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STRATIGRAPHY, STRUCTURE, AND PALINSPASTIC SYNTHESIS OF THE WESTERN BROOKS RANGE, NORTHWESTERN ALASKA

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ABSTRACT

This report is an effort to describe and decipher the mid-Paleozoic to Lower Cretaceous stratigraphy and the orogenic evolution of the western Brooks Range. The western Brooks Range primarily is composed of stacks of complexly deformed thrust sheets that contain mostly coeval sequences of rocks with slightly different lithologic facies. In order to simplify the thrust-faulted stratigraphy and palinspastic restoration, the rocks are grouped into eight principal structural levels. The lowest structural level is believed to be autochthonous or parautochthonous and above that, each succeeding level is designated allochthon one through seven. Allochthon seven is composed of the remnants of an extensive ophiolite sheet. Allochthon six is composed of pillow basalt with subordinate intermediate volcanic rocks, chert, and Devonian limestone. It is not certain whether this allochthon was formed in a continental or oceanic setting. Allochthons five through one consist of distinctive and coeval sequences of Devonian to Lower Cretaceous sedimentary rocks that were deposited in a continental setting. The present geographic distribution of each structural level is shown on the allochthon map of the western Brooks Range.

The stratigraphy of the southern part of northern Alaska has been reconstructed by systematically unstacking lower allochthons to the north of higher allochthons. The palinspastic map that results from this procedure shows that the minimum thrust displacement between allochthon seven and the autochthon is approximately 700 to 800 km. Schematic cross sections drawn across the palinspastic map show how the stratigraphy of the southern part of northern Alaska most likely appeared prior to the orogeny. During Devonian and Mississippian time, the sedimentary sequences that are now part of allochthons one to five are inferred to have been deposited in an ensialic basin with both northern and southern margins. During Pennsylvanian time, the sequences seem to have become part of a southward-sloping continental shelf when a southern land area moved away from northern Alaska by an inferred plate tectonic process of rifting or strike-slip motion. In Early Jurassic time just prior to the Brooks Range orogeny, northern Alaska probably was an extensive continental shelf with oceanic conditions to the south and land to the north.

The Brooks Range orogeny seems to have begun in the Middle Jurassic as the Arctic Alaska plate was underthrust (subducted) southward beneath oceanic crust of allochthon seven. At progressively later stages in the underthrusting process, the upper parts of the continental shelf were detached from the subthrust basement on which they were deposited, resulting in the other allochthons of the western Brooks Range. The period of major thrusting ceased by Albian time in the Early Cretaceous. During middle and Late Cretaceous time, epeirogenic uplift in the Brooks Range caused large quantities of clastic detritus to be shed into successor basins to the north and south. Broad folds and reverse faults in Upper Cretaceous sediments north of the Brooks Range provide evidence for a later period(s) of less intense deformation in northern Alaska.

INTRODUCTION

The western Brooks Range is situated at the northwest end of the Cordilleran orogenic belt of North America. Like its counterparts to the south in the Canadian Rockies and the thrust belts of Idaho, Montana, and Wyoming, an important part of the Mesozoic orogeny is characterized by a period of intense compression in which large panels of shelf stratigraphy were thrust onto what had been a stable continental platform. In the Brooks Range, this process also involved the obduction of an extensive sheet of ophiolite and is here viewed as the underthrusting of a continental margin below an oceanic plate to the south. The western part of the Brooks Range provides a particularly good place to study the effects of this process, because erosion has stripped away just enough of the major thrust sheets to permit a comprehensive three dimensional view of the juxtaposed stratigraphy. As such, this region is an excellent place in which to study orogenic processes and to reconstruct a detailed picture of the depositional history of the continental edge prior to the orogeny.

This report describes the stratigraphy and structure of the western Brooks Range. During the orogeny that created the Brooks Range in Jurassic and Cretaceous time, a stable continental shelf that contained Devonian to Early and Middle(?) Jurassic sediments was broken up and telescoped by numerous thrust sheets with a combined displacement measured in hundreds of kilometers. In the first part of this report a tectonostratigraphic scheme is outlined that is an attempt to simplify and catalogue the thrust-faulted stratigraphy. This is followed by a palinspastic synthesis in which the rock units are restored to their original basins of deposition. The report concludes with a plate tectonic model which seems to explain the principal orogenic processes that created the Brooks Range.

The palinspastic synthesis of the western Brooks Range primarily concentrates on a 300 m.y. period from Devonian to Cretaceous time. The geologic history of this period includes the time of deposition of most of the regional sedimentary rocks units that crop out in the north and western parts of the western Brooks Range. In the southeastern part of the western Brooks Range, Precambrian and lower Paleozoic rocks are extensively exposed but much of their geologic history was obscured by a regional metamorphism during the Brooks Range orogeny in Jurassic and Cretaceous time.

The tectonostratigraphic scheme presented in this report is documented by 12,000 km^2 of geologic field mapping at 1:63,360 scale (1 mile = 1 in.) which was completed during the summer months of 1978, 1979, and 1981. This mapping project was an effort to reach a better understanding of the complex structure and stratigraphy of the western Brooks Range in connection with the exploration program of the National Petroleum Reserve in Alaska. The geologic maps from part of this field project are currently available as U. S. Geological Survey Open-File Reports 82-611, 82-612, 82-613, 83-183, 83-184, and 83-185. The remainder of the area that was mapped is currently being prepared for publication. Areas of previous geologic mapping not covered by the new maps have been reinterpreted using the scheme presented in this report.

For the purposes of this report, the western Brooks Range consists of the area bounded on the east by long 156° W. and bounded on the west by the

Chukchi Sea. The area consists mainly of the Howard Pass, Ambler River, Misheguk Mountain, Baird Mountains, De Long Mountains, Noatak, and Pt. Hope, 1:250,000 scale quadrangles (fig. 1). This region has been extended a short distance north and south of the Brooks Range, through the northern foothills and south to the Arctic Circle respectively, to show important geologic details in adjacent provinces that relate to the Brooks Range orogeny.

The present understanding of how the Brooks Range was formed and how the rocks were distributed prior to the orogeny has been built upon numerous geologic studies. Reports that have presented generalized stratigraphic and structural synthesis of this region include those by Tailleur and others (1966), Tailleur and others (1967), Snelson and Tailleur (1968), Tailleur (1969a,b), Tailleur and Brosgé, (1970), Brosgé and Tailleur (1970), Martin (1970), Mayfield and others (1978a), Churkin and others (1979a), Ellersieck and others (1979), and Mull (1979; 1982). Differences in nomenclature and in interpretation between these reports reflect the fact that the stratigraphic and structural synthesis has been, and still is, in a process of evolution. This report confirms, documents, and refines many of the ideas reported earlier, and where possible, the same concepts and terms are used. Details of the stratigraphic sequences and allochthons can be field checked, either using the allochthon-sequence map in this report or the more detailed geologic maps on which the current interpretations are based. Important differences from previous stratigraphic and structural interpretations are discussed under the appropriate subject headings.

GEOLOGIC SETTING

The general geology of the western Brooks Range and adjacent areas can be simplified by dividing this region into four geologic provinces: 1) the Colville basin; 2) the De Long Mountains allochthon belt; 3) the Schwatka Mountains province; and 4) the Yukon-Koyukuk province (fig. 2). The rocks in the provinces have a related geologic history that presents a comprehensive picture of the evolution of the Brooks Range.

The Colville basin, sometimes called Colville geosyncline (Payne, 1955) or the Colville trough, consists of Lower and Upper Cretaceous clastic rocks that form a thick successor basin along the north side of the Brooks Range. The rocks consist predominantly of immature to moderately mature sandstone, mudstone, and conglomerate composed of clastic materials that were shed from the developing Brooks Range orogen. The basin is more than 6.5 km (20,000 feet) thick near the northern edge of the study area and thins gradually to the south where it onlaps Lower Cretaceous and older rocks of the De Long Mountains allochthon belt. Under the Colville basin, there is a succession of gently south-dipping Lower Cretaceous (Neocomian) and older sedimentary rocks whose stratigraphy is inferred from seismic traces that extend to the strata in oil exploration wells located farther to the north. The Permian and Carboniferous stratigraphy under the Colville basin can be correlated by age and lithology to rocks exposed in the Schwatka Mountains province in the southwestern Brooks Range (Mull, 1982).

Important rock units in this part of the Colville basin are the Lower Cretaceous (Albian) Torok and Fortress Mountain Formations that are composed mostly of flyschoid marine turbidites deposited at the close of the major thrusting period in the Brooks Range. These rocks are succeeded by the middle

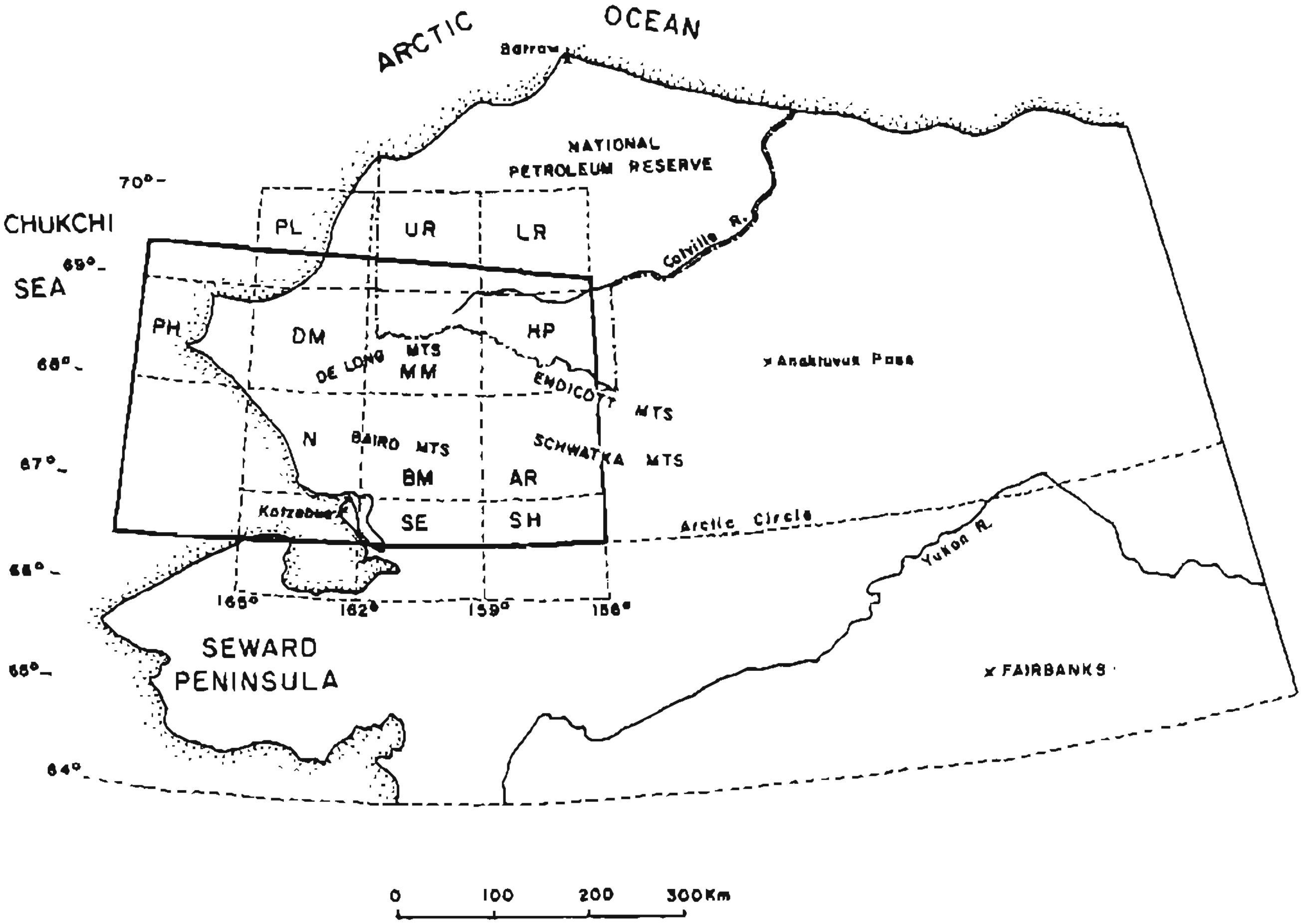

Figure 1. Index map of central and northern Alaska. Bold lines mark boundary of the western Brooks Range as defined in this report. Dashed lines mark boundaries of the following 1:250,000-scale quadrangles: PL = Pt. Lay; UR = Utukok River; LR = Lookout Ridge; PH = Point Hope; DM = De Long Mountains; MM = Misheguk Mountain; HP = Howard Pass; N = Noatak; BM = Baird Mountains; AR = Ambler River; SE = Selawick; SH = Shungnak. Also shown are the principal mountain belts within the western Brooks Range.

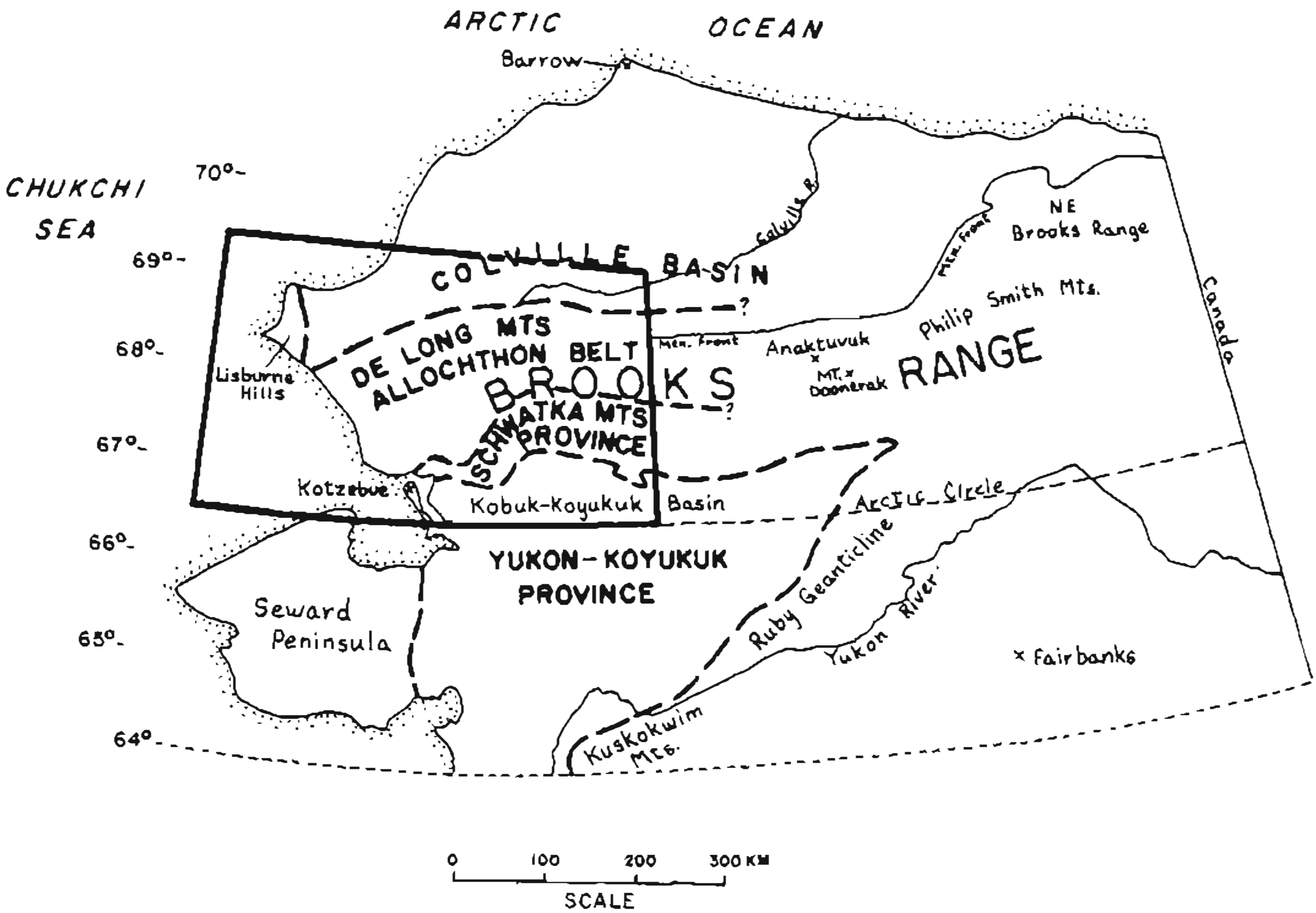

Figure 2. The four principal geologic provinces of the western Brooks Range and selected geographic features. Bold lines mark area of this report. Bold dashed lines mark geologic province boundaries.

and Upper Cretaceous (Albian to Maestrichtian) Nanushuk and Colville Groups that are composed of marine and deltaic sandstone, shale, conglomerate, and coal deposited during the culmination and waning stages of the orogenic uplift.

The rocks of this province have been gently folded into broad anticlines and synclines with fold axes that generally trend westerly. Deformation gradually decreases from south to north in the Colville basin and within the Fortress Mountain and Torok Formations, it decreases from lower to higher in the section. In some places along the southern margin of the province, discussed in a later section of this report, thrust faults and northward overturned folds in the lower strata of the Fortress Mountain and Torok Formations are overlain by gently folded and sparsely faulted strata of the the upper part of the same rocks units. These structural relations show that the period of most intense deformation had ceased before late Fortress Mountain and Torok time.

The De Long Mountains allochthon belt encompasses the Endicott Mountains, De Long Mountains, Lisburne Hills, and northern and western parts of the Baird Mountains (fig. 1). In this region the bedrock is composed of sedimentary and, to a lesser extent, igneous rocks that range in age from Ordovician to Early Cretaceous in the Lisburne Hills (fig. 2) and Devonian to Early Cretaceous in the De Long, Endicott, and Baird Mountains. The rocks occur in a series of stacked thrust sheets that have been gently folded and then eroded to create numerous klippen and fensters. This province is thought to make up a large synclinorium with strata that dip south or southwest along the north front of the De Long and Endicott Mountains and north or northwest along the southern boundary with the Schwatka Mountains province.

While many folds have diverse orientations, most axes in the De Long and Endicott Mountains generally parallel the westerly or southwesterly physiographic trend of the mountain ranges and are thought to be at right angles to the principal thrust direction. Incompetent rocks such as shale and chert have been deformed most intensely, and in some places there are numerous complex disharmonic folds. Anticlinal folds are commonly overturned toward the north in the Endicott Mountains and eastern De Long Mountains and overturned toward the northwest in the western parts of the De Long and Baird Mountains. In the Lisburne Hills, fold axes generally trend north-south and appear to transect the westerly structural trends of the foothills north of the Brooks Range.

The Schwatka Mountains province makes up the bedrock in the southern and eastern part of the Baird Mountains quadrangle and the central part of the Ambler River quadrangle. In general, this province is an internally complex anticlinorium. Its northern edge dips north, under a series of thrust sheets that form the base of the De Long Mountains allochthon belt, and its southern edge dips south under thrust-faulted mafic igneous rocks that are partly covered by mid-Cretaceous clastic rocks. This province is believed to be autochthonous or parautochthonous, because the late Paleozoic metasediments are more closely rooted to the crustal rocks on which they were deposited than are the coeval rocks in the De Long Mountains allochthon belt where the sedimentary and igneous rocks are widely separated from the crust on which they were formed.

