upward into a sequence of dolomitic and argillaceous limestone. This sequence of dolomitic and argillaceous limestone was named the Kanauguk Formation by Sainsbury (1974). Its age is definitely pre-Ordovician and may be Precambrian or Cambrian. Sainsbury (1975) suggested that the Kigluaik and Nome Groups are metamorphic equivalents of the slate of the York region, which he named the York Slate.

High-grade schist and gneiss constituting gneiss dome cores in the Kigluaik and Bendeleben Mountains were also considered by Sainsbury (1975) equivalent to the slate of the York region. A Precambrian age for some of these high-grade metamorphic rocks is suggested by Rb-Sr (rubidium-strontium) dating. The data for five whole-rock samples of paragneiss and a conformable pegmatite from the Kigluaik Mountains lie on an isochron corresponding to an age of 735±45 m.y. (Bunker and others, 1977). The data of Bunker and others were recalculated using the new decay constant for ^{87}Rb. The uncertainty is the standard deviation of the fit to the isochron. This date was interpreted as the age of metamorphism, with scatter about the isochron perhaps related to the effects of plutonism and tectonism during the Cretaceous period. The foliation of the orthogneiss in the Kigluaik Mountains is parallel to that of the enclosing paragneiss. Thus, if the foliation developed during the 720-Ma metamorphic event, the orthogneiss must also be Precambrian.

Bunker and others also analyzed orthogneiss from three different areas; although their results show considerable scatter on a strontium evolution diagram, this is not surprising because one would not expect the various granitic masses to have the same initial strontium composition. No unique interpretation of these orthogneiss data is possible, but Bunker and others preferred to consider the orthogneiss to be Precambrian, with disturbance of the isotopic systems by Cretaceous plutonism and tectonism.

This metamorphic event about 720 Ma has not been documented elsewhere on the Seward Peninsula. At present no evidence has been found for the age of the protolith of metamorphic rocks of the region.

Mineral resources.—The Seward Peninsula is known to be richly endowed with resources of gold, tin, beryllium, fluorite, and graphite and to have significant mineral potential for antimony, tungsten, lead, zinc, silver, iron, copper, uranium, and thorium; however, none of the known ore deposits is unequivocally of Precambrian age. Nevertheless, strong evidence exists for at least one epoch of Precambrian metallogenesis, whose greatest potential appears to be identified with the belt of orthogneiss in the Kigluaik Mountains and its less well known eastward extension into the Bendeleben Mountains.

The orthogneiss generally ranges in composition from granite to granodiorite, and it forms tabular sill-like intrusions into the paragneiss that clearly have had the same metamorphic history. All compositional variants of the orthogneiss show an abnormally high background in uranium and especially in thorium (Bunker and others, 1977; C. C. Hawley, oral commun., 1978). This background is particularly notable in the more felsic phases. In places the orthogneiss is petrologically similar to "tin granite" and is tourmalinized where no evidence is found for the presence of younger Cretaceous intrusions. At least four occurrences of metamorphosed, scheelite-bearing skarn zones with local galena and sphalerite have been reported from the Nome area (Hummel, 1961); and more occurrences have been discovered as a result of company exploratory programs during 1976–78 (C. C. Hawley, oral commun., 1978). Most of these zones are at the hanging-wall contact of sill-like bodies of orthogneiss with enclosing interbedded quartzite, marble, and intermediate- to high-grade schist. Locally, small, crudely zoned garnetiferous allanite-bearing pegmatites that are probably related to the orthogneiss contain as much as 1,000 ppm or more uranium and thorium (C. C. Hawley, oral commun., 1978). Collectively these indicators make the areas of orthogneiss currently more attractive targets for detailed prospecting than in the past.

SOUTHWESTERN ALASKA

The Kilbuck tectonostratigraphic terrane of southwestern Alaska, previously named the Kanektok metamorphic complex, is exposed discontinuously throughout a narrow belt no more than 15 km wide that extends northeastward from Kuskokwim Bay on the Bering Sea coast for a distance of about 150 km (fig. 1, pl. 1, H). The terrane is composed of crystalline schists and gneisses believed to have been derived by metamorphism of an interbedded sequence of sedimentary and volcanic rocks and associated mafic and felsic intrusive rocks (Hoare and others, 1974). Field relations and aeromagnetic data suggest that the metamorphic terrane is allochthonous and has the form of a thin, rootless slice (J. M. Hoare, oral commun., 1978; Griscom, 1978); the Kilbuck terrane evidently contains rocks that are older than other known areas of Precambrian rocks in Alaska. The Kilbuck is an exotic terrane whose original location has not been established: it was emplaced at its present position in pre-Early Cretaceous time because it is overlain by Lower Cretaceous conglomerate that contains clasts of metamorphic rocks derived from the terrane (Hoare and others, 1974).