The autochthonous or parautochthonous rocks of the Schwatka Mountains province also are considered to be relatively unmoved with respect to rocks in the Colville basin. Upper Paleozoic rocks are interpreted to be linked in the subsurface to the north with coeval and lithologically similar rocks that occur under the Colville basin and have been drilled in oil exploration wells under the North Slope (Mull, 1982).

Most rocks of the Schwatka Mountains province were isoclinally folded and regionally metamorphosed to the greenschist metamorphic facies during Cretaceous time. Consequently, the older part of the sedimentary sequence that makes up the protolith is poorly dated and poorly understood. Based on lithologic correlations and sporadic fossil evidence, the youngest parts of the stratigraphic section in the Schwatka Mountains province are Devonian, Carboniferous, and locally Permian(?) (Mull and Tailleur, 1977; Mayfield and Tailleur, 1978). This makes them partly coeval with the allochthonous sedimentary sequences in the De Long Mountains allochthon belt. Mississippian rocks in this province rest upon Devonian and older rocks with a regional angular unconformity. This is in sharp contrast to all but the lowest allochthonous sedimentary sequences in the allochthon belt, which record relatively unbroken sedimentation from Devonian into Mississippian time. The protolith for the autochthonous pre-Mississippian rocks appears to have been a thick pile of sedimentary and igneous rocks of Early Paleozoic and late Precambrian age.

Within the area covered by this report, the Yukon-Koyukuk province (fig. 2), described in greater detail by Patton (1973), includes the rocks south of the Brooks Range in the Selawik, Shungnak, and southern edge of the Ambler River quadrangles (fig. 1). The bedrock chiefly is composed of orogenic clastic rocks and volcanogenic sedimentary and andesitic volcanic rocks of Cretaceous age. Locally, these rocks are intruded by plutons of Late Cretaceous and earliest Tertiary age.

Immediately south of the Brooks Range, the Yukon-Koyukuk province is underlain by sandstone, conglomerate, coal, and shale that form a basin, called the Kobuk-Koyukuk basin by Patton (1973). Clastic materials were shed into this east-trending trough-like basin from andesitic rocks to the south and from the Brooks Range to the north. Unlike the Colville basin, which preserved the continuous flood of detritus shed from the Brooks Range in Early Cretaceous (late Neocomian) to Tertiary time, most deposition in the Kobuk-Koyukuk basin appears to record a relatively short episode in mid-Cretaceous (Albian and Cenomanian) time (Patton, 1973). In some places along the north margin of the basin, the clastic rocks rest on south-dipping, thin, and discontinuous thrust sheets of mafic and ultramafic rocks which are thought to be the root zone for similar igneous rocks in the De Long Mountains allochthon belt (Tailleur, 1969a,b; Patton and others, 1977; Roeder and Mull, 1978; Gealey, 1980). In other places, the Cretaceous rocks onlap low-grade metamorphosed Devonian limestone and pelitic schist that are part of the Schwatka Mountains province.

South of the Kobuk-Koyukuk basin is an extensive area of slightly older andesitic volcanic rocks which probably underlie most of the sedimentary rocks in the Yukon-Koyukuk province. The volcanic assemblage is composed predominantly of volcaniclastic rocks, flows, and hypabyssal intrusives. Fossils from volcaniclastic beds are Early Cretaceous (Neocomian) and potassium-argon ages from andesitic volcanic rocks range from 134 to 117 m.y. Some tuff beds are considered to be mid-Cretaceous in age. Late Cretaceous granitic plutons with potassium-argon ages of approximately 100 to 80 m.y. intrude the older rocks in the province. Local felsic extrusive, tuffaceous, and hypabyssal rocks that are probably related to the plutonic activity have Late Cretaceous to Early Tertiary potassium-argon ages that range from 85 to 58 m.y. (Patton, 1973).

DEFINITIONS OF SEQUENCES AND ALLOCHTHONS

The hundreds of thrust sheets that exist in the De Long Mountains allochthon belt and the Schwatka Mountains province contain parts of structurally overlapping sequences that are composed of sedimentary, metasedimentary, and (or) igneous rocks. On the allochthon map (plate 1), there are 15 sedimentary and two igneous sequences named in the De Long Mountains allochthon belt. All the rocks in the Schwatka Mountains province have been assigned to one sequence. Sedimentary sequences are mostly coeval. They are characterized by having a distinctive column of sedimentary rocks that have slightly different lithologic facies compared to coeval rocks of other sequences. The rocks of each sequence are believed to have been deposited contiguously. The interpretation of depositional contiguity is based on similarity of stratigraphic sections, present geographic proximity of outcrops, and a regional occurrence at the same structural level. Igneous sequences are predominantly composed of distinctive igneous rocks that have wide geographic extent.

Sequences are differentiated by lithologic differences in certain coeval rock units. Both of the igneous sequences and a few of the sedimentary sequences have certain unique rock units which serve to easily distinguish them from all other sequences. The other sedimentary sequences do not have a single unique rock unit and must be distinguished by differences in the succession of several rock units. Sediments deposited during Late Mississippian time have the greatest variety of lithologies and so are most useful for distinguishing among the various sedimentary sequences. Where Mississippian rocks that occur in different sequences have similar lithologies, differences in sequences most commonly are determined by comparison of their Upper Devonian rocks. Pennsylvanian to Early Cretaceous rocks are more similar so they have been used only sparingly to help differentiate certain sequences.

In the De Long Mountains allochthon belt, thrust sheets with the same or similar sequences almost always occur at the same structural levels. The smallest division of a structural level is a thrust sheet, but because there are hundreds of thrust sheets, often poorly exposed, it is prohibitively complex to describe each of them. Therefore, in order to provide a simple structural scheme for this large region, multiple thrust sheets that contain similar sequences and occur at approximately the same structural level are grouped into seven structural units called "allochthons". Allochthons are sequentially numbered with allochthon number one, the Brooks Range allochthon, at the bottom of the stack and allochthon number seven, the Misheguk Mountain allochthon, at the top. Autochthonous or parautochthonous metasedimentary rocks in the Schwatka Mountains province are not numbered.

Many previous studies which recognized major structural dislocations in the western Brooks Range did not distinguish between the structural units and the sedimentary sequences within them, but used the same names for both. Most of these names correspond to the structural units that are here called allochthons. Mapping over a large area, however, shows that there are significant stratigraphic changes from place to place within most of the allochthons. The facies differences within allochthons generally are not as pronounced as the facies differences between different allochthons. Thus, the allochthons also can be used as generalized tectonostratigraphic units. This simplification may be useful in correlations across hundreds of kilometers, or for mapping at regional scales.

The scheme of seven allochthons in this report provides for simplicity when structural units are unstacked on a palinspastic map. The designation of 18 sedimentary and igneous sequences emphasizes facies changes between and within allochthons. The distinction of minor differences in sequences, permits a more accurate view of the limits that can be placed on structural interpretations as well as a more complete palinspastic view of the original basins of deposition of the rock units.

It is likely that detailed study of some areas will provide data for further division of some of the sequences used in this report. There is commonly some degree of facies change between some of the coeval rocks in any two thrust sheets, or even within the same sheet. Different observers might decide to define their sequences in different ways, because of differences between the areas where they have worked, or because they may base their interpretations on different units within the sequences. Undoubtedly the system presented here will undergo some expansion and the units will undergo subdivision, as more regional and detailed studies are done.

SUCCESSION OF ALLOCHTHONS COMPARED TO EQUIVALENT STRUCTURAL UNITS OF PREVIOUS STUDIES

From the bottom to the top, the stack of allochthons that are differentiated in the De Long Mountains allochthon belt are: 1) the Brooks Range allochthon; 2) the Picnic Creek allochthon; 3) the Kelly River allochthon; 4) the Ipnavik River allochthon; 5) the Nuka Ridge allochthon; 6) the Copter Peak allochthon; and 7) the Misheguk Mountain allochthon. The first five allochthons are composed mostly of coeval sedimentary sequences. The base of the sequences are as old as Ordovician, Devonian, or Mississippian, and the top of each sequence is Early Cretaceous in age. The top two allochthons are composed of distinctive igneous sequences that are Triassic and (or) Jurassic in age. Each allochthon is named after a prominent geographic feature where the structural position of one or more sequences in the allochthon is well exposed. Allochthon names are taken from previous publications. Because other authors commonly have used different names for equivalent structural units, table 1 is included to correlate the presently used structural nomenclature with those of previous reports.

The process of naming and mapping sequences and structural units in the western Brooks Range began with the publication of geologic maps from the northern part of the Howard Pass and Misheguk Mountain quadrangles by Tailleur and others (1966). That report represents the first significant step toward understanding and mapping the distribution of thrust-juxtaposed sequences. By

Table 1.--Comparison of allochthons in this report with equivalent structural units of other authors

This report	Curtis and others, 1982;'83 Ellersieck and others, 1982;'83 Mayfield and others, 1982a;'83	Mull, 1982	Ellersieck and others, 1979	Mull, 1979	Churkin and others, 1979a; Churkin and Trexler, 1981	Mayfield and others, 1978a	Martin, 1970	Snelson and Tailleur, 1968; Tailleur, and Brosge 1970	Tailleur and others, 1966
Misheguk Mountain allochthon	Misheguk Mountain allochthon	Misheguk Mountain allochthon	Misheguk Mountain thrust sequence	Misheguk sequence	Not distinguished	Misheguk Mountain thrust sequence	Ultrabasic pluton sequence	Misheguk thrust tectonic unit	Not distinguished
Copter Peak allochthon	Copter Peak allochthon	Copter Peak allochthon	Copter Peak thrust sequence	Misheguk sequence	Not distinguished	Misheguk Mountain thrust sequence	Ultrabasic pluton sequence	Misheguk thrust tectonic unit	Not distinguished
Nuka Ridge allochthon	Nuka Ridge allochthon	Nuka Ridge allochthon	Nuka Ridge thrust sequence	Nuka sequence	Not distinguished	Nuka Ridge thrust sequence	Nuka Ridge sequence	Nuka Ridge thrust tectonic unit	Nuka Ridge sequence
Ipnavik River allochthon	Ipnavik River allochthon	Ipnavik River allochthon	Ipnavik River thrust sequence	Ipnavik sequence	Not distinguished	Ipnavik River thrust sequence	Ipnavik sequence	Ipnavik thrust tectonic unit	Ipnavik sequence
Kelly River allochthon	Kelly River allochthon	Kelly River allocthon	Kelly River thrust sequence	Kelly sequence	Not distinguished	Kelly River thrust sequence	De Long sequence	Kelly thrust tectonic unit	Not distinguished
Picnic Creek allochthon	Picnic Creek allochthon	Not distinguished	Picnic Creek thrust sequence	Not distinguished	Not distinguished	Northwestern Brooks Range thrust sequences	Not distinguished	Wulik thrust tectonic unit	Sequence at Kiligwa River
Brooks Range allochthon	Brooks Range allochthon	Endicott Mountains allochthon	Brooks Range thrust sequence	Endicott sequence	Kagvik structural sequence	Northwestern Brooks Range thrust sequences North Central Brooks Range thrust sequence	Brooks Range sequence Ivotuk Hills sequence	Foothills thrust tectonic unit	Foothills sequence Assemblages on Drenchwater Creek Sequence at Mount Bupto

1970, six out of the seven presently distinguished structural units (equivalent to the allochthons of present usage) had been published in one or more of several reports on the regional geology. These were by Tailleur and others (1967); Snelson and Tailleur (1968); Tailleur (1969a,b); Tailleur and Brosgé (1970); and Martin (1970). When these reports were published most of the allochthons were named even though different names were sometimes given to equivalent structural units.

In these earlier reports, the structural position of the Nuka Ridge allochthon was one of the least understood aspects of the tectonostratigraphic relations. For example, Tailleur and others (1966) thought the Nuka Ridge allochthon was on top of the Ipnavik and Brooks Range allochthons. However, a few years later Tailleur (1969a,b) and Tailleur and Brosgé (1970) reported that the Nuka Ridge allochthon was either on the top or on the bottom of the stack of allochthons. Martin (1970) thought it was near the bottom of the stack, and mapped it over a wide area, much of which is presently known to be parts of the Brooks Range or Picnic Creek allochthons. Part of the problem in understanding this allochthon was due to poorly dated stratigraphy and misinterpretation of the structural positions of isolated tectonic blocks of the Nuka Formation which are widely scattered in areas of low relief and poor exposure in the foothills north of the Brooks Range. The Nuka Ridge allochthon is presently considered to be the fifth allochthon in the stack of seven on the basis of detailed mapping in the mountainous areas where structural relationships are well exposed (Ellersieck and others, 1979; Mull, 1979; Curtis and others, 1982; Ellersieck and others, 1982; and Mayfield and others, 1982a). It is structurally the highest allochthon of those that contain the sedimentary sequences.

Evidence for the allochthoneity of the Brooks Range allochthon relative to the Schwatka Mountains province was not published until the latter half of the 1970's by Mull and others (1976); Dutro and others (1976); and Mull and Tailleur (1977). These reports contain descriptions of the late Paleozoic part of the sequence of rocks in the Schwatka Mountains province. Subsequent maps of the Baird and Schwatka Mountains (Mayfield and Tailleur, 1978; Nelson and Grybeck, 1980; and Turner and others, 1978) show the general distribution of the northern part of the Schwatka sequence based on the location of outcrops of the Mississippian to Permian Kekiktuk Conglomerate, Kayak Shale, Lisburne Group, and Sadlerochit Group.

DESCRIPTION OF ALLOCHTHONS AND SEQUENCES

In order to understand the evidence for the palinspastic synthesis and tectonic implications given in a later section of this report, it is necessary to become familiar with the stratigraphic and structural subdivisions in the western Brooks Range. This section gives a brief description of each of the 18 sequences and seven allochthons (plate 1) that are differentiated in this report. The discussion begins with a description of the autochthonous or parautochthonous Schwatka sequence and progresses to descriptions of the allochthons and the sequences of rocks that occur in each allochthon. A generalized stratigraphic column (figs. 3 to 21 on plate 2) is given for each sequence along with highlights of the most distinctive characteristics and areas of most complete exposure of the sequences and allochthons. Because of complex structural deformation and of sparse paleontologic dates, the original depositional thicknesses and age ranges for the various rock units are approximated in many cases.

THE SCHWATKA SEQUENCE

The late Paleozoic and older parts of the Schwatka sequence (fig. 3, plate 2) are exposed in the area of the southern Brooks Range here called the Schwatka Mountains province. This is the least understood sequence in the western Brooks Range, because it was regionally metamorphosed during the Cretaceous (Turner and others, 1978; Turner and others, 1979; Dillon and others, 1980) and, in some areas, in the Precambrian (Turner and others, 1979; Mayfield and others, 1982b). The protolith is believed to range in age from Precambrian to Mississippian or Permian? (Mull and Tailleur, 1977). The sequence probably consists of hundreds, or even thousands, of meters of lower Paleozoic and Precambrian metasedimentary rocks. Because the older rocks of the protolith for the Schwatka sequence are largely undated and their structure is complex, the stratigraphic column is partly speculative and is composed of a composite of sparsely-dated rock units from a wide geographic area.

Upper Paleozoic rocks, mostly of Mississippian age, make up less than two percent of the geographic area of this province. They are mapped in a discontinuous narrow belt of outcrops that extends from east and north of Shishakshinovik Pass to Nanielik Creek near Hub Mountain (plate 1; Pessel and Brosgè, 1977; Tailleur and others, 1977; Mull and Tailleur, 1977; Mayfield and Tailleur, 1978). In the Schwatka Mountains, this succession of metasediments consists of Upper Mississippian carbonate rocks of the Lisburne Group underlain by the mid-Mississippian Kayak Shale and Lower Mississippian Kekiktuk conglomerate. The conglomerate unconformably overlies older metamorphic rocks. In the vicinity of Shishakshinovik Pass, siltstone and slate appear to lie stratigraphically on the Lisburne and may correlate with the Permian part of the Sadlerochit Group (Mull and Tailleur, 1977). The same stratigraphic sequence also occurs at Mount Doonerak (fig. 2) in the central Brooks Range (Dutro and others, 1976).

Upper Paleozoic strata in the Schwatka sequence are believed to correlate with autochthonous rocks under the Colville basin. Oil exploration wells show that the foundation for the north part of the Colville basin has deformed Devonian and older sedimentary rocks and granite unconformably overlain by the Mississippian to Lower Cretaceous Kekiktuk Conglomerate, Kayak Shale, Lisburne Group, Sadlerochit Group, Shublik Formation, Kingak Shale, and "pebble shale". Seismic profiles in the National Petroleum Reserve (Bruynzeal and others, 1982) show that these strata extend southward from the wells to at least the latitude of the Colville River where they lie beneath five to seven km of mid-Cretaceous basin fill and dip gently south. Similar Mississippian to Permian(?) strata reappear in the Schwatka and Baird Mountains (Mull and Tailleur, 1977) and similar Mississippian to Triassic strata reappear in the southern Endicott Mountains (Dutro and others, 1976). Intense deformation of Cretaceous sediments south of the Colville River makes seismic records nearly uninterpretable, but gently south dipping seismic reflectors at inferred depths of approximately seven to ten km under the mountain fronts of the De Long and Endicott Mountains probably represent continuity between autochthonous rocks to the north and those in the Schwatka sequence to the south. A representative section of rocks under the Colville basin is shown on figure 4 (plate 2).

Below the Kekiktuk angular unconformity in the southern Brooks Range is a poorly understood succession of intensely deformed lithologic units including marble, phyllite, calcareous schist, metawacke, quartz-mica schist, greenstone, and gneissic granitic rocks. Most of the thick and wide-spread metamorphosed limestone and dolomite is correlative with the Silurian and Middle Devonian Skajit Limestone. In a few places, slate and marble of Ordovician and Silurian age also have been dated by fossils (U.S. Geological Survey, 1975; Mayfield and Tailleur, 1978; Mayfield and others, 1983b). Most other rocks in this sequence are too recrystallized to preserve identifiable fossils, although correlation of certain of these lithologies to the widely spaced areas that have fossil control or radiogenic ages suggest that most of the protolith ranges in age from early Paleozoic into the Precambrian.

The stratigraphy of the Schwatka sequence differs in a few important respects from the allochthonous sequences structurally above it. The predominantly shaly Permian to Triassic Sadlerochit Group and, at Mount Doonerak in the central Brooks Range, the Shublik Formation occur only in this sequence. These units are lithologically distinct from and the same age as the predominantly cherty Etivluk Group in the allochthonous sequences. The pre-Mississippian angular unconformity under the Kekiktuk Conglomerate is in contrast to a continuous succession of Devonian through Mississippian rocks in all the allochthonous sedimentary sequences except for the sequence of rocks in the Lisburne Hills. In the Lisburne Hills, there is a pre-Mississippian unconformity similar to the Schwatka sequence, but post-Mississippian rocks are much more like those in other allochthonous sequences.

THE BROOKS RANGE ALLOCHTHON (1)

The Brooks Range allochthon is the most extensively exposed and the lowest in the stack of allochthons in the western Brooks Range (plate 1). It was named by Martin (1970), who called it the Brooks Range sequence because of its widespread occurrence throughout the north and western parts of the Brooks Range. It is widely exposed in the Lisburne Hills, Mulgrave Hills, Endicott Mountains, north and western parts of the Baird Mountains, and in numerous fensters in the De Long Mountains. This is the only allochthon in the western Brooks Range that has a nearly continuous outcrop area extending from the Chukchi Sea in the west to the Philip Smith Mountains in the eastern Brooks Range. The total outcrop area makes up a third to a quarter of all the exposures in the Brooks Range. The estimated aggregate thickness of the thrust sheets in this allochthon, measured approximately normal to the upper and lower fault surfaces, may total five to ten km in the foothills and under the De Long and Endicott Mountains.

Sequences in the Brooks Range allochthon have certain characteristics which can be used to distinguish them from sequences in other allochthons. This allochthon contains the thickest and most widespread occurrences of Upper Devonian and Lower Mississippian sandstone, shale, and conglomerate of the Endicott Group. The Etivluk Group is generally shalier and less cherty and Upper Triassic rocks have a greater proportion of limestone than in other allochthonous sequences.

There are three sequences in the Brooks Range allochthon called the Ivotuk, Key Creek, and Lisburne Hills sequences. They are grouped into the same allochthon because they have important lithologic similarities and occur at approximately the same structural level. In the foothills north of the

Endicott Mountains, the Ivotuk sequence occurs in a series of thrust sheets that are structurally below the Key Creek sequence. West of long 158° W., the distinctive Mississippian carbonate rocks in the Ivotuk sequence appear to grade into lithologies characteristic of the Key Creek sequence. The Lisburne Hills sequence only occurs in exposures on the Lisburne Peninsula. It is thought to be structurally below the Key Creek sequence, but the sequences are separated by a belt of Cretaceous orogenic clastic rocks that make direct structural relations uncertain.

The Ivotuk Sequence

The Ivotuk sequence (fig. 5, plate 2) was named and described by Martin (1970) for exposures at Ivotuk Ridge in the Killik River quadrangle east of the area of this report. Outcrops occur in a relatively limited geographic location in the foothills north of the Endicott Mountains. Best exposures occur at Lisburne Ridge and at Mount Bupto in the Howard Pass quadrangle (plate 1). This sequence is composed of Mississippian to Lower Cretaceous sedimentary rocks. Pre-Cretaceous rocks are approximately 600 m thick.

The Ivotuk sequence is distinguished from the Key Creek sequence by differences between the Upper Mississippian rocks in each sequence. In the Ivotuk sequence, a relatively thin black carbonaceous shaly Kuna Formation overlies several hundred meters of light gray-weathering dolomite and limestone with black chert nodules and lenses. The upper part of the Mississippian strata contains a phosphatic zone which is believed to be correlative with phosphatic beds in the upper part of the Alapah Limestone in the foothills and mountains of the north-central Brooks Range (Patton and Matzko, 1959) and with phosphatic shale in the Kuna Formation of the Key Creek sequence.

Rocks older than the Lower Mississippian Kayak Shale have not been identified and must have been structurally detached from most of the Ivotuk sequence. Like the other sequences in allochthon one, the Ivotuk sequence probably was deposited upon Lower Mississippian and possibly Upper Devonian sandstone of the Endicott Group. In the Lisburne Well which was drilled to a depth of 17,000 feet in the southern part of the National Petroleum Reserve, at least five partly repeated sections (Mickey, 1980) of the Ivotuk sequence were encountered but no coarse clastic rocks of the Endicott Group were found. The older rocks on which the Ivotuk sequence was deposited may have been the northern part of the thick clastic wedge of Late Devonian and Early Mississippian age, similar to the Key Creek sequence, or they may have been paralic coaly sandstone and shale on a pre-Mississippian unconformity, similar to the Lisburne Hills sequence.

The Key Creek Sequence

The Key Creek sequence (fig. 6, plate 2) was named by Curtis and others (1982) for exposures at Key Creek in the De Long Mountains A1 quadrangle (Curtis and others, 1983). This sequence is the most extensively exposed sequence in the western Brooks Range. It crops out from the southwestern edge of the Mulgrave Hills at the sea coast in the Noatak quadrangle to the Endicott Mountains in the Howard Pass quadrangle. There are numerous places where parts of this sequence are well exposed, but there appears to be no place where there is a complete unbroken succession of strata. The Mississippian to Cretaceous part of the section is well exposed at Key Creek. The Late Devonian to Mississippian part of the section is well exposed along the northern mountain front of the Endicott Mountains. The lower part of this sequence is exposed along the north and west edge of the Baird and Schwatka Mountains. Pre-Cretaceous rocks are approximately 1,900 m thick.

The Key Creek sequence differs from the other two sequences in allochthon one, the Ivotuk and Lisburne Hills sequences, by having a thick section of widely exposed black shale and chert of the Kuna Formation of Late Mississippian and Early Pennsylvanian age (Mull and others, 1982) which overlies a thin (less than 20 m) and discontinuous light gray-weathering limestone with black chert nodules. The Pre-Mississippian part of Key Creek sequence differs from all other sequences in the western Brooks Range, because it is composed of a 1,000-m thick clastic wedge of Late Devonian and Early Mississippian age called the Endicott Group (Tailleur and others, 1967; Nilsen, 1981).

The Lisburne Hills Sequence

The Lisburne Hills sequence (fig. 7, plate 2) is named for exposures along the seacliffs in the southern part of the Lisburne Hills (plate 1) which were described by Campbell (1967). Exposures are confined to the Lisburne Hills. The base of the exposed section is Ordovician (U. S. Geological Survey, 1972; Grantz and others, 1983), and the top is Early Cretaceous. The composite depositional thickness is more than 2,700 m.

Because the Lisburne Hills sequence does not have any exposed contacts with the other sequences in the western Brooks Range, its structural and stratigraphic position is uncertain. It is assigned to allochthon one, because Carboniferous and younger rocks are similar to other sequences in this allochthon and the stratigraphy records the same Neocomian tectonic history during the Brooks Range orogeny.

In the past, this sequence has been correlated with allochthon three, primarily because the Upper Mississippian carbonate beds in the Lisburne Hills and De Long Mountains are similar in lithology and thickness (Tailleur, 1969a,b; Mull, 1979). Although the Upper Mississippian dolomitic carbonate rocks, mapped as the Kogruk(?) Formation by Campbell (1967), are similar in thickness to the Kogruk Formation in the sequences of allochthon three, the overall Mississippian to Lower Cretaceous stratigraphic section is also similar to coeval beds in sequences of allochthon one. For example, the upper part of the Triassic and Jurassic Otuk Formation in the Lisburne Hills has numerous distinctive limestone beds, and its general lithologic character is more similar to correlative beds in the Key Creek and Ivotuk sequences than to any of the sequences in allochthon three. The Siksikpuk Formation and the lower part of the Otuk Formation are shalier in the Lisburne Hills sequence than they are in correlative beds in sequences of allochthon three. These shaly beds are quite similar to coeval beds in the Ivotuk and Key Creek sequences. The Upper Mississippian dolomitic carbonate beds in the Lisburne Hills are thicker, but lithologically similar to correlative beds in the Ivotuk sequence. Outside the Lisburne Hills, coal beds of similar stratigraphic setting are known only to occur in a few places in the lower sandy part of the Kayak Shale in the Key Creek sequence and in autochthonous rocks under the Colville basin.

Lower Mississippian rocks in the Lisburne Hills rest unconformably on black, graptolitic Ordovician and Silurian wacke and shale (Grantz and others, 1983). This is similar to the stratigraphic relationships at the basal Mississippian unconformity in the Schwatka sequence and in the succession of Neocomian and older rocks under the northern part of the Colville basin. However, in the Lisburne Hills sequence rocks of Pennsylvanian to Early Cretaceous age are markedly different in lithology from coeval rocks under the Colville basin and from suspected Permian rocks in the Schwatka sequence (compare figs. 3, 4, and 7).

Thus, the pre-Mississippian stratigraphy of the Lisburne Hills is similar to the sequences in the Schwatka Mountains and under the Colville basin, and the Pennsylvanian to Lower Cretaceous stratigraphy is similar to sequences in allochthon one. On the basis of these stratigraphic relationships, it is here inferred that before the Brooks Range orogeny the Lisburne Hills sequence was in the northern part of the region occupied by the sequences in allochthon one and south of the Schwatka sequence. For structural simplicity, the Lisburne Hills sequence and other exposures of allochthonous rocks with no sequence designation in the foothills north of the De Long Mountains (plate 1) are included as part of allochthon one.

PICNIC CREEK ALLOCHTHON (2)

The Picnic Creek allochthon is the second allochthonous structural level in the western Brooks Range. It was named by Ellersieck and others (1979) for exposures in the Picnic Creek fenster in the Misheguk Mountain quadrangle (Mayfield and others, 1982a). The sequences in this allochthon are exposed from the hills southeast of Cape Seppings to the foothills along the north margin of the Endicott Mountains. The Picnic Creek allochthon occurs discontinuously between allochthon one and three or four. Best exposures of the structural relationship to allochthons one and three are found in the mountains drained by the Wulik River, north of the Avan Hills along the Kuruk Creek valley, in the Picnic Creek fenster, and in the Cutaway fenster (plate 1). This allochthon probably does not exceed 1000 m in thickness, and in most areas it is less than 500 m thick.

Sequences in the Picnic Creek allochthon are lithologically distinguished from most other sequences by having a section of well-bedded black chert with subordinate fine-grained carbonate of Late Mississippian age. In sequences of allochthon four, coeval sedimentary rocks are lithologically similar but contain locally abundant diabase sills. In allochthon two Mississippian rocks appear to be deposited upon Upper Devonian and (or) lowest Mississippian sandy rocks of the Endicott Group. In one sequence of allochthon two, these sandy beds interfinger with latest Devonian (Famennian) carbonate beds that are here correlated by age and lithology with the Baird Group. This contrasts with allochthon four in which Mississipian rocks appear to have been deposited only upon Middle and Upper Devonian carbonate rocks of the Baird Group.

Four sequences in the Picnic Creek allochthon are differentiated in this report. They are distributed in a east-trending series of outcrops from the foothills of the Endicott Mountains through the De Long Mountains and are called, from west to east: the Amaruk sequence, Wulik sequence, Picnic sequence, and Nigu sequence. The sequences are mostly found in adjacent geographic areas and each is believed to have been deposited contiguously. Border areas between these sequences either have gradational lithologies or are believed to be separated by thrust faults with relatively minor displacements.

The Amaruk Sequence

The Amaruk sequence (fig. 8, plate 2) was named by Mayfield and others (1983a) for exposures at the headwaters of the Amaruk River in the De Long Mountains quadrangle. This sequence extends from the western De Long Mountains to the hills southeast of Cape Seppings. Best exposures are found along the northeast and northwest margins of the Wulik Peaks (plate 1). This sequence is composed of Upper Devonian or Lower Mississippian to Lower Cretaceous sedimentary rocks. Pre-Cretaceous rocks are approximately 350 m thick.

The Amaruk sequence occurs structurally below the Kelly sequence of allochthon three and above the Key Creek sequence of allochthon one. Upper Mississippian rocks are distinguished from bordering sequences in structurally higher and lower allochthons by being composed predominantly of black chert.

Within the Picnic Creek allochthon, the Amaruk sequence grades eastward into the Wulik sequence. Unlike the Wulik sequence, the Amaruk sequence contains only a few shaly rocks that correlate with the Kuna Formation and only a small amount of noncherty micritic limestone. The oldest rocks in the Amaruk sequence are best exposed in the hills southeast of Cape Seppings where the Kayak Shale grades downward into increasingly sandier beds that are poorly exposed and imprecisely dated by stratigraphic correlation as Late Devonian and (or) Early Mississippian in age. These beds are stratigraphically correlated with the Noatak Sandstone or the sandstone member of the Kayak Shale and are similar to coeval clastic beds at the base of the Wulik and Nigu sequences.

The Wulik Sequence

The Wulik sequence (Fig. 9, plate 2) was named by Snelson and Tailleur (1968) for exposures in the Wulik River area of the De Long Mountains quadrangle. Discontinuous exposures occur throughout the De Long Mountains and in the foothills north of the range. Best exposures are in the Wulik knot on the south side of Inaccessible Ridge and in the Kuruk Creek valley about 4 km north of the Avan Hills (plate 1). This sequence is composed of Upper Devonian to Lower Cretaceous sedimentary rocks. Pre-Cretaceous rocks are approximately 400 m thick.

The Wulik sequence is structurally overlain by the Amphitheatre and Kelly sequences of allochthon three and is underlain by the Key Creek sequence of allochthon one. It is best distinguished by having a relatively thick section of Upper Mississippian black chert or black chert and limestone. This contrasts with coeval limestone of the Kogruk Formation in sequences of allochthon three and black carbonaceous shale and chert of the Kuna Formation in the Key Creek sequence. Upper Devonian (Famennian) rocks in this sequence are exposed only in Kuruk Creek valley. Here, limestone, correlated with the Baird Group, and sandstone and shale, correlated with the Endicott Group, are interbedded. This contrasts with Upper Devonian rocks in the overlying sequences in allochthon three that are mostly carbonate of the Baird Group, and Upper Devonian rocks in the underlying Key Creek sequence of allochthon one that are entirely sandstone and shale of the Endicott Group.

Within the Picnic Creek allochthon, the Wulik sequence grades east and west into the Picnic and Amaruk sequences. It is distinguished from them by having a persistent micritic limestone unit beneath Upper Mississippian black chert. In the De Long Mountains quadrangle, the Wulik sequence appears to crop out in the foothills north of the Amaruk sequence which suggests that part of the Wulik sequence occurs in structurally lower thrust sheets. North of Inaccessible Ridge, Upper Mississippian rocks of this sequence have more shale and less limestone, similar to the lithologies in the Key Creek sequence (Curtis and others, 1983).

The Picnic Sequence

The Picnic sequence (fig. 10, plate 2) was named by Ellersieck and others (1979) for exposures in the Picnic Creek fenster in the Misheguk Mountain quadrangle. This sequence is exposed throughout the eastern De Long Mountains in an outcrop belt that extends from the Kuna River in the Howard Pass quadrangle west to the headwaters of the Kugururok and Utukok Rivers in the Misheguk Mountain quadrangle. Best exposures of this sequence occur in the Cutaway fenster, on the north side of the Picnic fenster, and southeast of the Drenchwater fenster (plate 1). The base of the sequence is Early Mississippian in age and the top is Early Cretaceous. Pre-Cretaceous rocks are approximately 270 m thick.

The Picnic sequence structurally overlies the Key Creek sequence and, in most places, is overlain by discontinuous thrust slices of the Kelly sequence of allochthon three or the Ipnavik and Nachralik Pass sequences of allochthon four. Upper Mississippian rocks are mostly well-bedded black chert in contrast to coeval rocks in the Kelly and Key Creek sequences. Sedimentary rocks in the Picnic, Nachralik Pass, and Ipnavik sequences are lithologically similar. Mafic igneous rocks are common in the Ipnavik sequence and uncommon in the Nachralik Pass, and Picnic sequences. In general, the Picnic sequence contains less limestone in the Lisburne Group and a smaller percentage of maroon chert in the Etivluk Group in comparison to the Nachralik Pass and Ipnavik sequences.

Within the Picnic Creek allochthon, the Picnic sequence grades east and west into the Nigu and Wulik sequences respectively. In the foothills of the northwestern De Long Mountains, the Picnic sequence appears to grade westward into the Wulik sequence. The Picnic sequence is distinguished from the Wulik sequence by having more chert and less limestone in the Lisburne Group.

The Nigu Sequence

The Nigu sequence (fig. 11, plate 2) is named for exposures at Nigu Bluff in the foothills north of the Endicott Mountains which were described by Murchey and others (1981). The outcrop area of this sequence is confined to the low rolling hills with rubble slopes in the foothills north of the Endicott Mountains. Best exposures occur along stream cuts; the most prominent is the one at Nigu Bluff (plate 1). The base of the sequence is Late Devonian or Early Mississippian in age and the top is Early Cretaceous. Pre-Cretaceous rocks are approximately 220 m thick based on isolated exposures of different parts of the section.

The Nigu sequence lies structurally above the Ivotuk and Key Creek sequences of allochthon one and below the Ipnavik sequence of allochthon four. Sequences in allochthon three do not occur as far east as the outcrop belt of the Nigu sequence. The Nigu sequence is distinguished from the Key Creek and Ivotuk sequences by having Upper Mississippian well-bedded black chert overlying a thin micritic limestone unit. The cherty part of the section is similar to coeval rocks in the Ipnavik sequence except that cherts in the Ipnavik sequence have numerous brown-weathering diabase sills.

Within the Picnic Creek allochthon, the Nigu sequence appears to grade westward into the Picnic sequence. In contrast to the Picnic sequence, the Nigu sequence contains mid-Mississippian fine-grained limestone that is overlain by dark-gray and black chert. On the allochthon map, an arbitrary boundary between the Nigu and Picnic sequences was chosen in the area of discontinuous exposures between the Ipnavik and Etivluk Rivers.

KELLY RIVER ALLOCHTHON (3)

The Kelly River allochthon is the third allochthonous structural level in the western Brooks Range. It was named the Kelly tectonic unit by Snelson and Tailleur (1968) for excellent exposures of this allochthon in the mountains at the head of the Kelly River in the De Long Mountains quadrangle. The sequences which compose this allochthon are well exposed throughout the De Long Mountains and in a southwest-trending belt in the western Baird Mountains. The greatest aggregate thickness of thrust sheets is probably more than 2 km in the Wulik Peaks (plate 1), and in the hills southeast of Cape Seppings. East of Misheguk Mountain, this allochthon becomes much thinner and more discontinuous. In the Nimiuktuk River drainage and the Picnic Creek fenster, it is probably no more than 200 m thick. East of long 159^{o} W., it is not present except for possibly a few thin thrust slivers of Devonian and Mississippian carbonate rocks at the south margin of the Drenchwater fenster and on the north side of the Pupik Hills (plate 1).

Except for two sequences in allochthon one, the sequences in allochthon three are distinguished from sequences in other allochthons of the western Brooks Range in that they contain a thick section of Upper Mississippian bioclastic limestone, called the Kogruk Formation. The Lisburne Hills and Ivotuk sequences of allochthon one also have similar Upper Mississippian carbonate sections. In sequences of the Kelly River allochthon, the Etivluk Group has a higher proportion of chert and less Triassic limestone than in either the Lisburne Hills or Ivotuk sequences. Also, the Ipewik Formation has not been recognized from sequences in the Kelly River allochthon.

There are three sequences in the Kelly River allochthon: the Amphitheatre sequence, Kelly sequence, and Eli sequence. They generally have thrust fault contacts with the Amphitheatre sequence structurally lowest, the Kelly sequence in the middle, and the Eli sequence structurally highest.

The Amphitheatre Sequence

The Amphitheatre sequence (fig. 12, plate 2) was named by Curtis and others (1983) for exposures around Amphitheatre Mountain in the eastern part of the De Long Mountains quadrangle. Exposures occur in the mountains at the headwaters of the Kelly River (plate 1) in the De Long Mountains quadrangle and at the mountain front in the hills southeast of Cape Seppings. This sequence consists of sedimentary rocks that range in age from Late Devonian to Early Cretaceous. Pre-Cretaceous rocks range in thickness from approximately 900 m in the De Long Mountains to about 500 m in the hills southeast of Cape Seppings.