Isotopic ages suggest that the Kilbuck terrane consists of Early Proterozoic sedimentary, volcanic, and intrusive rocks which were metamorphosed to amphibolite and granulite facies in the Early Proterozoic and, subsequently, were affected by a Mesozoic thermal event associated with intrusion of granitic plutonic rocks (Turner and others, 1983). Uranium-lead analyses indicate that the protolith of granitic orthogneiss crystallized at 2,050 Ma and that amphibolite and granulite facies metamorphism occurred about 1,770 Ma. Rubidium-strontium analyses also are consistent with a metamorphic event 1,770 Ma. A K-Ar age of 1,770 m.y. was measured on one hornblende, but most K-Ar ages were partly or totally reset during the Mesozoic thermal event. $^{40}Ar/^{39}Ar$ incremental heating data suggest that a metamorphic event also occurred about 1,200 Ma.

SOUTHEASTERN ALASKA

Ancient rocks are exposed throughout the Alexander terrane, a large allochthonous borderland region of predominantly sedimentary, volcanic, and metamorphic rocks that lies west of the plutonic and metamorphic complex of the Coast Range and extends for about 1,000 km along the Pacific coast from the southernmost tip of southeastern Alaska to the Wrangell Mountains of southern Alaska (Berg and others, 1972). Jones and others (1972) suggested that the Alexander terrane may constitute a displaced continental fragment that perhaps was derived from the south. Geologic evidence in support of this view was summarized by Churkin and Eberlein (1977), and the view is supported by recent paleomagnetic investigations that suggest movement of the terrane northward across latitude lines from a paleoposition of about lat 40°N., long 120°W., and in-place 25° counterclockwise rotation during post-Carboniferous time (Van der Voo and others, 1980).

The Wales Group constitutes a metamorphic basement of possible Precambrian age underlying much of southern Prince of Wales, Dall, and Long Islands in southernmost southeastern Alaska (fig. 1, pl. 1, I). The Wales Group is a structurally complex, volcanic arc assemblage of predominantly andesitic to basaltic volcanic rocks, graywacke, and mudstone with subordinate interlayered marble, regionally metamorphosed to greenschist and locally to the amphibolite facies. Thin marker beds of quartz-albite metakeratophyre believed to have originally been rhyolitic tuff are also present. As of 1983 the Wales Group had yielded no fossils.

In most places the Wales Group is in fault contact with unmetamorphosed Ordovician and Devonian strata, but locally it appears to be unconformably overlain by basal sedimentary breccia and conglomerate containing scattered clasts of schist that are petrologically similar to units of the Wales Group, and by a thick section of graywacke, rhythmically layered and graded siliceous mudstone, mafic volcanic rocks, and sparse thin cherty-limy strata that are at least in part coeval with and may be correlative with parts of the Descon Formation, the nearest exposures of which occur about 25 km to the north and northwest (Eberlein and others, 1983). In the Klakas Inlet area of Prince of Wales Island, Middle Ordovician (Caradocian) graptolites occur in black cherty shale beds of the eugeosynclinal sequence. The exact thickness of the section is not known because the strata are folded, locally overturned, and cut by thrust and strike-slip faults. However, the graptolites are believed to occur significantly above the lowest beds (fig. 4), suggesting that the latter may be as old as Cambrian and that the underlying penetratively deformed and metamorphosed Wales Group may be of Precambrian age (Eberlein and Churkin, 1973).