The Amphitheatre sequence overlies the Wulik and Amaruk sequences of allochthon two and the Key Creek sequence of allochthon one. It is distinguished from all other sequences by having several hundred meters of light gray bioclastic limestone with black chert nodules (the Kogruk Formation), underlain by more than 100 m of buff-weathering, non-cherty, "micritic limestone" that commonly weathers to platy and flaggy talus slopes. At its southern boundary, this sequence is structurally overlain by imbricated thrust sheets of the Kelly sequence. At the southwest end of Inaccessible Ridge, the Amphitheatre sequence appears to grade laterally into the Kelly sequence. In the hills southeast of Cape Seppings, the cherty zone at the top of the Kogruk in the Amphitheatre sequence becomes much thicker, and at this location, the Mississippian part of the Amphitheatre sequence approaches parts of the Wulik sequence in overall lithology.

The Kelly Sequence

The Kelly sequence (fig. 13, plate 2) was named the Kelly tectonic unit by Snelson and Tailleur (1968) for exposures in the mountains west of the Kelly River in the De Long Mountains. Its outcrop area extends from the Picnic fenster (plate 1) west to the sea coast south of Cape Seppings. East of the Picnic fenster, the Kelly sequence occurs as a few thrust slices at the mountain front south of the Drenchwater fenster and possibly along the north side of the Pupik Hills. The thickness of the Mississippian part of the Kelly sequence decreases from west to east in the De Long Mountains. In the west, the Mississippian part of the section is at least 800 m thick, and in the east, it is less than 75 m. It probably was not deposited at the longitude of the eastern part of the map area (plate 1). This sequence ranges in age from Late Devonian to Early Cretaceous. Pre-Cretaceous rocks are approximately 600 to 1000 m thick west of long 162^{o} W. and are less than 300 m thick east of long 160^{o} W.

In the western De Long Mountains, thrust sheets that contain the Kelly sequence are at a structural middle level in the Kelly River allochthon. They overlie the Amphitheatre sequence wherever the two sequences are in contact, and they underlie the Eli sequence. Where the Amphitheatre sequence does not occur, they directly overlie the Picnic, Wulik, and Amaruk sequences of allochthon two and the Key Creek sequence of allochthon one. In many places they are structurally overlain by sequences in allochthon four.

The Kelly sequence is distinguished from the Amphitheatre and Eli sequences by the character of the Lower Mississippian Utukok Formation. The Utukok has not been recognized in the Amphitheatre sequence. In the Eli sequence, the Utukok is thin and discontinuous, generally not more than 50 m thick, in contrast to the Kelly sequence where thicknesses of 300 m or more are common.

The Eli Sequence

The Eli sequence (fig. 14, plate 2) was named by Curtis and others (1982) for exposures in the mountains around the Eli River in the Baird Mountains and Noatak quadrangles. This sequence also occurs west of the Mulgrave Hills in the Noatak quadrangle and discontinuously in the southern part of the De Long Mountains. Best exposures occur along a southwest-trending mountainous belt extending along the east side of the Avan Hills to the east side of Maiyumerak Mountain and Asik Mountain (plate 1). The base of this sequence is at least as old as Middle Devonian in age and the top is Early Cretaceous. Pre-Cretaceous rocks are approximately 1300 to 1500 m thick based on a composite of sections in the western Baird Mountains.

The Eli sequence occurs structurally below the Ipnavik and Nachralik Pass sequences and above the Kelly, Wulik, and Key Creek sequences. It is distinguished from sequences in other allochthons by having a thick section of carbonate rocks called the Kogruk Formation and Baird Group. The Utukok Formation is thin or locally absent in the Eli sequence in contrast to the other sequences in the Kelly River allochthon. In a few places, such as east and west of the Kugururok River, the Kogruk Formation appears to rest directly on the Baird Group. This sequence contains the most extensive exposures of the Baird Group carbonate rocks in any of the sequences in the De Long Mountains allochthon belt.

IPNAVIK RIVER ALLOCHTHON (4)

The Ipnavik River allochthon is the fourth allochthonous structural level in the western Brooks Range. It was first named the Ipnavik tectonic unit by Snelson and Tailleur (1968) for exposures in the foothills of the Endicott Mountains west of the Ipnavik River. The sequences which compose this allochthon are well exposed in the foothills of the Endicott Mountains and throughout the eastern part of the De Long Mountains. More limited exposures occur to the west and southwest in the western Baird Mountains, south of the Wulik Peaks, and west of Iyikrok Mountain. Best areas for viewing the structural level of this allochthon, compared to the higher and lower allochthons, are between Nuka Ridge and the Picnic fenster, at the Cutaway fenster, southeast of the Misheguk mafic and ultramafic complex, and in the mountains around the upper Kugururok River drainage. In some places between Mount Bastille and the Drenchwater fenster (plate 1), this allochthon is composed of up to three or four thrust sheets which probably reach an aggregate thickness in excess of two kilometers. Farther to the west, in the hills southeast of Cape Seppings, this allochthon is more discontinuous and appears to be missing in some places between allochthons three and five.

Sequences in the Ipnavik River allochthon are distinguished from sequences in most other allochthons by having Upper Mississippian black chert or interbedded black chert and fine-grained limestone. However, with the exception of distinctive diabase sills that are common in some places and rare in others, the Mississippian to Cretaceous sedimentary rocks in sequences of the Ipnavik River allochthon are similar to the rocks in allochthon two. One way to distinguish sequences in these allochthons in the absence of diabase sills is to ascertain the Devonian rocks of the questionable sequence. If the Upper Devonian rocks consist of sandstone and shale of the Endicott Group, then they belong to a sequence in allochthon two. If they are limestone and dolomite of the Baird Group, then the sequence belongs to the Ipnavik River allochthon. Devonian rocks are commonly missing from thrust sheets of these allochthons, and where they do occur at the base of the section, they are thin and discontinuous thrust slices. In areas where it is difficult to find Devonian rocks or diabase sills, the structural position in relation to known allochthons has been used to determine if a sequence is in the Ipnavik River allochthon or in allochthon two.

There are three sequences in the Ipnavik River allochthon. They are the Nachralik Pass, Puzzle Creek, and Ipnavik sequences. The Nachralik Pass sequence is structurally overlain by the Ipnavik sequence. Outcrops of the Puzzle Creek sequence are isolated geographically to the north and west of the Nachralik Pass and Ipnavik sequences.

The Nachralik Pass Sequence

The Nachralik Pass sequence (fig. 15, plate 2) was named by Curtis and others (1982) for exposures in the mountains east and west of Nachralik Pass, which is located a few kilometers northeast of Copter Peak (plate 1). Exposures of this sequence occur as isolated outcrop areas in the central and southern parts of the Misheguk Mountain quadrangle. The section is composed almost entirely of sedimentary rocks which range in age from Early Mississippian to Early Cretaceous. Pre-Cretaceous rocks are approximately 300 m thick.

In most places, the Nachralik Pass sequence overlies the Kelly and Eli sequences; in a few places, it appears to overlie the Picnic and Key Creek sequences. It underlies the Ipnavik sequence throughout most of its outcrop belt.

The lithologies of coeval sedimentary rocks in the Nachralik Pass, Puzzle Creek, and Ipnavik sequences are essentially the same. There are few mafic sills and dikes in the Nachralik Pass and Puzzle Creek sequences in comparison with the great abundance of mafic rocks in the Ipnavik sequence. Because the Nachralik Pass and Puzzle Creek sequences are structurally lower, they are believed to have been deposited relatively north of the Ipnavik sequence in a part of the depositional basin not reached by most of the mafic intrusive activity. Mississippian to Cretaceous rocks in the Nachralik Pass and Puzzle Creek sequences are similar. Unlike the Puzzle Creek sequence, Devonian rocks are not exposed at the base of the Nachralik Pass sequence.

The Puzzle Creek Sequence

The Puzzle Creek sequence (fig. 16, plate 2) was named by Mayfield and others (1983a) for exposures in the hills around Puzzle Creek which is located south of the Wulik Peaks in the De Long Mountains quadrangle (plate 1). Exposures are limited to the Puzzle Creek area where this sequence is composed of sedimentary rocks that range in age from Middle or Late Devonian to Early Cretaceous. Pre-Cretaceous rocks are approximately 800 to 900 m thick. The greater thickness of the Puzzle Creek sequence compared to other sequences in the Ipnavik River allochthon is due to a greater exposed thickness of the Baird Group in the lower part of this sequence.

Mississippian to Jurassic sedimentary rocks of the Puzzle Creek sequence are similar to coeval rocks in the Ipnavik and Nachralik Pass sequences. There are only a few mafic igneous rocks in the Puzzle Creek sequence in contrast to the Ipnavik sequence. The Nachralik Pass sequence is both lithologically and structurally similar to the Puzzle Creek sequence, and if the outcrop belt of these sequences were continuous across the De Long Mountains, it is probable that the two sequences could be mapped with a single name. The two separate names are retained in this report so that the allochthon-sequence map (plate 1) will conform to terminology used previously on more detailed maps of this region (Mayfield and others, 1983a; Curtis and others, 1982) and to provide greater flexibility for discussions concerning their structural relationships.

The Ipnavik Sequence

The Ipnavik sequence (fig. 17, plate 2) was named and described by Tailleur and others (1966) for exposures in the foothills of the Endicott Mountains in the vicinity of the Ipnavik River. This sequence is discontinuously exposed from the lower Kivalina River area in the west to the east edge of the study area in the foothills of the Endicott Mountains. Some of the best exposures of this sequence are found in the mountains around the Picnic, Drenchwater, and Cutaway fensters (plate 1). The rocks in this sequence range in age from Devonian to Early Cretaceous. Pre-Cretaceous rocks range in thickness from 400 to greater than 600 m dependent upon the thickness and abundance of mafic igneous sills.

In different places, the Ipnavik sequence structurally overlies most of the other sequences in allochthons three, two, and one. Within the Ipnavik River allochthon, this sequence structurally overlies the Nachralik Pass and Puzzle Creek sequences. It is distinguished from all other sequences by having numerous mafic igneous sills and dikes which intrude rocks of the Lisburne and Etivluk Groups. The prominent brown-weathering character of the igneous rocks and light-weathering bleached chert and limestone makes this sequence readily distinguishable from all other sequences, even when viewed from a distance.

NUKA RIDGE ALLOCHTHON (5)

The Nuka Ridge allochthon is the fifth allochthonous structural level in the western Brooks Range. It is structurally highest in the stack of allochthons that are composed predominantly of sedimentary rocks. It was first mapped and described by Tailleur and others (1966) from exposures at Nuka Ridge in the Misheguk Mountain quadrangle. Outcrops of this allochthon also are found as isolated thin thrust slivers from the hills southeast of Cape Seppings to the foothills north of the Endicott Mountains. Outcrop areas which best show the structural relationships between this allochthon and the adjacent allochthons occur in the hills around Nuka Ridge and in the mountains along the upper Kugururok River valley (plate 1). The thickest part of the Nuka Ridge allochthon occurs at Nuka Ridge where at least five stacked thrust sheets are folded into an overturned syncline which reaches a depth from the surface of approximately 1 to 1.5 km. In most other places, this allochthon is less than 200 m thick and is commonly missing at the thrust fault contact between allochthons four and six.

There are two sequences in the Nuka Ridge allochthon: the Bastille and Bogie sequences. The structural and stratigraphic relation between these two sequences is uncertain even though both sequences structurally overlie allochthon four and underlie allochthon six. The apparent lithologic difference between the two sequences is that in the Bastille sequence, possible Carboniferous rocks appear to be thin-bedded, fine-grained limestone, and in the Bogie sequence, coeval rocks are arkosic limestone of the Nuka Formation that overlie shale and siltstone of the Kayak Shale. A quandary stems from uncertainty about the stratigraphic position and age of the possible Carboniferous limestone in the Bastille sequence. The upper part of the limestone section in the Bastille sequence has thus far proved to be unfossiliferous. Because this limestone occurs in outcrop beneath a relatively unfaulted section of Etivluk Group chert, the field relationships suggest it is in part Carboniferous in age and therefore correlative with, but lithologically distinct from, the Nuka Formation. However, if future fossil collections establish that these limestone beds are Devonian in age and in fault contact with the overlying Etivluk Group, then the Bastille sequence would no longer need to have a separate designation, because its upper and lower parts would become the Etivluk Group and Baird Group of the Bogie sequence. If future study can show that there is an unconformity between the Etivluk Group and Baird Group that cuts out Carboniferous rocks, the Bastille sequence would remain distinct.

The Bastille Sequence

The Bastille sequence (fig. 18, plate 2) was named by Curtis and others (1982) and Ellersieck and others (1982) for exposures in the upper Kugururok River valley and at Mount Bastille in the De Long Mountains (plate 1). Outcrops of this sequence as mapped on plate 1 are confined only to this area where the structural position of this sequence in relation to other sequences above and below is well exposed. This sequence is composed of sedimentary rocks that range in age from Devonian to Early Cretaceous. Pre-Cretaceous rocks are approximately 500 to 600 m thick.

There are numerous other places in the western Brooks Range where Devonian limestone thrust slices similar to those in the Bastille sequence overlie allochthon four and either underlie or occur as thrust slices within allochthon six. Many of these isolated limestone outcrops have been tentatively correlated with allochthon five without a sequence designation. On the allochthon map (plate 1) some of the larger limestone outcrops are labeled with the numeral 5 to signify a probable correlation with the Nuka Ridge allochthon.

The Bogie Sequence

The Bogie sequence (fig. 19, plate 2) was named by Mayfield and others (1982) for exposures along Bogie Creek at the southeast end of Nuka Ridge. This sequence is mapped discontinuously in the hills southeast of Cape Seppings, in the southern and eastern DeLong Mountains, in the western Baird Mountains, and in the foothills of the Endicott Mountains (plate 1). The best exposures of this sequence occur at Nuka Ridge. The age of the Bogie sequence is Early Mississippian to Early Cretaceous. An unfaulted and (or) uncovered stratigraphic contact of the Upper Devonian limestone below the Lower Mississippian Kayak Shale has not been observed in outcrop. It is possible that some if not all of the isolated Devonian limestone outcrops that occur at this structural level belong in this stratigraphic interval. The thickness of Pre-Cretaceous rocks in the Bogie sequence probably exceeded 500 m, but because of thrust faulting, no place has been found where more than 200 m of unfaulted section is exposed.

The Upper Mississippian and Lower Pennsylvanian(?) part of the Bogie sequence, called the Nuka Formation, has the most distinctive lithology of all the sedimentary sequences in the western Brooks Range. It consists of coarse-grained arkose, arkosic limestone, and glauconitic or hematitic limestone. This contrasts with the limestone, chert, and shale that characterize coeval parts of the sedimentary sequences in other allochthons. Exposures of the Bogie sequence commonly occur as small discontinuous thrust slices or blocks that structurally overlie the Ipnavik sequence and underlie the Copter igneous sequence. Some outcrops are believed to be olistoliths that have slid onto structurally lower allochthons and were subsequently encased in Lower Cretaceous flyschoid sediments.

COPTER PEAK ALLOCHTHON (6)

The Copter Peak allochthon is the sixth allochthonous structural level in the western Brooks Range. It was named by Ellersieck and others (1979) for exposures at Copter Peak in the western part of the Misheguk Mountain quadrangle. The most extensive exposures of this allochthon are preserved as erosional remnants of large synforms and are commonly best exposed around the margins of the klippen of allochthon seven. Extensive exposures also occur in the Pupik Hills in the Endicott Mountains, as a northeast linear trend through Maiyumerak Mountain in the western Baird Mountains, and as mountain top klippen in the Copter Peak and Mount Bastille areas of the eastern De Long Mountains. Poorly exposed rubbly outcrops occur in the low hills around Iyikrok Mountain and the lower Kivalina River in the southwestern De Long Mountains (plate 1). Similar outcrops, thought to be structurally equivalent to the Copter Peak allochthon, occur along the southern edge of the Brooks Range trending through the Jade Mountains and Cosmos Hills. The thickness of this allochthon varies greatly throughout the outcrop belt. In most areas, it is at least up to 650 m thick; in some areas such as at Maiyumerak Mountain (plate 1), the thickness may be as much as one or two kilometers.

The only sequence in this allochthon is called the Copter igneous sequence. In most places, it lies structurally above sequences in allochthons four and five and below allochthon seven.

The Copter Igneous Sequence

The Copter igneous sequence (fig. 20, plate 2) was named by Curtis and others (1982) for excellent exposures at the top of Copter Peak in the Misheguk Mountain quadrangle. This sequence is predominantly composed of pillow basalt and, to a lesser extent, andesite. A small granitic dike cuts the basalt northeast of Misheguk Mountain, and there are also small granitic dikes or stocks in the lowlands south and west of Maiyumerak Mountain. Areas of andesitic volcanic and intrusive rocks intercalated with basalt occur in the lower Kugururok River valley and north of Asik Mountain (plate 1). Similar rocks of uncertain structural position are mapped tentatively as part of this sequence northwest of Siniktanneyak Mountain (plate 1). At this location it is possible that some intermediate volcanic rocks and basalts may have formed at the top of the Misheguk igneous sequence in allochthon seven.

Gray, green, and maroon chert and gray or maroon shale appear to be interbedded with the basalt in some areas. Triassic and indefinitely dated Mesozoic radiolaria have been identified from the chert intercalated with pillow basalt at several widely scattered localities in the De Long Mountains (Ellersieck and others, 1982) and in the Anguyucham Mountains east of the Cosmos Hills (Plafker and others, 1978). Based on this radiolarian fossil evidence and the possible correlation of some of the basalts to the Jurassic gabbroic rocks in the Misheguk igneous sequence, the pillow basalts and andesite are currently thought to be Triassic and Jurassic(?) in age.

There are widely scattered outcrops of fossiliferous shallow-water Devonian limestone intercalated with the basalt in some areas. Some of these limestone blocks are close to the basal thrust fault of the Copter Peak allochthon, or occur along fault planes parallel to the basal thrust and so are thought to be thrust slivers (Ellersieck and others, 1982). The stratigraphic significance of the dated Devonian carbonate rocks is debatable; they may be thrust slices of the Baird Group from sedimentary sequences in lower allochthons, or they may be rocks upon which the volcanic rocks were extruded.

MISHEGUK MOUNTAIN ALLOCHTHON (7)

The Misheguk Mountain allochthon is the seventh and highest allochthonous structural level in the western Brooks Range. It was first named the Misheguk tectonic unit by Snelson and Tailleur (1968) for exposures at the Misheguk Mountain mafic and ultramafic complex. This allochthon is exposed as large synformal erosional remnants in the igneous complexes around Iyikrok Mountain, Asik Mountain, Avan Hills, Misheguk Mountain, and Siniktanneyak Mountain (plate 1). Correlative rocks thought to be at this structural level, composed of serpentinite and partly serpentinized peridotite, also crop out at the southern margin of the Brooks Range in the Jade Mountains, in the Cosmos Hills, and elsewhere in small isolated outcrops at the southern edge of the Baird Mountains. Erosion has stripped away much of the original thickness of the Misheguk Mountain allochthon. This allochthon is probably no more than one or two kilometers thick at most of the igneous exposures listed above.

The Misheguk Mountain allochthon is thought to be part of an ophiolite (Tailleur and Brosgé, 1970; Tailleur, 1973; Patton and others, 1977; Roeder and Mull, 1978; Nelson and others, 1979; Zimmerman and Soustek, 1979; and Gealey, 1980). It is thought to have been a series of thrust sheets that overlaid at least three-fourths of the western Brooks Range and dipped south under the Yukon-Koyukuk province.