No radiometric evidence for a Precambrian age has been obtained on the Wales Group itself. Preliminary discordant zircon U-Pb ages on the oldest trondhjemitic phase of an ensimatic igneous complex that was thought to intrude the Wales Group permitted a possible Precambrian age assignment for the group (Churkin and Eberlein, 1977), but these U-Pb ages proved to be an artifact of undetected uranothorite impurities within

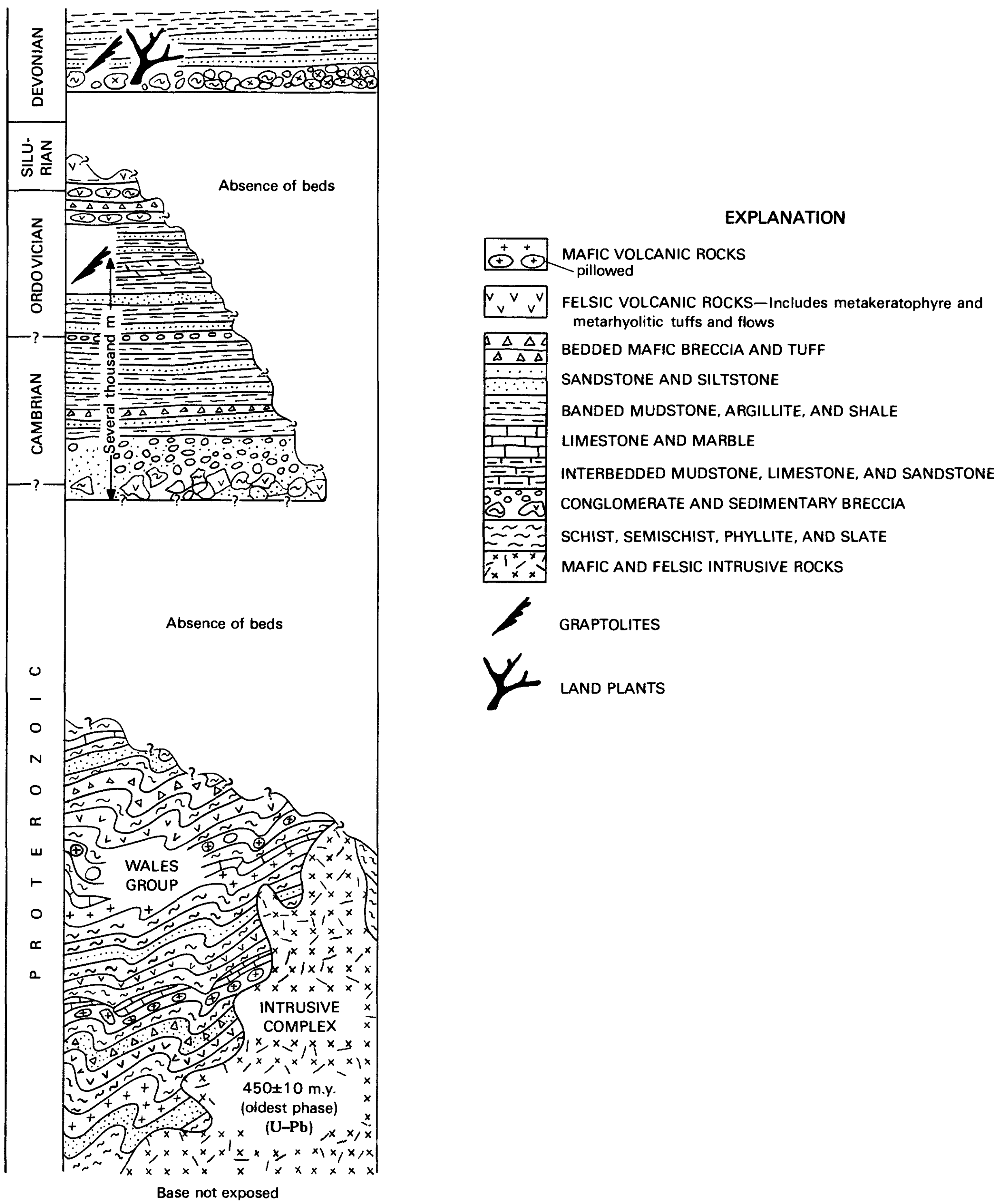

FIGURE 4.—Generalized stratigraphic relations of the Wales Group, southeastern Alaska. Queries in section indicate uncertainty of extent and stratigraphic and structural relations of discontinuous deposits. Modified from Churkin and Eberlein (1977).

the zircon populations. Subsequent analyses of a hornblende diorite yielded concordant ages within and between multiple zircon fractions, indicating a crystallization age of 450±10 m.y. (Saleeby and Eberlein, 1981). On the basis of stratigraphic evidence, the intrusive complex is known to be of pre-middle

Lower Devonian (Pragian) age, because clasts of the complex are a major constituent of an overlying sedimentary breccia that in turn is conformably overlain by calcareous siltstone, conglomerate, and black slaty shale that contains *Monograptus pacificus*.

Zircon from a deformed dike in a gneissic phase of the Wales Group at Sunny Cove, Prince of Wales Island, yielded a concordant U-Pb age of 525 m.y. (Jason Saleeby and G.D. Eberlein, unpub. data, 1977). If one assumes an age of about 570 m.y. for the base of the Cambrian, then given the apparent stratigraphic thickness of the Wales Group it seems likely that at least part of the Wales Group is Precambrian in age.

Mineral resources.—The Wales Group has served as the host for a wide variety of mineral deposits, including polymetal veins, copper-iron skarns, stratabound volcanogenic massive sulfide deposits, dolomite replacements, and mineralized shear zones. Most mines and known occurrences are clearly related to the emplacement of Cretaceous (about 102 m.y.) granitic plutons. However, certain stratabound deposits may be Precambrian in age and of volcanogenic origin. At the Khayyam mine on eastern Prince of Wales Island, lenses of massive iron and copper sulfide minerals, with subordinate zinc, silver, and gold, are aligned parallel to the layering of enclosing gneissic amphibolite host rock and define a mineralized zone 3–8 m wide that can be traced for a distance of about 340 m (Fosse, 1946). Similar relations occur at the Mammoth (Stumble-on) prospect about 2.4 km on strike to the northwest. The Polymetal zinc-lead prospect, located on the west side of the South Arm, Cholmondeley Sound, eastern Prince of Wales Island, reportedly occurs in banded chloritic quartz-sericite schist similar to metarhyolitic(?) host rock in the lenticular volcanogenic massive sulfide deposits of Niblack Anchorage (Brooks, 1902, p. 87; Peeke, 1975). However, recent geologic mapping by one of us (Eberlein) suggests that the Niblack assemblage is of early Paleozoic age, although the evidence is not unequivocal. The lenticular banded chalcopyrite-pyrite-sphalerite massive sulfide deposits of Corbin and Copper City on the east side of Hetta Inlet, western Prince of Wales Island, also occur in chloritic quartz-sericite schist of the Wales Group, along with locally interlayered metakeratophyre. The settings strongly suggest a syngenetic origin in a submarine felsic volcanogenic environment, although most descriptions in the literature emphasize the relation of the deposits to faults and shear zones. At Lime Point, the eastern headland of Hetta Inlet, lenses and veinlets of barite are interlayered with and transect dolomite and marble of the Wales Group (Twenhofel and others, 1949; Eberlein, unpub. field data, 1971). Although field relations indicate that the deposit was probably formed by selective replacement of the original limestone, a premetamorphic origin is suggested by the fact that the barite shows local evidence of folding. Thus, the deposit is considered stratabound and of possible Precambrian age.

EAST-CENTRAL ALASKA (YUKON-TANANA UPLAND)

The Yukon-Tanana upland, lying between the Yukon and Tanana Rivers in east-central Alaska (fig. 1, pl. 1, J), is mainly a region of complexly deformed, largely polymetamorphic rocks intruded by batholiths of Mesozoic age and smaller plutons of Mesozoic and Tertiary age (Foster and others, 1973). The metamorphic rocks are of both igneous and sedimentary origin, ranging in grade from greenschist to upper-amphibolite facies. These rocks extend southeastward into Canada, where they constitute part of the Yukon crystalline terrane (Templeman-Kluit, 1976). To the northwest, in the Livengood–Crazy Mountains region discussed previously (fig. 1, pl. 1, F), they pass into or are thrust over relatively little-metamorphosed sedimentary rocks of early Paleozoic and (or) late Precambrian age (Foster and others, 1973). These same metamorphic rocks are separated from the unmetamorphosed Tindir Group to the north (fig. 1, pl. 1, B) by the Tintina fault zone.