The only sequence in this allochthon is called the Misheguk igneous sequence. In different places, it lies directly on sequences of allochthons one, two, three, four, and six. In some places below the basal thrust contact, this sequence rests directly on thin zones of well-foliated metamafic igneous and metasedimentary rocks. North of the Avan Hills and Asik Mountain igneous complexes metabasite and (or) meta-andesitic rocks of the underlying Copter igneous sequence are metamorphosed to garnetiferous amphibolite which, at the Asik Mountain locality, grades into nonfoliated and unmetamorphosed basalt and andesite thought to be part of the Copter igneous sequence. North and west of Misheguk Mountain there are metabasites, metapelites, and marble that represent metamorphosed igneous and sedimentary rocks from structurally lower sequences. These discontinuous thin zones are interpreted to have been caused by contact metamorphic effects from residual heat in the gabbro and peridotite during ophiolite obduction (Ellersieck and others, 1982; Zimmerman and Frank, 1982).

The Misheguk Igneous Sequence

The Misheguk igneous sequence (fig. 21, plate 2) is named for excellent exposures at the igneous complex around Misheguk Mountain (Ellersieck and others, 1982). The sequence is predominantly composed of a wide variety of gabbroic and peridotite-related rocks (Roeder and Mull, 1978; Zimmerman and Soustek, 1979; Nelson and others, 1979; Zimmerman and others, 1981; Frank and Zimmerman, 1982; Nelson and Nelson, 1982). Dioritic and granitoid plutonic rocks occur locally in the Avan Hills and Siniktanneyak igneous complexes (plate 1). They are speculated to have been late-stage differentiates (Frank and Zimmerman, 1982) or felsic plutons produced by anatexis of wall rocks during ophiolite obduction (Roeder and Mull, 1978).

This sequence is the lower part of a classical ophiolite sequence. The layers of the basalt and oceanic sediments above the gabbroic and ultramafic rocks have not been reported and presumably were stripped away by erosion. The bottom of the sequence is a zone of olivine-rich peridotite and dunite with both tectonite and cumulate characteristics. Above this is a transitional zone that contains alternating layers of peridotite, pyroxenite, and gabbroic rocks. The top of the sequence mainly consists of gabbroic rock that tends to display cumulate layering of pyroxene-rich and plagioclase-rich layers in the lower part; in the upper part, it is not layered and is more leucocratic. Local occurrences of granitoid rocks are more prevalent in the upper part and seem to occur both as layers and as cross-cutting dikes in the gabbro (Roeder and Mull, 1978; Nelson and others, 1979; and Zimmerman and others, 1981).

Biotite from granitoid rocks and hornblende from gabbro pegmatites collected at the Misheguk and Siniktanneyak igneous complexes have been dated as 170 to 150 m.y. old by the potassium-argon method (Patton and others, 1977; Ellersieck and others, 1982). These Middle Jurassic dates record the cooling of this sequence and are thought to coincide with the process of ophiolite obduction.

SUMMARY OF DIFFERENCES IN STRATIGRAPHY BETWEEN ALLOCHTHONS

Certain generalizations can be made about the comparison of coeval sedimentary rocks that occur in the different allochthons. For example, Upper Devonian rocks do not occur in the Lisburne Hills sequence of allochthon one and appear to be thin and discontinuous in the Schwatka sequence. In these sequences, Late Devonian time is thought to be mostly represented by an erosional interval. In the Key Creek sequence of allochthon one, Upper Devonian rocks consist of a thick succession of sandstone, shale, and conglomerate of the Endicott Group in comparison to coeval rocks in allochthons three, four, and five which consist of limestone and dolomite of the Baird Group (Tailleur and others, 1967). North of the Avan Hills (plate 1) in the Wulik sequence of allochthon two, interlayered clastic and carbonate rocks with latest Devonian (Famennian) fossils appear to be a transitional facies between the Endicott Group and upper parts of the Baird Group.

Lower Mississippian rocks consist of interfingering shale, limestone, and sandstone of the Kayak Shale and the Utukok Formation. These formations contain similar lithologies in different allochthons. Thus, isolated exposures of these rock units are not very useful for distinguishing among the allochthons.

Upper Mississippian rocks contain a variety of lithologies in different allochthons. The few exposures of Upper Mississippian rocks in the Schwatka sequence consist of limestone and dolomite with black chert nodules. In allochthons one and two, there is black carbonaceous shale and (or) black chert underlain by thick to thin and discontinuous limestone. Sequences in allochthon three contain mostly limestone with black chert nodules. Sequences in allochthon four contain well-bedded black chert or interbedded black chert and limestone, and sequences in allochthon five contain noncherty limestone and (or) arkose.

Pennsylvanian to Lower Jurassic rocks generally have only minor lithologic differences in different allochthons. These rocks mainly consist of radiolarian chert and siliceous shale of the Etivluk Group (Mull and others, 1982). For example, the Otuk Formation has more Upper Triassic limestone in sequences of allochthon one than it does in higher allochthons. Also, the Etivluk Group generally has a greater proportion of chert and maroon-weathering beds in higher allochthons. These differences are usually not distinctive enough to differentiate individual sequences, but in areas of poor exposure, they commonly can be used as guides to approximate the structural level.

The Ipewik Formation of Jurassic to Early Cretaceous age (Crane and Wiggins, 1976) is exposed most prominently in sequences of allochthon one and the Wulik sequence of allochthon two. In most places in the De Long Mountains, this formation consists of maroon and gray clay beds and papery carbonaceous shale. However, in a few of the lower thrust sheets of allochthon one, this formation also contains distinctive coquinoid limestone beds and (or) quartzose sandstone beds of the Tingmerkpuk Member (Curtis and others, 1983).

The top of each allochthonous sedimentary sequence has rocks of Early Cretaceous and (or) Late Jurassic age that are mainly composed of shale, wacke, and local conglomerate which in most sequences are called the Okpikruak Formation. In a few local places variations in the proportion of shale and wacke can be used to help differentiate between allocthons, but in larger geographic areas these variations are not consistent enough to be used as mapping criteria. The age of the base of the Okpikruak Formation, as dated by sparse pelecypod fossils, appears to be older in higher-numbered allochthons and younger in lower-numbered allochthons. It appears to be at least as old as Late Jurassic in allochthons four and five and Neocomian in allochthons one, two, and possibly three (Mayfield and others, 1983a). At the Surprise and Brady anticlines in the farthest north exposures of allochthon one (plate 1), the base of similar wacke and mudstone is no older than latest Valanginian and likely no older than Albian in age. Because there are few fossils in these rocks, this diachronous characteristic has not been useful for distinguishing sequences in most places.

APPROXIMATE TIMING OF MAJOR TECTONISM IN THE WESTERN BROOKS RANGE

The tectonic event which created most of the Brooks Range orogen is believed to have begun in the Middle Jurassic, about 170-150 m.y. ago (Tailleur and Brosgé, 1970). Stratigraphic evidence for the initiation of the orogeny comes from study of the sedimentary record on the allochthonous sequences. During Early or Middle Jurassic time, the period of slow deposition of siliceous sediments in the southern part of northern Alaska came to an end and was followed by rapid deposition of sediments composed of flyschoid mudstone and wacke. In allochthon four, the top cherty beds of the Etivluk Group are dated by radiolarian fossils that range from Toarcian to Bajocian in age (Mayfield and others, 1983a), and in allochthon one, siliceous shales at the top of the Etivluk Group contain the pelecypods Otapiria tailleuri and Inoceramus lucifer Eichwald (Imlay, 1955; 1967) that are considered to be Bajocian in age (Mull and others, 1982). Although sparsely dated by pelecypods, the flyschoid sediments that overlie the Etivluk Group appear to have begun to be deposited in sequences of upper allochthons during Middle and Late Jurassic time. The oldest identified megafossil reported from the flyschoid deposits in the western Brooks Range is a pelecypod Buchia fischeriana d'Orbigny of Tithonian age (Curtis and others, 1982). This fossil was collected from the middle of a section of graywacke and mudstone more than 150 m thick so it is possible, if not likely, that the base of the Brookian orogenic sediments are older than Tithonian in this region. Upper Jurassic turbidites and olistostrome units also have been reported by Kleist and others (1983). In the north-central Brooks Range fragments of the pelecypod Inoceramus sp. similar in appearance to immature forms of Inoceramus lucifer found elsewhere in northern Alaska in beds of Bajocian age and the ammonite Arkelloceras cf. A. tozeri Frebold, also of Bajocian age, have been found in tuffaceous graywacke (Jones and Grantz, 1964).

Radiometric evidence for the initiation of thrusting comes from potassium-argon ages on the ophiolite of allochthon seven. Though difficult to prove, the fact that the ophiolite cooled to argon retention at about the same time as the change from a stable to a tectonic depositional regime in northern Alaska is strongly suggestive that the obduction of the ophiolite also occurred at the same time. Additional indication that the ophiolite might have been hotter than argon-retentive temperatures during the early stages of the obduction process comes from the basal thrust contact of the peridotite and gabbro in allochthon seven. At Asik Mountain, Misheguk Mountain, and the Avan Hills (plate 1), there are discontinuous thin zones of metamorphic rocks that consist of garnet amphibolite, dark gray phyllite or schist, fine-grained quartzite, and marble. These metamorphic rocks are inferred to have been basalt, shale, chert, and limestone in the sequences of lower allochthons that were heated and recrystallized by residual heat from the overlying panel of peridotite and gabbro in allochthon seven.

Evidence for the time of cessation of the major thrusting period comes from fossil dates in the relatively autochthonous Fortress Mountain Formation that crops out in the foothills of the Endicott and De Long Mountains. The Fortress Mountain Formation, which contains Albian pelecypods and ammonites (Imlay, 1961), is the oldest rock unit in the Brooks Range that has not undergone significant thrust transport. This relationship is particularly well displayed at Ekakevik Mountain (plate 1) in the foothills north of the Endicott Mountains (Tailleur and Kent, 1951; Mull, 1982). Here, relatively gently folded and faulted sedimentary rocks of the upper part of the Fortress Mountain Formation unconformably overlie allochthon four which is composed of highly deformed and faulted sedimentary rocks of the Neocomian Okpikruak Formation and of older rock units.

After the major thrusting period had come to an end, the metamorphic welt in the southern Brooks Range isostatically rebounded during middle and Late Cretaceous time. Evidence for this period of epeirogeny comes from the cooling of metamorphic minerals to argon retention in the Schwatka Mountains province (Turner and others, 1979) and from the concurrent deposition of large volumes of clastic detritus in the successor basins north and south of the Brooks Range.

At a late stage in the Brooks Range orogeny, the allochthons, whose internal strata were highly deformed during the thrusting period, probably underwent another period of deformation in which they were folded into complex-shaped broad anticlines and synclines. Broad folds with west-trending axes also affect the Upper Cretaceous clastic rocks in the foothills north and south of the Brooks Range. This period of deformation appears to have been accompanied by local small-scale thrust faulting visible in middle and Upper Cretaceous rocks in the northern foothills and may date some small-scale late thrust faulting in the mountains. In the foothills north of the Brooks Range, Late Cretaceous or younger high-angle normal faults, commonly with less than a few tens of meters displacement, cut both the flat thrust sheets and broadly folded Upper Cretaceous rocks. In the Baird and De Long Mountains some east-trending, high-angle faults with apparent displacements up to a few hundred meters cut the major thrust sheets and may date to this or other episodes of late-stage deformation.

The Lisburne Hills also appear to have undergone a late-stage deformational event which has been termed the Tigara uplift (Payne, 1955). The structural grain of the Lisburne Hills has northerly trends with some eastward-verging folds and westward-dipping thrust faults along the east side. The deformed rocks in the Lisburne Hills are believed to couple with the west end of the De Long Mountains in the subsurface, and marine seismic evidence indicates they continue offshore to the northwest (Grantz and others, 1975). Subparallel folds and faults also have affected Albian and Cenomanian(?) clastic rocks northeast of the Lisburne Hills. From this evidence, previous studies of the regional geology have concluded that the Tigara uplift was caused by eastward-directed tectonic forces in post-late Albian(?) time (Campbell, 1967; Grantz and others, 1975) or in Late Cretaceous or Tertiary time (Chapman and Sable, 1960; Martin, 1970). However, these previous estimates for the age of tectonism of this region have given no explanation for the fact that Paleozoic and early Mesozoic rocks are overlain by Neocomian flysch. The Neocomian flysch and the underlying pre-Cretaceous rocks in the Lisburne Hills are exposed in major thrust sheets in the same style of intra-allochthon deformation common in the De Long Mountains. The stratigraphy records nonorogenic deposition in early Mesozoic time overlain by a sudden influx of orogenic sediments in Neocomian time. These tectonostratigraphic relationships are the same as found in comparable thrust sheets in the De Long Mountains. Though fold evidence for a Neocomian period of northly-directed thrust dislocation has not yet been cited in regional geologic reports on the Lisburne Hills, the overall history of orogeny from stratigraphic evidence is the same as the rest of the western Brooks Range. It is therefore probable that large thrust dislocations also occurred in the rocks in the Lisburne Hills during Neocomian time just as they did in structurally higher allochthons in other parts of the western Brooks Range. Subsequent deformation of the older allochthonous sheets during the Tigara uplift in post mid-Cretaceous time has produced folds with northerly-trending axial planes and thrust faults that have displaced upper thrust sheets to the east along the east side of the Lisburne Hills (Chapman and Sable, 1960; Campbell, 1967; and Martin, 1970).

The tectonic origin of the Tigara uplift is uncertain. Tailleur (1969a;b) and Tailleur and Brosgé (1970) observed that the Cordilleran fold trends of the western Brooks Range, Seward Peninsula, and Lisburne Hills formed a series of deflections, called the Chukchi syntaxis, that they believed were caused by eastward-directed compression between Siberia and northwestern Alaska. Patton and Tailleur (1977) speculated that the deflections were formed by a giant southward-looping oroclinal flexure. Grantz and others (1975) argued that the deflections may have formed when the westward structural trends of the western Brooks Range were refolded during late-stage deformation in the offshore Herald fault zone and its extension through the Lisburne Hills and is not necessarily due to oroclinal bending. In any case, it seems likely that the average southwest structural bend of the western De Long and Baird Mountains, which approximately parallels the fold axes in the southern Lisburne Hills, was caused by a late deformational event.

CROSS SECTIONS TO THE ALLOCHTHON MAP

Cross sections for the western Brooks Range allochthon map (plate 1) appear on plate 3. In spite of the attempt to keep the vertical and horizontal scale the same, the thickness of allochthons had to be exaggerated slightly in some places so that the allochthons could be traced on the sections. This is especially true of allochthons two, four, and five which in many places are less than half a kilometer thick.

The depth of the boundary fault at the base of allochthon one is not well constrained by geological or currently available geophysical evidence under the De Long and Endicott Mountains. An approximation of the upper boundary of the succession of rocks under the Colville basin that correlates with the Schwatka sequence is taken here as the top of the Lower Cretaceous "pebble shale" stratigraphic horizon from seismic maps in the southern part of the Petroleum Reserve (Bruynzeel and others, 1982). The northern limit of allochthon one is approximated on plate 1 and corresponds to the southward limit of the seismically traceable and relatively gently folded Neocomian to Albian strata in the Colville basin. The leading edges of the thrust sheets in allochthon one probably were moved by reverse faults of progressively diminishing displacement in shale and sandstone of Early Cretaceous age.

The northern outcrop boundary of the Schwatka Mountains province is difficult to map in many areas. The rocks at the boundary zone in the Baird and Schwatka Mountains are low-grade metamorphic rocks of the greenschist metamorphic facies. As a consequence, the stratigraphic units in the Schwatka sequence and at the base of the Key Creek sequence of allochthon one have been difficult to date; so the stratigraphy of these sequences is not completely understood and the contact between them is difficult to locate precisely. Carboniferous sedimentary rocks of the Schwatka sequence are exposed north of Hub Mountain and in the northern part of the Schwatka Mountains. The contact between the Schwatka sequence and allochthon one has been approximated north of these exposures, elsewhere this boundary is even more speculative. In many, if not most areas, it is likely that the contacts as shown on the allochthon map (plate 1) and the cross sections (plate 3) will change somewhat in the future as the early Paleozoic metasedimentary rocks are studied in greater detail.

The southern part of section lines A-A' and B-B' reflect the uncertainty of whether the terrane of mostly Devonian carbonate rocks that extend from the southwest Baird Mountains to the Igichuk Hills are part of allochthon one or allochthon three. This area needs more paleontologic dates before the stratigraphic section can be fully understood. If the upper part of this carbonate section is Late Devonian (Famennian) or younger, then it is probably the lower part of a sequence in allochthon three. If the upper part of the carbonate section is Late Devonian (early Frasnian) or older then these rocks could be the lower part of a sequence in allochthon one that has been juxtaposed by intrasequence thrust faults.

PALINSPASTIC SYNTHESIS

Two assumptions are made about the movement of the thrust faults and northern Alaska. Both are used to construct the palinspastic map (plate 4). The first assumption concerns the direction of movement along any thrust fault relative to the rocks that border it. The second assumption concerns the movement of the Arctic Alaska plate (Sweeney and others, 1978) relative to the North American craton.

Assumption #1: The relative movement of the thrust sheets is north under south. This assumption is based on three observations and (or) interpretations. 1) The overall fold style of the De Long and Endicott Mountains is that of anticlines and synclines overturned to the north, and the leading or northern edges of the thrust sheets commonly are rolled over into northward vergent anticlinal folds (Curtis and others, 1982; 1983; Ellersieck and others, 1982, 1983; and Mayfield and others, 1982a, 1983a). 2) The root zone for the ophiolite suite in allochthon seven and the pillow basalt in allochthon six appears to be present in southward-dipping thrust sheets at the southern edge of the Brooks Range (Tailleur and Brosgè, 1970; Patton and others, 1977; Roeder and Mull, 1978). 3) A simple and reasonable reconstruction of sedimentary facies patterns in allochthons one through five and the autochthonous or parautochthonous rocks in the Schwatka sequence, to be discussed in a later section of this report, results when the Schwatka sequence is restored to a position farthest to the north, and the sequences in allochthon five are restored to a position farthest to the south.

Assumption #2: Relative to the north American craton, the Arctic Alaska plate has moved southward out of the Beaufort Sea in a counterclockwise motion and collided with another crustal plate at a southward-dipping subduction zone along the south side of the Brooks Range. This assumption is based upon the proposals of Carey (1958), Tailleur (1969a,b; 1973), Rickwood (1970), Freeland and Dietz (1973), Mull and others (1976), Patton and others (1977), Roeder and Mull (1978), Grantz and others (1981), and Mull (1982) that the continental shelf of northern Alaska is a rifted, Atlantic-type margin which began to move away from another continental plate at its northern margin sometime between Early Jurassic and Early Cretaceous (Neocomian) at about the same time that thrusting occured in the Brooks Range. There is no evidence for or against overthrusting as being a component of the process of major thrust dislocation in the Brooks Range orogeny, because the movement of the oceanic crust south of the Brooks Range relative to the North American craton is not known. Thus for simplicity, it is assumed that the ophiolite klippen of allochthon seven, represented by Iyikrok Mountain, Avan Hills, Asik Mountain, Misheguk Mountain, and Siniktanneyak Mountain have remained in a fixed position relative to the North American craton. Thus, the thrusting process is viewed here completely as the underthrusting of more northerly rocks beneath more southerly rocks, as first proposed by Tailleur and Snelson (1969).