The various metamorphic rocks of the Yukon-Tanana upland and the adjacent Yukon Territory were assigned a number of stratigraphic names by United States and Canadian geologists in the late 1800's and early 1900's. Mertie (1937), in his comprehensive review of the geology of the Yukon-Tanana upland, named and described the Birch Creek Schist, a name he applied to what he considered to be the oldest rocks in the region. He, in effect, equated these rocks with the equally ill defined Yukon Group of Yukon Territory (Cairnes, 1914a). Mertie considered the Birch Creek Schist to be of early Precambrian age, primarily because of drastic lithologic differences between it and the Tindir Group, which he considered to be of Precambrian and Early Cambrian age. It is now evident that the two units are juxtaposed along the Tintina fault zone (Templeman-Kluit, 1976) so that their lithologic differences have no bearing on the age relations inferred by Mertie. Foster and others (1973) abandoned the name "Birch Creek Schist" because of its doubtful value as a stratigraphic unit. Similarly, Templeman-Kluit (1976) called attention to the stratigraphic limitations of the name "Yukon Group" and recommended either that it be discontinued or that its meaning be restricted.

Wasserburg and others (1963) reported whole-rock Rb-Sr ages on schist ranging from 1,170 to 664 m.y. and discordant younger ages on biotite and muscovite from schist of the Yukon-Tanana upland. These results were reported before the problem of redistribution of radiogenic ^{87}Sr during metamorphism was fully appreciated. The currently preferred interpretation of these data supports a pervasive Mesozoic metamorphic event. The schist terrane may include a component of inherited, perhaps even Precambrian material, but this possibility has not yet been definitely proved.

Several K-Ar mineral ages have been measured on metamorphic rocks of the Fairbanks district; the oldest age is 470±35 m.y. on hornblende (Foster and others, 1973). McCulloch and Wasserburg (1978) reported Sm-Nd (samarium-neodymium) and Rb-Sr model ages on a single sample of schist, called by them the Birch Creek Schist, from the Alaska Range. They correlated this sample on the basis of lithologic similarity with schist of the Yukon-Tanana upland. The Sm-Nd model age on the sample is 2,330±50 m.y., which McCulloch and Wasserburg interpreted as evidence that the sample was derived from an ancient Precambrian source, probably the Canadian Shield. The Rb-Sr model age of 714±8 m.y., which is similar to the total rock Rb-Sr ages of Wasserburg and others (1963), does not uniquely prove a Precambrian depositional or metamorphic age for the schist.

More recently, U-Pb-Th analyses of zircons from an orthoaugen gneiss intrusive body in the Yukon-Tanana upland of east-central Alaska have provided substantiating evidence for the presence of Early Proterozoic material in that area. Uranium-lead data reported by Aleinikoff and others (1981) define a chord that intersects concordia at approximately 2,300 m.y. and 345 m.y. Two alternate interpretations are suggested: (1) the protolith was emplaced during the Proterozoic and subsequently metamorphosed in Paleozoic time, or, more likely, (2) the protolith was emplaced in the Paleozoic and entrained material of Proterozoic age. These authors also presented a 1,880±80 m.y. Sm-Nd model age on a whole-rock sample of the augen gneiss, which may be considered additional evidence for the presence of a Proterozoic component in the gneiss.

Aleinikoff, Foster, and others (1984) subsequently confirmed Early Proterozoic sources for sedimentary rocks in the Yukon-Tanana upland through isotopic analyses of detrital zircons from quartzite sampled at several widely separated localities in the upland. A best-fit line for U-Pb data for detrital zircon from quartzite and orthoaugen gneiss (Aleinikoff and others, 1981) intercepts with concordia at 346±38 m.y. and 2,232±34 m.y. These data were interpreted as indicating incorporation of detritus from Early Proterozoic rocks in sedimentary rocks of latest Proterozoic and (or) earliest Paleozoic age. There is no definitive evidence for the age of the quartzites, though one locality is considered to be Cambrian(?) because of the occurrence of the trace fossil *Oldhamia* (Churkin and Brabb, 1965). The lower concordia intercept was interpreted as the age of partial melting of sedimentary rocks to produce a magma or, alternatively, assimilation of sedimentary rocks into a magma that formed the plutonic protolith of the augen gneiss (Aleinikoff, Foster, and others, 1984).

Sillimanite gneiss in Big Delta quadrangle, some of the highest-grade metamorphic rock in the Yukon-Tanana upland, yielded similar U-Pb results. Selected U-Pb data for zircon from the gneiss lie along a chord that intersects concordia at ages of 302±156 m.y. and 2,383±398 m.y. (Aleinikoff, Dusel-Bacon, and Foster, 1984). The interpretation of the data was similar to the quartzite study above—deposition before mid-Paleozoic time of detrital material from an Early Proterozoic source followed by dynamothermal metamorphism that produced the sillimanite gneiss.

For the examples just discussed, the U-Pb and Sm-Nd data show a similar feature that may characterize the Yukon-Tanana upland in general. This feature is the evidence for a component of detrital material derived from an Early Proterozoic source terrane in the metasedimentary rocks of the upland. Direct evidence of the depositional age of the protolith of the metasedimentary rocks is still lacking, though the protolith may likely be Late Proterozoic in age.

Metavolcanic rocks in the Mount Hayes quadrangle provide the most persuasive evidence for Precambrian rocks in the Yukon-Tanana upland. Uranium-lead analyses of zircon from metarhyodacite yielded ^{207}Pb/^{206}Pb ages of about 2,000 m.y. (Aleinikoff and Nokleberg, 1984). The zircons appear to be igneous, not detrital like the zircons in quartzite discussed from Aleinikoff, Foster, and others (1984). The distribution of Early Proterozoic rocks in the Yukon-Tanana upland and the detailed Precambrian history of the upland remain to be determined.

TERRANES THAT CONTAIN ROCKS OF POSSIBLE PRECAMBRIAN AGE

At least one other region of low- to high-grade metamorphic rocks is considered Precambrian by some workers. However, little compelling stratigraphic evidence for a Precambrian age assignment has been found, and any isotopic evidence for a Precambrian history has been obliterated by tectonomagmatic events during the Mesozoic and Tertiary. The terrane in question is the orthogneiss and paragneiss belt of the Coast Range, southeastern Alaska (fig. 1, pl. 1, K).

SOUTHEASTERN ALASKA (COAST RANGE ORTHOGNEISS AND PARAGNEISS BELT)

The Coast Plutonic complex, which extends the entire length of the Coast Range for a distance of about 1,770 km, underlies much of the eastern part of southeastern Alaska. The complex is mainly composed of foliated and nonfoliated granitoid plutonic rocks but also contains large areas of metamorphic rocks, including quartz-mica-feldspar-hornblende orthogneiss and paragneiss, which have been assigned to the Central Gneiss Complex of the Prince Rupert region in British Columbia, Canada (Hutchinson, 1970). Although the age of at least some of these rocks and their metamorphism could conceivably be Precambrian, evidence in support of this assignment is at best only permissive and is mainly based on relations found in Canada.

In the Tulsequah area of Canada, north and east of Juneau, Alaska, Middle Triassic and older strata were regionally metamorphosed during late Middle Triassic time. The presence of crystalline clasts in the lower part of the Stuhini Group indicates that parts of the Coast crystalline belt and its gneissic components were emergent at the beginning of Late Triassic volcanism in early Karnian time (Souther and Armstrong, 1966; Souther, 1971). Some 300 km to the southeast, relatively unmetamorphosed Permian(?) limestone overlies the Central Gneiss Complex, which suggests that the metamorphic rocks may be of pre-Permian age and that the metamorphism itself may also be pre-Permian (Hutchinson, 1970). The only known isotopic data on postulated Precambrian units in the Central Gneiss Complex are U-Pb ages on zircon from leucogneiss near the eastern margin of the belt in the Prince Rupert–Terrace area, British Columbia. Highly discordant isotopic ratios obtained on two zircon size-fractions lie on a discordia line that projects to an upper concordia intercept of 425 or 700 m.y., depending on the choice of time at which lead is assumed to have been removed from the zircon (that is, 0 or 75 m.y., the average of U-Pb ages obtained on neighboring rocks; Wanless and others, 1975). We question the suggestion of Wanless and others that the occurrence of a "pre-Devonian" and possibly "pre-Ordovician" metamorphic complex on Prince of Wales Island and vicinity in southeastern Alaska is evidence for an early metamorphic event that could be related to the age of gneiss of the Central Gneiss Complex (Hutchinson, 1970, p. 384). Wanless and others (1975) apparently referred to the Wales Group, for which we have seen that good evidence of a Precambrian age exists. However, the Wales Group is part of the Alexander terrane, which is probably allochthonous and may therefore be a totally unrelated assemblage.