The pole of rotation for the counterclockwise motion of northern Alaska is assumed to be in the area of the Mackenzie River delta (Tailleur, 1969a,b; Rickwood, 1970; Newman and others, 1979). The evidence for the location of the pole of rotation is not conclusive. If northern Alaska moved in a southerly direction without a significant amount of rotation, as implied by the scheme of Dutro (1981), the relative palinspastic position of the allochthons and the minimum estimated foreshortening would not be changed significantly through the central part of the palinspastic map. However, somewhat larger gaps and therefore greater displacement distances would be measured between allochthons at the eastern edge of the palinspastic map. In this report the pole of rotation has been chosen in the Mackenzie delta, because this plate tectonic model is currently the most favored explanation for the origin of the Canada Basin. Also the outcrop pattern of allochthons on the palinspastic map fits together more tightly when the allochthons are unstacked using the rotational model.

THE PALINSPASTIC MAP

The palinspastic map of the western Brooks Range (plate 4) was constructed using the outcrop areas shown on the allochthon map (plate 1). Allochthon seven has been held in a fixed position and each lower-numbered allochthon (allochthons one through six and the parautochthonous rocks of the Schwatka Mountains province) has been restored to a position north of the allochthon structurally above it.

The present method that has been used to unstack the allochthons does not take into account several factors which in some cases act to lengthen and in other cases act to shorten the estimated thrust displacement. Most allochthons vary considerably in thickness from place to place. In some exposures, a sequence may be thickened significantly by imbricated thrust sheets that duplicate parts of the sequence, and in other exposures, the same sequence may be thinned by the omission of the upper or lower parts of the stratigraphic section. In many areas of poor exposure, it has not been possible to determine which is the case. Multiple sheets within allochthons have not been unstacked on the palinspastic map, but if they were, the north-south width of some of the outcrop areas would be increased. Thus, the minimum thrust displacement would be increased. In other areas, the width of some of the outcrop areas on the palinspastic map would be reduced if some thrust sheets, composed of the upper part of a sequence, were restored above other thrust sheets composed of the lower part of the same sequence. If complex folds that are common within thrust sheets were unfolded, the allochthon outcrop areas probably would be widened and total thrust displacement increased. Because allochthons pinch and swell in the thrusting direction, it is difficult to accurately estimate the amount of foreshortening within a single allochthon in areas that occur between outcrops. Erosion also has stripped away an undetermined amount of the actual depositional width of each sequence. In most cases, the depositional width of sequences was probably significantly broader than is shown by the present outcrop distribution. All these factors make it difficult to arrive at an accurate figure for the total thrust displacement in the western Brooks Range.

Another potentially important factor in the construction of a palinspastic model is the possible oroclinal flexure in the western Brooks Range and the eastward-directed thrusting on the Lisburne Peninsula, thought to have occurred after the period of major northward foreshortening in the Brooks Range (Tailleur, 1969a,b; Patton and Tailleur, 1977). For purposes of simplicity, the hypothetical orocline has not been taken into account on the palinspastic map. If the southwesterly structural trends in the western De Long Mountains were bent back to their possible pre-oroclinal westerly or northwesterly trends, the relative palinspastic positions of the allochthons in the western Brooks Range would not change appreciably, but the rocks in the Lisburne Hills might restore to a position up to 150 km west or northwest of their position on the palinspastic map (Tailleur and Brosgė, 1970).

THRUST DISPLACEMENT

The thrust displacement for any allochthon in the western Brooks Range is the distance between its present geographic location and its palinspastic location. Because the amount of pull-apart of allochthons on the palinspastic map (plate 4) is probably in error on the conservative side, the amount of thrust displacement inferred from this map is here considered to be a minimum estimate. The two areas labeled AH and SM on plate 4 are the present positions of the klippen of allochthon seven at Avan Hills and Siniktanneyak Mountain unmoved with respect to the Schwatka Mountains province. The minimum thrust displacement of the Avan Hills is the length of the arc between area AH and the palinspastic position of the Avan Hills. This distance is about 800 km. Measured in the same way, but closer to the pole of rotation, the minimum thrust displacement of Siniktanneyak Mountain is about 700 km. These numbers are significantly greater than most estimates published previously. To give an idea of how thrust displacement estimates have increased as detailed geologic maps in the western Brooks Range have progressively encompassed a larger part of this region, a sample of these estimates is given as follows: 80 km minimum and 160 km reasonable (Tailleur and others, 1966); 32 km minimum, 160 km reasonable (Snelson and Tailleur, 1968); 130 km minimum (Martin, 1970); 240 km minimum, 500 km reasonable (Tailleur, 1973); 250 km minimum, 600 km reasonable (Ellersieck and others, 1979); 500 km minimum (Mull, 1980); 580 km minimum (Mull, 1982). Many of these estimates are based on studies of smaller geographic areas within the western Brooks Range, but most previous estimates reflect the minimum amount of thrust displacement that was known at the time they were published.

An estimate of the minimum rate of plate convergence can be made by dividing the distance moved by the duration of the thrusting event. If it is assumed that the minimum thrust displacement in the western Brooks Range was 700 to 800 km and the duration of thrusting was 50 million years (between mid-Jurassic and mid-Cretaceous, 160 and 110 m.y.), then the average minimum rate of plate movement would be 1.4 to 1.6 cm/year.

Another estimate of the minimum rate of convergence can be made by comparison of two areas that should have been displaced by a much lesser amount. For example, the minimum foreshortened distance between the Schwatka sequence and the Surprise anticline located in the northeastern part of the De Long Mountains quadrangle (plate 1) is about 230 km. The lower part of the sequence of rocks exposed at the Surprise anticline is composed of chert and carbonaceous shale that is Triassic, Jurassic, and Early Cretaceous (Valanginian) in age. These sediments record slow rates of deposition and their clastic components have distal or nonorogenic sources. Orogenic turbidite deposits, composed of silty mudstone and graywacke, overlie the Valanginian beds and are younger than similar orogenic sediments in sequences farther to the south. This evidence suggests that rocks in the Surprise anticline were some of the last rocks to become involved in the orogeny and that thrusting did not affect them until at least late Valanginian time (about 125 m.y.). Because the major thrusting episode had ceased by Albian time (about 110 m.y.), there was approximately 15 million years during which the rocks of the Surprise anticline might have been affected by thrust movement. Calculated by these assumptions, the rate of convergence between the Schwatka Mountains province and the Surprise anticline is approximately 1.5 cm/year. When these estimates of plate movement are compared to the average half rate of about two cm/year for spreading centers in the world today, they show that, even with moderate rates of convergence, thrust displacement in the western Brooks Range could have exceeded 1,000 km.

It is also possible to test the feasibility of the estimated thrust displacement in the western Brooks Range using the counterclockwise rotational model for the Arctic Alaska plate. On the palinspastic map, the minimum angular convergence between the Schwatka Mountains province and allochthon seven, measured about a pole of rotation in the Mackenzie River delta, is about 40 degrees (plate 4). The amount of rotation necessary to restore northern Alaska against the Canadian Arctic islands, shown on figure 22, is about 67 degrees (Rickwood, 1970). The minimum amount of thrust displacement given above for Siniktanneyak Mountain is 700 km. The distance between the continental edges of northern Alaska and the Canadian Arctic islands measured along an arc that projects through Siniktanneyak Mountain is 1150 km. These measurements show that the minimum amount of thrust displacement currently estimated in the western Brooks Range supplies about 60 percent of the distance required to open the Canada Basin.

THE ARCTIC ALASKA BASIN

The palinspastic map (plate 4) outlines a small part of an extensive epicontinental sedimentary platform that existed across northern Alaska and part of northeastern Siberia prior to the Brooks Range orogeny. This depositional regime has been termed the Arctic Alaska basin by Tailleur (1969a). A generalized geologic history of the Arctic Alaska basin is given below. Details of the stratigraphy within the basin and reasons for specific interpretations about its geologic history are based on analysis of the palinspastic stratigraphy which is covered in more detail in the next section.

Although the Arctic Alaska basin was an area where sedimentary rocks were deposited during most of middle Paleozoic to early Mesozoic time, deposition did not take place in a simple sedimentary basin. During Middle Devonian to Missippian time, land areas existed in the region presently occupied by the Schwatka sequence and by rocks in the subsurface under the Colville basin. By late Carboniferous time, the emergent rocks were planed by erosion and the northern shoreline of the Arctic Alaska basin shifted north toward the Barrow area. Land also probably existed south of sequences that are now part of allochthon five. This southern land area appears to have periodically shed clastic detritus into the southern edge of the basin during Devonian and Mississippian time. After that time, the southern emergent area apparently disappeared, because it's distinctive arkosic detritus is not observed in the sedimentary record. Through much of the late Paleozoic and early Mesozoic time, the northern land area is inferred to have shed clastic detritus south into the Schwatka sequence. South of the Schwatka sequence lay a depositional area in which strata accumulated with only minor interruption on an ensialic platform during Devonian and early Carboniferous time and on what seems to have become an extensive continental shelf more than 800 km wide in late Carboniferous to Jurassic time. Remnants of the seaward-most 400 km of this depositional area are presently exposed in the sequences in allochthons one through five.

Areas of similar depositional facies on the palinspastic map (plate 4) appear to follow relatively narrow belts with westerly trends. To some extent this may be an artifact of the minimum pull apart by which the map was constructed so the original north-south depositional width of these facies could have been much greater than their palinspastic outcrop distribution. In order to show these principal stratigraphic changes, schematic cross sections X-X' (figs. 23 and 24) and Y-Y' (figs. 25 and 26) have been made approximately

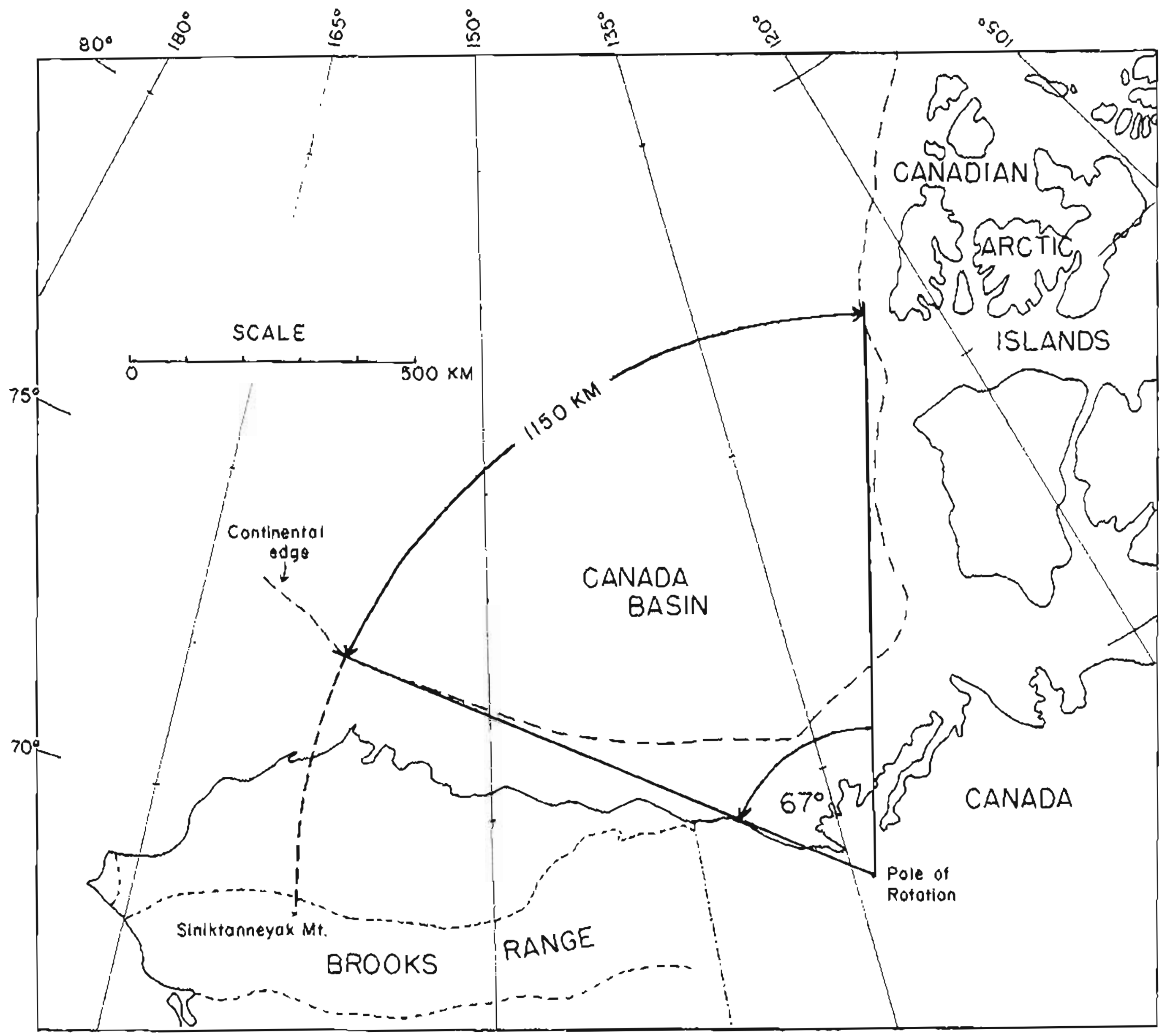

Figure 22. Map showing the distance required to open the Canada Basin by rotating northern Alaska about a pole near the Mackenzie River delta. This distance is 1150 km measured along an arc of 67 degrees that projects through Siniktanneyak Mountain.

normal to the allochthon boundaries from the Schwatka Mountains province through allochthon six. Each section is drawn twice to show lithologies and principal stratigraphic units. Above each section, the allochthons and their associated sequences are labeled.

IMPORTANT FEATURES OF RESTORED NORTHERN ALASKA STRATIGRAPHY

During Middle Devonian time, marine limestone of the Baird Group appears to have been deposited in most, if not all, of the sedimentary sequences of western Alaska (figs. 23, 24, 25, and 26). In the Key Creek and Schwatka sequences, these strata have been called the Skajit Limestone in the southern part of the Endicott Mountains and in the Schwatka Mountains (Pessel and Brosgè, 1977; Mayfield and Tailleur, 1978; Nelson and Grybeck, 1980). In sequences south of the Key Creek sequence, the Baird Group consisted of the Kugururok Formation and other unnamed carbonate rock units. At the base of the carbonate section in southern sequences, there was shale, limestone, and conglomerate.

In Late Devonian time, carbonate rocks of the Baird Group, including the Eli and Kugururok Formations, continued to be deposited in the sequences that later became parts of allochthons three, four, and five. To the north, in the Key Creek sequence which later became part of allochthon one, a complex interval of clastic and carbonate rocks that partly correlates regionally with the Beaucoup Formation graded upward into a thick clastic wedge of Frasnian and Fammenian age. The clastic wedge is a mostly marine and partly nonmarine fluvial-deltaic accumulation of sandstone, shale, and conglomerate called the Endicott Group (Tailleur and others, 1967). Important rock units in the Endicott Group are the Hunt Fork Shale, Noatak Sandstone, Kanayut Conglomerate, and Kayak Shale. The source area was located to the north and northeast (Tailleur and others, 1967; Donovan and Tailleur, 1975; Nilsen, 1981), presumably in the Schwatka sequence and in rocks under the Colville basin. The clastic wedge seems to have interfingered southward with Baird Group carbonate rocks in the Wulik sequence that became part of allochthon two.

While the clastic wedge was deposited, rocks that are in the Schwatka sequence and are presently under the Colville basin appear to have been deformed and uplifted at the south side of an extensive orogen that extended north to Barrow and beyond. Granite plutons were intruded into the rocks of the Schwatka sequence presently exposed in the southern Brooks Range (Dillon and others, 1980), in the northeast Brooks Range (Reiser and others, 1980), and possibly at the base of the East Teshekpuk exploration well 150 km southeast of Barrow (Bird and others, 1978). Faulting and folding in the Lower Paleozoic and Precambrian sedimentary rocks accompanied the uplift and later erosional planation resulted in an extensive pre-Mississippian angular unconformity. This period of tectonism is called the Ellesmerian Orogeny (Lerand, 1973).

During Early Mississippian time, the Kekiktuk Conglomerate and Kayak Shale were deposited over the old erosional surface in the Schwatka sequence and in rocks under the Colville basin. Coal is interbedded with Lower Mississippian sandstone above a major unconformity in the Lisburne Hills sequence (plate 4) which suggests near-shore conditions in the western part of sequences in allochthon one (Collier, 1906; Tailleur, 1965). Shale, limestone, and sandstone were deposited south of the Schwatka sequence and are

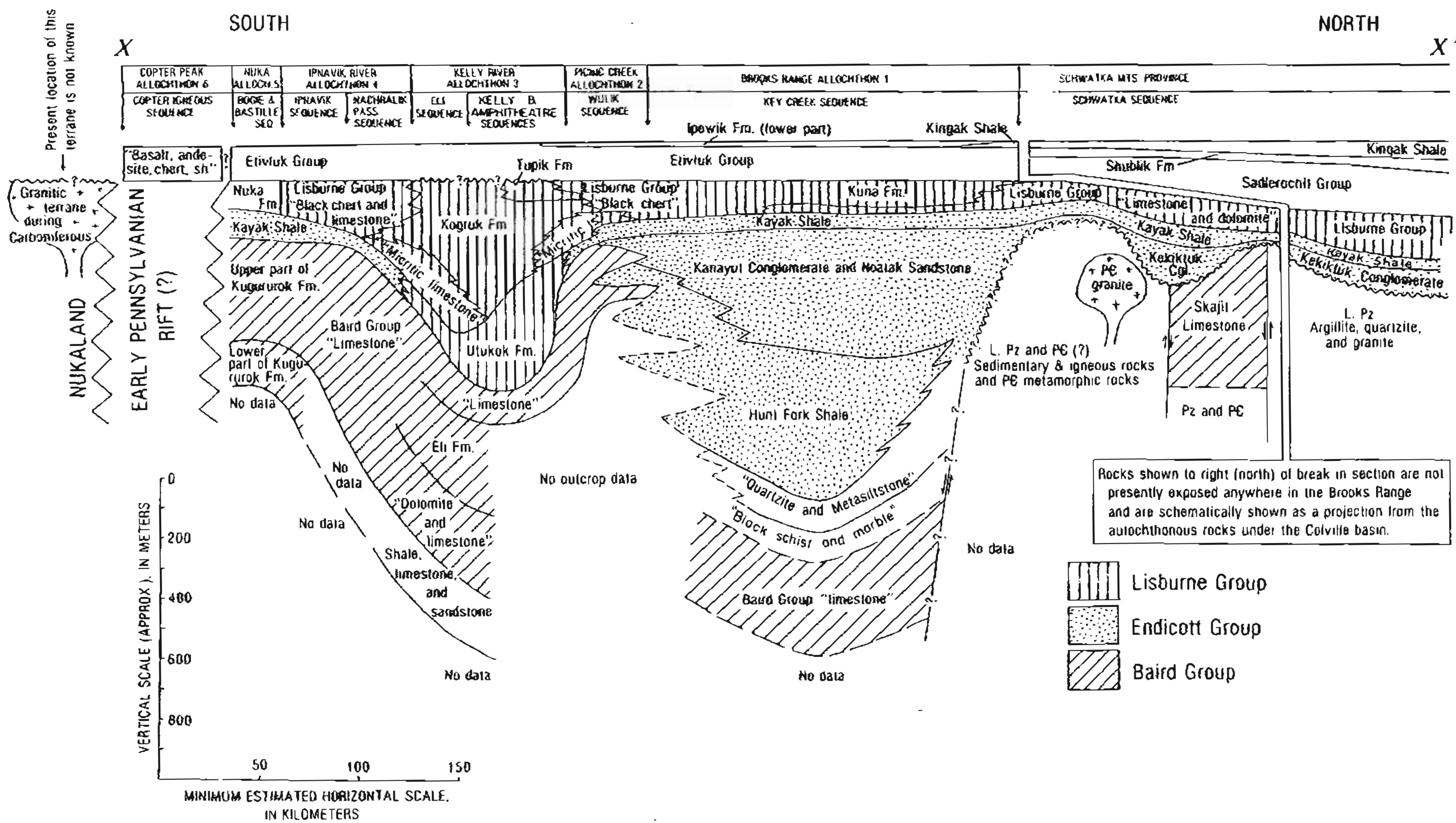

Figure 23. Schematic cross section X-X', from the Middle Jurassic palinspastic map of the western Brooks Range (plate 4), showing important rock units.

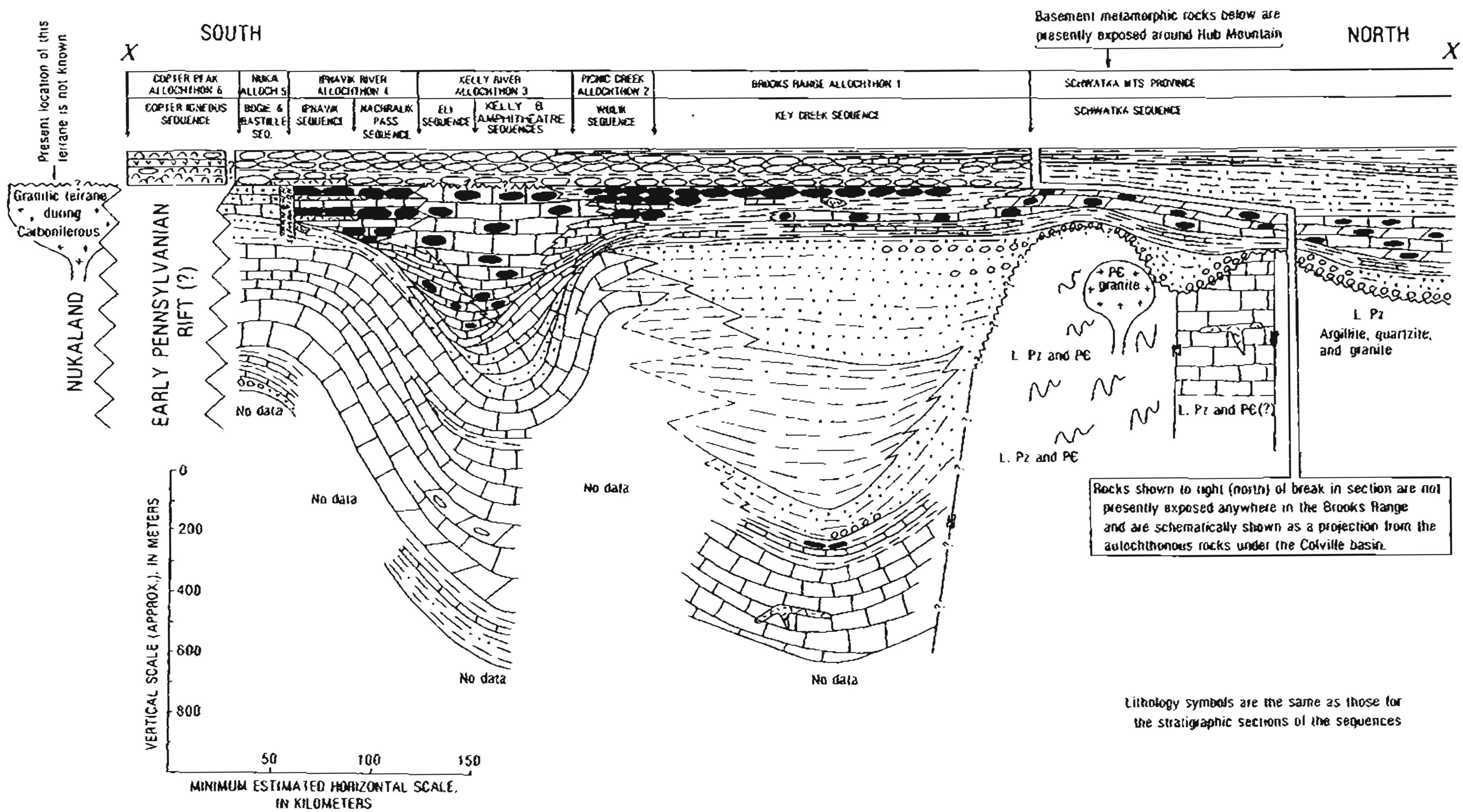

Figure 24. Schematic cross section X-X', from the Middle Jurassic palinspastic map of the western Brooks Range (plate 4), showing principal rock lithologies. Lithology symbols are the same as those used in figures 3-21 (plate 2).

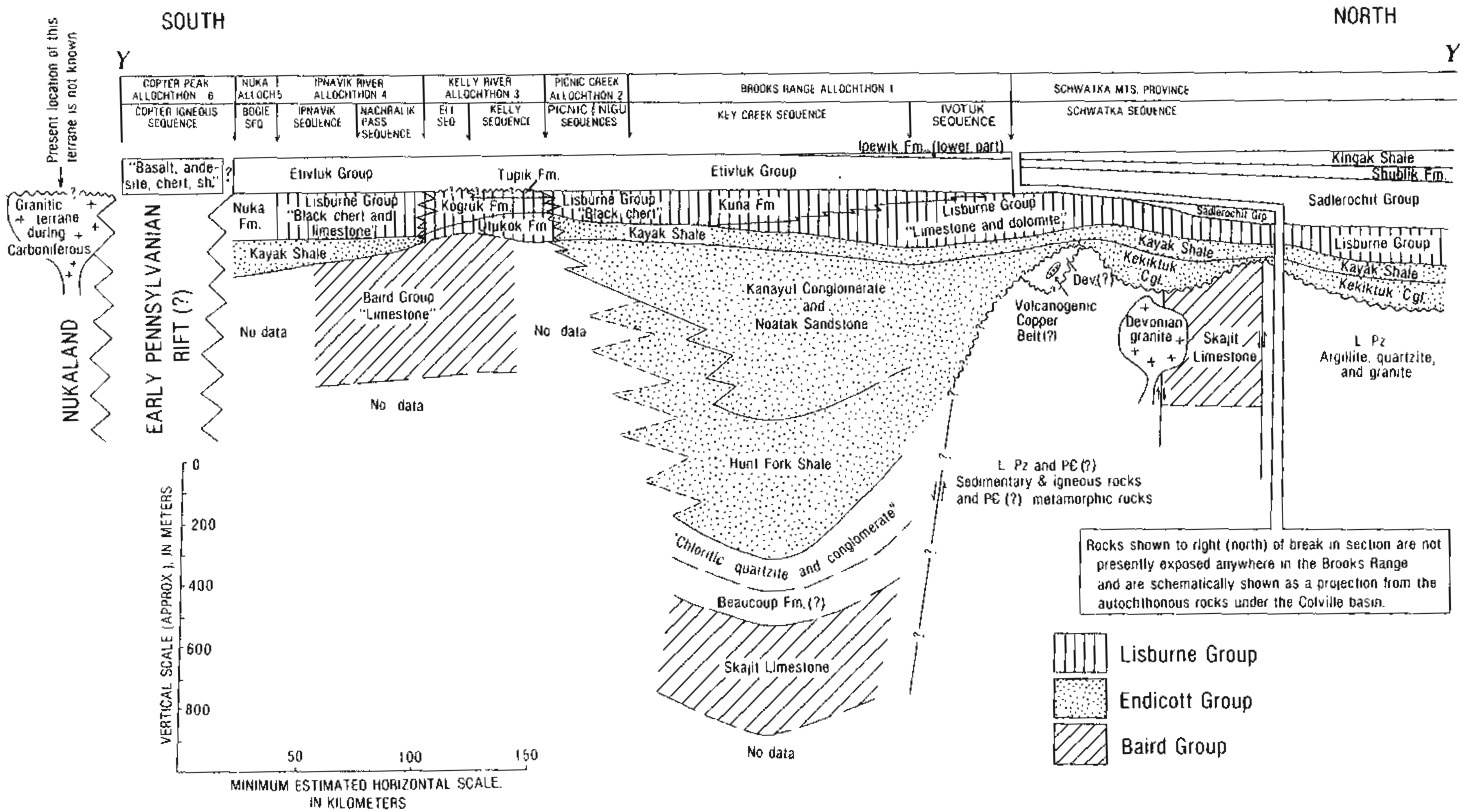

Figure 25. Schematic cross section Y-Y', from the Middle Jurassic palinspastic map of the western Brooks Range (plate 4), showing important rock units.

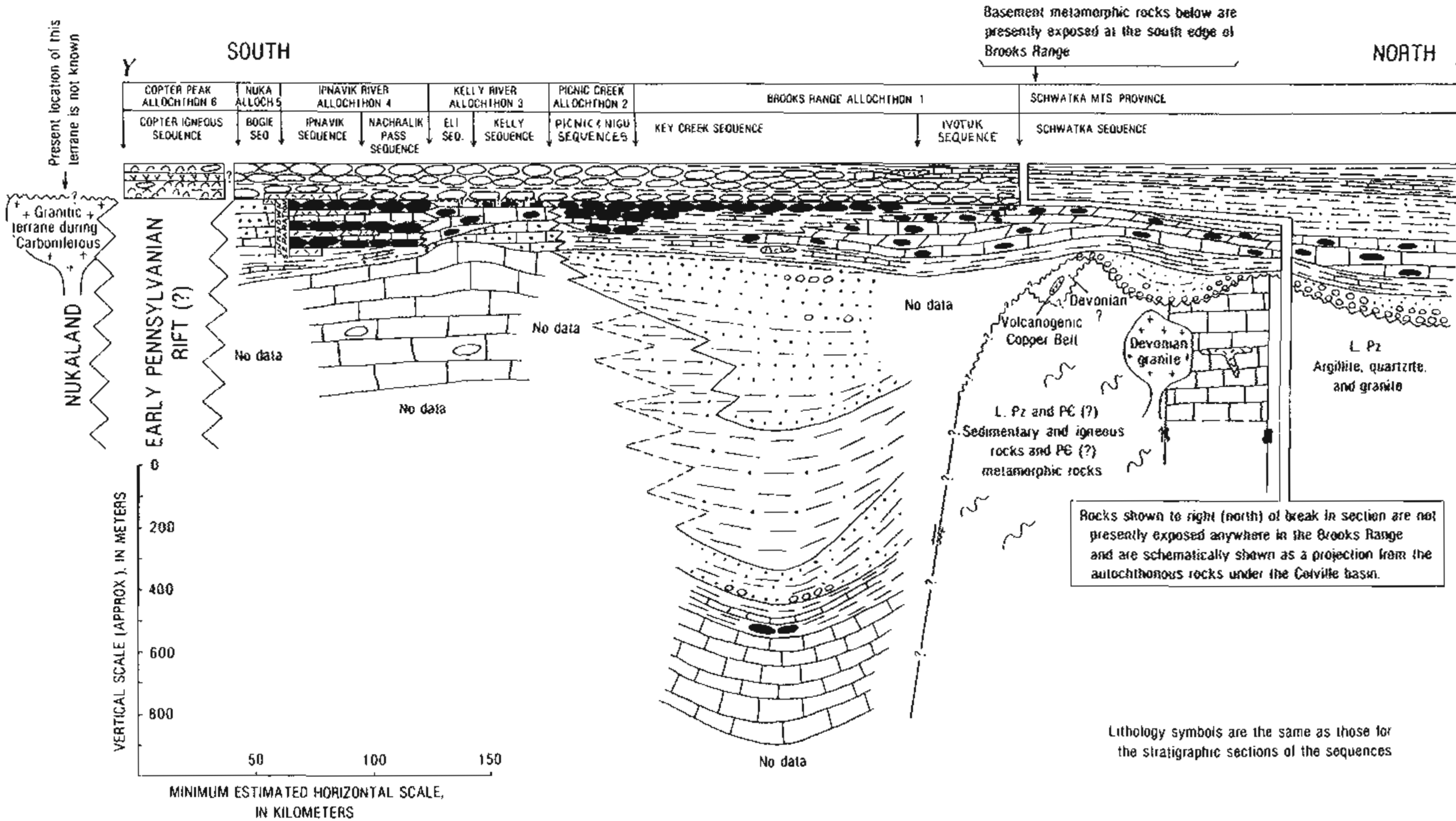

Figure 26. Schematic cross section Y-Y', from the Middle Jurassic palinspastic map of the western Brooks Range (plate 4), showing principal rock lithologies. Lithology symbols are the same as those used in figures 3-21 (plate 2).

mostly called either the Kayak Shale or Utukok Formation. Clastic detritus for the shale and sandstone in sequences that are now part of allochthons one and two probably were derived from a land area to the north. In sequences that are now part of allochthons three, four, and five, Lower Mississippian sandstone is a more prevalent component of the rocks to the west than it is to the east. Thus, it is possible that sands also were being shed from a western and (or) southerly source during this time.

During Late Mississippian and Early Pennsylvanian time, the sediments that were deposited had many pronounced facies changes across the Arctic Alaska basin. Limestone and dolomite of the Lisburne Group were deposited in the Schwatka sequence and in rocks under the Colville basin. These carbonate rocks probably graded and interfingered southward with the Key Creek sequence in which thin and discontinuous carbonate beds are overlain by basinal black carbonaceous shale and chert of the Kuna Formation. The Kuna Formation graded southward into what appears to have been mostly low-energy sediments composed of discontinuous local micritic limestone overlain by well-bedded black chert and subordinate black shale in the Amaruk, Wulik, Picnic, and Nigu sequences. Upper Mississippian rocks of the Wulik and Amaruk sequences were gradational to the south into the Amphitheatre and Kelly sequences that are now part of allochthon three. Here, limestone with nodular to bedded black chert make up the rock units called "micritic limestone", and the Kogruk and Tupik Formations. Most rocks in these sequences were deposited as part of a bioclastic carbonate buildup. A large part of the Kogruk Formation is composed of coarse-grained limestone with locally abundant corals, echinoderms, and other biogenic debris indicative of normal marine and shoaling-water depositional environments (Armstrong, 1970). The sequences of allochthon three thin rapidly to the east and are not recognized at the east margin of the palinspastic map (plate 4). Comparison of sections X-X' and Y-Y' (figs. 23-26) shows that the Kogruk and underlying Utukok Formations were hundreds of meters thicker in the western part of the area than they were to the east. Farther to the south and gradational with rocks in the Eli and Kelly sequences, interbedded black chert and fine-grained limestone of Late Mississippian age formed in the Puzzle Creek, Nachralik Pass, and Ipnavik sequences that are now part of allochthon four. These lithologies were deposited in a low-energy setting, perhaps in a submarine trough between sediments deposited in higher energy settings to the north and south.

A sharp break exists in the sedimentary facies of Upper Mississippian and Lower Pennsylvanian rocks of the Ipnavik sequence and sequences in allochthon five. Black chert is common in Upper Mississippian rocks in sequences of allochthon four and missing in the coeval rocks in the sequences of allochthon five. On the other hand, Upper Mississippian siliciclastic rocks are common in the Bogie sequence of allochthon five and are very rare in coeval rocks of the lower allochthons. It is not known if this sharp facies change represents an abrupt change in depositional setting or if it is an artifact of the incomplete preservation of what might have been a gradational boundary.

During Upper Mississippan (Chesterian) and Early Pennsylvanian(?) time, arkose and arkosic limestone were deposited in the Nuka Formation of the Bogie sequence. These rocks presently are preserved in thin, discontinuous thrust sheets and olistoliths from the Chukchi seacoast to at least as far east as the central Brooks Range. Coarse-grained arkose, indicative of a nearby source, is interbedded with arkosic limestone in many places. Red beds, glauconite, and numerous brachiopod and crinoid fossils are indicative of deposition in shallow-water conditions (Tailleur and Sable, 1963). An unrecognized granitic source area for the Nuka Formation is inferred to have been south of the sequences that are now part of allochthon five.

The hypothetical source terrane for the arkose in the Nuka Formation is herein called Nukaland. During Late Mississippian and Early Pennsylvanian(?) time, there must have been large areas of exposed granitic rocks, because the clastic component for the arkose, which is composed of quartz, microcline, and plagioclase, has a nearly uniform composition for up to 500 km along the east-west outcrop belt of the Nuka Formation. Nukaland also may have been emergent during Middle and Late Devonian time, because quartz, feldspar, and low-grade metamorphic rock fragments were shed into the Bastille sequence at this time. The Kugururok Formation at Mount Bastille has feldspathic limestone at the top of the section and shale with rare, hematite-stained, quartz conglomerate at the bottom of the section. The same source terrane also could have contributed to the shale and siltstone, interbedded with Middle(?) Devonian limestone at the base of the Eli and Puzzle Creek sequences in allochthons three and four.

Late Carboniferous time marks a significant change in lithology and depositional setting in the allochthonous sequences. Radiolarian chert and siliceous shale of the Etivluk Group were deposited in all the sequences of allochthons one through five from Pennsylvanian to Early or Middle Jurassic (Toarcian to Bajocian) time. These rocks record low-energy condensed sedimentation virtually unaffected by continental clastic detritus.

During Permian and Triassic time, the Sadlerochit Group was deposited in the area that later became covered by the Colville basin. Based on subsurface well information and on geologic mapping in the northeast Brooks Range, the clastic facies in the Sadlerochit under the Colville basin is generally coarser to the north and finer to the south (Detterman, 1974; 1976). There are only two places in the southwest and south-central Brooks Range where the Sadlerochit Group is exposed. These are at Shishakshinovik Pass (plate 1) in the east-central Ambler River quadrangle (Mull and Tailleur, 1977) and near Mount Doonerak (fig. 2) in the central Brooks Range (Dutro and others, 1976). At both locations, shale and siltstone have been recognized which are interpreted to be a distal facies of the Sadlerochit Group. Farther to the northeast in the subsurface at Prudhoe Bay and in outcrops in the northeast Brooks Range, near-shore marine and fluvial sandstone and conglomerate compose much of the Sadlerochit. South of the Schwatka sequence in coeval rocks of the Etivluk Group, the proportion of shale to chert was generally greater in sequences deposited farthest to the north compared to those deposited farthest to the south. Thus, the Sadlerochit Group and the age-equivalent part of the Etivluk Group are thought to have been a continuum of depositional clastic facies in which coarse-grained clastic rocks were deposited in a near-shore setting near the present coastline of northern Alaska and progressively became finer-grained southward grading to siliceous shale and radiolarian chert. This gradual facies gradient across hundreds of kilometers of northern Alaska suggests that the Arctic Alaska basin may have been a continental shelf with oceanic conditions south of the rocks in the Bogie and Bastille sequences during Late Pennsylvanian to Jurassic time.

SPECULATIONS CONCERNING THE ROCKS SOUTH OF THE ARCTIC ALASKA BASIN

During Devonian and the first half of Carboniferous time, Nukaland appears to have shed clastic detritus into the southern part of the Arctic Alaska basin. After latest Mississippian or earliest Pennsylvanian time, this source area is not sensed in the sedimentary record. It is unlikely that Nukaland was attached to the south edge of the sequences in allochthon five at the beginning of the Brooks Range orogeny, because parts of a granitic terrane have not been found between allochthons five and six.