Precambrian rocks may possibly occur in orthogneiss and paragneiss of the Central Gneiss Complex, but limiting stratigraphic evidence indicates only that these rocks are pre-Late Triassic or perhaps pre-Permian in age.

SUMMARY AND CONCLUSIONS

Our evaluation of currently available information on the Precambrian of Alaska leads to the conclusion that no Archean (>2,500 m.y.) rocks are present, and it is likely that most of the Precambrian rocks are younger than Late Proterozoic. The oldest known rocks occur in the Kilbuck terrane of southwestern Alaska and the Yukon-Tanana upland of east-central Alaska. In the Kilbuck terrane the protolith of granitic orthogneisses evidently crystallized about 2,050 Ma (Early Proterozoic). Uranium-lead analyses also indicate that these rocks were subjected to amphibolite to granulite facies metamorphism about 1,770 Ma. Field and geophysical evidence indicates that this terrane is rootless and may have moved substantially, but the direction and amount of movement are unknown. Metavolcanic rocks in the Yukon-Tanana upland have zircon $^{207}Pb/^{206}Pb$ ages of about 2,000 m.y. Other rocks in the upland contain inherited zircon that was derived from a slightly older, Early Proterozoic source.

If the correlation of the Tindir Group with parts of the Belt and Purcell Supergroups is correct, it may be inferred that a maximum older limit for the age of the Tindir is about 1,500 m.y.

Metamorphic and (or) plutonic events in the range of 1,000 to 600 Ma have been isotopically documented for gneiss of the Seward Peninsula, the belt of schist that rims the northeastern apex of the Cretaceous Kuskokwim basin in central Alaska, and probably for the schist belt of the southern central and western Brooks Range.

Evidence bearing upon the geologic evolution of Alaska within a framework of global tectonics is accumulating rapidly, but more field data are required before more than general conclusions can be drawn regarding the role of Precambrian lithologic assemblages. It now appears that the only truly autochthonous terranes containing Precambrian rocks are in eastern Alaska (the Tindir Group) and perhaps in the eastern part of the Brooks Range (the Neruokpuk Quartzite and related strata); all the other terranes are considered to some extent allochthonous.

The Tindir Group of east-central Alaska is interpreted as having been deposited near the shelf edge of the North American continental margin in relatively shallow water, perhaps in part under intertidal to subtidal conditions. A westward transition into deeper water, hemipelagic deposits and turbidites is evidenced by an argillite-quartzite sequence of comparable age in the Mount Schwatka-Crazy Mountains region 160–290 km to the west. The presence of *Oldhamia*, a *Nereites* infaunal type of trace fossil, is believed to signify a deep-water, bathyal-abyssal environment (Seilacher, 1964, 1967; Chamberlain, 1971a, b). It has not yet been possible to relate the Neruokpuk Quartzite and underlying units to other sequences of comparable age within the North American craton because the units cannot be traced eastward beyond the British and Barn Mountains of Northwestern Canada. The Precambrian–early Paleozoic sequence in the eastern Brooks Range to which the Neruokpuk Quartzite belongs is possibly part of an ancient borderland terrane similar to that of central and eastern Ellesmere Island in the Canadian Arctic Archipelago.

The Precambrian terranes of the Seward Peninsula and the northeastern Kuskokwim Mountains, as well as the low-grade schist terranes of the southern Brooks Range and the Ruby geanticline, probably were imbricated and shuffled rather than moved great distances, but we lack data bearing on the distances of transport. The striking similarities within the geologic sequences on either side of the Bering Strait suggest that the Seward Peninsula and northeastern Chukotka, U.S.S.R., may have been connected since Precambrian time (Gnibidenko, 1969; Churkin, 1970). The movement and collision of terranes, which probably took place during the Mesozoic era, have markedly degraded the isotopic evidence on the age of Precambrian rocks.

In southeastern Alaska, the Wales Group, of probable Precambrian age occurs in the Alexander terrane, which on the basis of geologic and paleomagnetic evidence did not originate at its present position. Northward movement across latitude lines from a paleoposition of about lat 40° N., long 120° W., during the Mesozoic, and a post-Carboniferous 35° counterclockwise rotation of the terrane (Van der Voo and others, 1978) are favored by existing geologic and paleomagnetic evidence.

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