There is some evidence to suggest that Nukaland may have become detached, possibly by rifting or strike-slip motion, from the south edge of northern Alaska in the Carboniferous, marking the end of deposition in the Nuka Formation and Lisburne Group throughout the allochthonous sequences. Upper Mississippian and Lower Pennsylvanian sediments in the allochthonous sequences appear to have been deposited on a sea floor that resulted in a complex pattern of high- and low-energy sediments. Before and after this time period, sedimentologic conditions produced much more gradual lithologic changes. It is possible that a rifting event could have produced block faulting in Late Mississippian and Early Pennsylvanian time which resulted in a series of subparallel rises and troughs on the sea floor. Deposition of sediments on a horst and graben submarine topography seems to be the most probable explanation for the many pronounced facies changes that are mapped in Upper Mississippian rock units of different allochthons. At the same time, Carboniferous sediments under the Colville basin were deposited in several large fault-bounded thickened basins that might indicate this was a period of regional extensional tectonics throughout northern Alaska. Such an extensional event also has been proposed to explain the tectonic setting for the Late Mississippian volcanism and lead-zinc mineral deposits in the Key Creek sequence (Metz, and others, 1979; Metz and others, 1982). Perhaps, when Nukaland disappeared, the continental shelf of northern Alaska foundered which resulted in a favorable open-marine environment for radiolaria that was distant from continental clastic sources. The consequent deposition of sediments are the chert and siliceous shale of the Etivluk Group.

The present location of Nukaland is problematical. A rifting event at the south edge of the Brooks Range has been proposed previously to explain the predominance of Cretaceous and younger rocks in the Yukon-Koyukuk province by W. W. Patton (Patton and others, 1977). By this scheme, the metamorphic and granitic terrane south of the Yukon-Koyukuk province, called the Ruby geanticline (fig. 2) by Miller and others (1959), would have been rifted south from the Arctic Alaska basin during late Paleozoic time. However, extensive granitic source rocks for the arkose in the Nuka Formation have not yet been mapped in this region. Most of the granitic rocks in the Ruby geanticline are thought to be Cretaceous in age (Silberman and others, 1979), whereas the source terrane for the Nuka Formation should contain a considerable amount of Carboniferous or older granitic rocks. Stratigraphic study suggests that the Ruby geanticline mostly contains pre-Permian (and probably pre-Ordovician) regional metamorphic rocks (Patton and Dutro, 1979), but no mineralogic evidence has been found from petrographic study of the Nuka arkose to suggest that there were extensive areas of metamorphic rocks in the source terrane. Conclusive evidence for the location of Nukaland is not at hand, and further clues to its location must wait until the geotectonic setting of the continental rocks in central and western Alaska is better understood.

During early Mesozoic time south of sequences that are now part of allochthon five, pillow basalt with intercalated shale and chert formed in the Copter igneous sequence (figs. 23-26). Blocks of limestone, some of which have Devonian fossils, also presently occur within and at the base of the basalt. The stratigraphic setting and tectonic history of the Copter igneous sequence is problematical. If the volcanic rocks were erupted upon a continuous layer of Devonian limestone, then they might have formed in a continental setting. If the limestone blocks are thrust slices from sequences below, then it is possible that the Copter igneous sequence was erupted on oceanic crust south of the Bogie sequence. It has been suggested that the pillow basalts are part of a dismembered ophiolite sequence by Patton and others (1977), but because the basalts consistently occur structurally below gabbros and peridotites of the ophiolite complex, a comagmatic origin for these two suites of rocks is not necessarily an obvious conclusion, as debated by Roeder and Mull (1978).

Intermediate and granitic rocks make up less than ten percent of the exposures in the Copter igneous sequence. In some places granitic rocks intrude the pillow basalts. In other places, basalts and andesites are interlayered. The association of granitic rocks, which are mostly quartz diorite, with basalt and andesite suggests the possibility that parts of the Copter igneous sequence might have island arc affinities. Detailed chemical and petrographic studies might provide more definitive evidence. Remnants of a hypothetical obducted arc may be preserved as the heretofore unexplained Jurassic igneous cobbles and boulders found in Lower Cretaceous conglomerate in flyschoid sediments along the northern foothills of the De Long and Endicott Mountains (Mayfield and others, 1978b).

THRUSTING MECHANISM -- HYPOTHETICAL CONSIDERATIONS

A simple model that seems to explain the great amount of foreshortening in the western Brooks Range can be described as underthrusting (or subduction) of the Arctic Alaska plate beneath another crustal plate to the south (Tailleur, 1969a,b; Martin, 1970; Mull and others, 1976; Gealey, 1980; Mull, 1982). The subthrust plate consisted largely of continental rocks and the upper plate consisted of oceanic crust in allochthon seven. Such a model has been proposed previously by Gealey (1980) as a likely mechanism for many other places around the world where ophiolites have been obducted onto continental crust.

According to this model, the Arctic Alaska plate began to move into a south-dipping subduction zone in about Middle Jurassic time as schematically illustrated on plate 5. When the ophiolite (allochthon seven) was subthrust by the less dense sialic crust below, it was uplifted and cooled to argon-retentive temperatures between 170 and 150 m.y. ago. At the subduction zone, the allochthons were detached from the lower part of the crust on which their sequences had been deposited. The process probably first started at the south edge of the continental shelf where it involved allochthon six and then five. At progressively later stages, allochthons four, three, two, and finally allochthon one detached from their basement along shallow-angle thrust faults as each allochthon was tucked under the previously detached allochthon. The sole thrusts for each allochthon commonly occur below Mississippian strata in the northern De Long Mountains and commonly occur below Devonian strata in the southern De Long Mountains and in the Baird Mountains.

Evidence that the faults began to move at an earlier time in the south than in the north comes from comparison of the sporadic fossil dates in the orogenic flysch at the top of the allochthonous stratigraphic sequences. The basal part of the synorogenic flyschoid mudstone and graywacke, in most places called the Okpikruak Formation, appears to be at least as old as Late Jurassic in the higher allochthons and no older than Early Cretaceous (late Valanginian) in the lowest exposed thrust sheets of the lowest allochthon (Curtis and others, 1983; Ellersieck and others, 1983; Mayfield and others, 1983a). This fossil evidence for the diachronous nature of the flyschoid rocks is also supported by the occurrence of lithologically distinct conglomerate clasts derived from structurally higher allochthons that are now found in the subthrust parts of the Okpikruak Formation in structurally lower allochthons. These relations suggest that lower allochthons were thrust beneath higher allochthons after the higher allochthons had been imbricated and partially eroded.

During the later stages of the underthrusting event, the southern part of the Schwatka sequence and the lower parts of allochthon one, presently exposed in the Baird Mountains and Schwatka Mountains, were moved under more than ten km of thrust sheets. The resulting increase in heat and pressure transformed the rocks into slate, schist, quartzite, and marble of the greenschist metamorphic facies (Nelson and Grybeck, 1979; Gealey, 1980; Mayfield and others, 1983b). In most places, there is a steady and continuous metamorphic gradient southward from unmetamorphosed rocks at the latitude of the Noatak River to mostly recrystallized rocks in the central Baird and Schwatka Mountains.

South of the Brooks Range in the Yukon-Koyukuk province, an extensive terrane of Lower Cretaceous andesitic volcanic and intrusive rocks developed and clastic detritus was shed into the surrounding sedimentary basins. Potassium-argon dates from andesitic volcanic rocks in the Yukon-Koyukuk province (Patton, 1973) show that they were formed during the major thrusting episode in the Brooks Range. For this reason, it is speculated by some geologists that they were a volcanic arc generated from a subduction zone at the south edge of the Brooks Range (Gealey, 1980; Fisher and others, 1982).

The major thrusting process stopped in Early Cretaceous time during, or just prior to, deposition of the sparsely fossiliferous Fortress Mountain Formation which is Albian in age. The southern Brooks Range began to isostatically rebound, erosion continued to strip away the allochthonous thrust sheets, and large quantities of clastic sediments were shed north into the Colville basin during middle and Late Cretaceous time. Most potassium-argon ages from metamorphic micas in the southern Brooks Range are thought to record the uplift and cooling of these rocks between 110 and 80 m.y. (Tailleur and Brosgé, 1970; Turner and others, 1978; Turner and others, 1979).

SPACE PROBLEMS CREATED BY THE SUBDUCTION MODEL

It is assumed that sedimentary sequences of the western Brooks Range were deposited upon an unknown thickness of continental crust. Middle Devonian to Carboniferous parts of the allochthonous sequences contain reefoid, bioclastic, and glauconitic limestone, carbonaceous shale, and quartzose clastic sedimentary rocks that are characteristically deposited near shorelines and in epicontinental marine basins. Because these rock types were deposited for a period of about 50 million years in periodically shallow-water depositional environments, it is probable that their basement was composed of continental crust. Overlying these mid-Paleozoic rocks are radiolarian chert and siliceous shale of the Etivluk Group in the upper part of all the allochthonous sedimentary sequences.

This interpretation of the crustal setting for the siliceous rocks of the Etivluk Group differs from the conclusions reached by some previous studies. Churkin and others (1979a) named a succession of Mississippian to Lower Cretaceous rocks in the De Long Mountains the Kagvik sequence. Primarily on the basis of the siliceous character and fossils present in these rocks, they interpreted their sequence to be of oceanic depositional origin (Churkin and others, 1979b) or continental margin origin (Churkin and Trexler, 1981). The Kagvik sequence correlates with the upper part of the Key Creek sequence and possibly some other sedimentary sequences in this report. The lower part of the Key Creek sequence includes the Endicott Group, which contains fluvial quartzose clastic sediments, coal beds, and other features indicative of an epicontinental origin.

According to the palinspastic model outlined in this report, prior to the Brooks Range orogeny a panel of continental crust probably extended more than 400 km in a north-south direction under the sequences of allochthon one to allochthon five. The present location of the subthrust continental basement for the allochthonous sequences is a mystery. The subduction model outlined in this report requires that an unknown thickness of this crust was consumed at the south edge of the Brooks Range. At present, there is not much geological or geophysical evidence to constrain hypothetical models for the process of crustal consumption in northern Alaska. A simple solution is that the excess crust was subducted into the mantle. If it is assumed that the sialic part of the crust is not dense enough to be returned to the mantle at a subduction zone, then at least some of the missing crust must be under the southern part of the Brooks Range and (or) extend an unknown distance to the south under the Yukon-Koyukuk province.

If some of the excess crust is under the Brooks Range, it is one way to explain why gravity data suggests that the crust seems to be thicker in the southern half of the Brooks Range than to the north or south (Barnes, 1976). Such a crustal thickening process, shown as basement thickening by Roeder and Mull (1978), would also help to explain the greater amount of isostatic rebound that has occurred in the southern Brooks Range compared to the adjacent geologic provinces to the north and south. If some of the excess crust followed a course of shallow subduction south of the Brooks Range, it may help to explain why gravity data indicates a crustal thickness of approximately 30 km in the Yukon-Koyukuk province. This thickness is more similar to that of a continental margin or an island arc than normal oceanic crust.

The thickness of the continental basement which once lay under the allochthonous sequences prior to the Brooks Range orogeny is also a significant uncertainty for developing constraints to a subduction model at the south edge of the Brooks Range. Future deep seismic studies of crustal thickness in the Brooks Range and the Yukon-Koyukuk province might provide some additional clues. Geologic maps of the klippen in the Brooks Range and along the Ruby geanticline (Tailleur, 1969a; Patton and others, 1977; Roedder and Mull, 1978) indicate that the ophiolites are rooted in the Yukon-Koyukuk province. If so, this suggests that a panel of oceanic crust underlies much, if not all, of the province. However, if the basement beneath the ophiolite slab contains some low-density, continental crust, as seems permissible from the gravity model of Barnes (1976), then it is possible that an underthrust basement panel from the Brooks Range may underlie a signficant amount of west-central Alaska. Partial melting of a panel of attenuated sialic crust under the Yukon-Koyukuk province might explain some of the widespread Late Cretaceous granite plutonism south of the Brooks Range.

IMPLICATIONS FOR THE CENTRAL AND EASTERN BROOKS RANGE

Fewer allochthonous thrust sequences are known to occur in the central and eastern Brooks Range in comparison with the western Brooks Range (Tailleur and Brosgé, 1970). Part of the reason seems to be that the eastern two-thirds of the Brooks Range has been eroded to deeper structural levels than the western part, so there are fewer klippe of upper allochthons preserved in this region. Most of the Endicott and Philip Smith Mountains are composed of rocks that correlate both lithologically and structurally with sequences in allochthon one. Structurally higher allochthons have smaller outcrop areas with mainly rubble-covered exposures in the foothills north of the Endicott Mountains. As a consequence, many previous workers in this area have been reluctant to make palinspastic maps that restore these rocks south of rocks that correlate with the autochthonous or parautochthonous Schwatka sequence in the southern Brooks Range.

There is little doubt that the central and eastern Brooks Range underwent a significant compression during the Brooks Range orogeny. Numerous thrust faults and folds affect the rocks as far east as the Canadian border (Brosgé and others, 1976). Correlation of sedimentary rocks in allochthon one across the north-central Brooks Range, correlation of rocks in the Schwatka Mountains province across the south-central Brooks Range, and correlation of mafic igneous rocks along the south edge of the southwest and south-central Brooks Range makes it probable that most rocks exposed in the Endicott and Philip Smith Mountains would be restored south of the southern Brooks Range on a palinspastic map of pre-Jurassic northern Alaska. If the pole of rotation for the Arctic Alaska plate was situated in the Mackenzie delta that controlled most of the thrust dislocation in the Brooks Range, and the leading edge of the plate boundary was along the south edge of the Brooks Range, then a minimum thrust displacement between an ophiolite sheet and the autochthon of about 500 km would be expected for the central Brooks Range with progressively less thrust displacement in the eastern Brooks Range. However, it seems unlikely that a pole of rotation in the Mackenzie delta would be the sole determining factor for thrust displacement in the eastern Brooks Range, because significant thrust faulting with similar displacement geometry also occurred farther to the south in the Canadian Cordillera.

IMPLICATIONS FOR THE SEWARD PENINSULA

It is probable that most, if not all, of the sedimentary and metasedimentary rocks in the Seward Peninsula can be correlated with rocks that are part of the Schwatka sequence and possibly some of the allochthonous sequences in the southwest Brooks Range. Sainsbury (1969) described the rocks of the entire Seward Peninsula as being cut by imbricate thrust sheets which he named the A. J. Collier thrust belt. He interpreted that the upper thrust plates were moved to the north in the western part of the Seward Peninsula and to the east along the east side. The time of thrusting is inferred to have been Early Cretaceous. Similarities in metamorphic grade, mineralogy, structural trends, and Paleozoic stratigraphy between rocks in the Seward Peninsula and rocks in the southwestern Brooks Range have been noted by Tailleur and others (1967) and Patton and Tailleur (1977). These similarities suggest a similar Late Paleozoic and Mesozoic geologic history for the Seward Peninsula and the western Brooks Range.

Late Cretaceous or Early Tertiary tectonism in the Seward Peninsula has been speculated to be the result of an oroclinal flexure in the Bering Straight region (Tailleur, 1969a,b; 1973; Patton and Tailleur, 1977) or a fold belt that cuts across the dominant westerly trends of the Brooks Range (Miller and others, 1959). Regardless of which of these or other younger tectonic deformations occurred in the Seward Peninsula, it is probable that this area was also affected by the same Jurassic to Early Cretaceous thrusting event that affected the Brooks Range. Any scheme that explains the Seward Peninsula on a pre-Jurassic palinspastic basis needs to take into account the dramatic effects of Brooks Range tectonism on western Alaska. For example, if most of the metamorphic rocks in the Seward Peninsula are correlated with rocks in the Schwatka sequence, as suggested by Patton and Tailleur (1977), then the Seward Peninsula would need to be restored hundreds of kilometers to the north in a position west or southwest of the Schwatka sequence on the palinspastic map of this report (plate 4).

CONCLUSION

The first part of the Brooks Range orogeny was a period of low-angle thrust faulting in which great panels of oceanic crust and continental platform and shelf sediments were underthrust by the Arctic Alaska plate. This process is interpreted, in reference to the North American craton, as the underthrusting of the Arctic Alaska plate southward, first beneath oceanic crust, represented by allochthon seven and possibly allochthon six, and later beneath the southern parts of its own sedimentary cover, represented by allochthons one to five. The process appears to have been initiated at the southern edge of the Arctic Alaska plate by the obduction of an extensive ophiolite panel (allochthon seven) in the Middle Jurassic. Initial movement on the thrust faults appears to have become progressively younger from higher to lower in the stack of thrust sheets, and the major thrust faults had stopped most of their movement by Albian time in the Early Cretaceous. From the palinspastic model presented in this report, the minimum thrust foreshortening between the highest structural level and the autochthon is 700 to 800 km. A total thrust foreshortening of greater than 1,000 km is possible.

The underthrusting process moved autochthonous or parautochthonous rocks, presently exposed in the Schwatka Mountains, beneath a substantial thickness of already imbricated allochthonous thrust sheets. Increased heat and pressure resulted in regional metamorphism in the Schwatka sequence and in the lower parts of the overlying lowest allochthon. During this period of underthrusting the continental crust in the southern Brooks Range appears to have been thickened. After the compressional episode ceased, the southern Brooks Range isostatically rebounded, and the northern Brooks Range and Colville basin developed broad folds, high-angle faults, and small-scale thrust faults. These late tectonic processes probably continued from Late Cretaceous into Tertiary time and may be part of the Laramide orogeny in more southerly regions of the Cordillera.

During Devonian and Mississippian time, the southern part of northern Alaska seems to have been an ensialic basin with land areas to the north and south. During late Carboniferous (probably Early Pennsylvanian) time, the southern granitic land area, here called Nukaland, disappeared. Stratigraphic and structural evidence suggests that Nukaland was moved away from the Arctic Alaska basin during a widespread extensional tectonic event by a rift or a strike-slip fault. In late Paleozoic and early Mesozoic time, prior to the Brooks Range orogeny, northern Alaska is inferred to have been an extensive continental shelf with oceanic conditions to the south and a land area to the north. The stratigraphy of this old sedimentary basin and continental shelf has been reconstructed by systematically restoring lower allochthons to the north of higher allochthons. The resulting palinspastic map provides a reasonable stratigraphic model for further study of Paleozoic and Mesozoic stratigraphy in the western Brooks Range.

The tectonostratigraphic model outlined in this report provides a framework that will help in the exploration of energy and mineral resources of this region. In oil and gas exploration, it is crucial that there be some way to predict what rock units will be encountered in the subsurface and what facies trends will occur within key stratigraphic horizons. Unlike the promising areas of petroleum potential in the thrust belts of the Rocky Mountains which commonly are described as being composed of single stratigraphic sequences, prediction of facies trends in rocks of the Brooks Range is complicated by the presence of stacks of thrust sheets that contain multiple stratigraphic sequences. Geologic maps of the stratigraphic sequences in the western Brooks Range show that in different allochthons there are many pronounced facies changes in Devonian and Mississippian rocks, and only a few such changes in Pennsylvanian to Early Cretaceous rocks. The tectonostratigraphic model of sequences and allochthons in this report provides a way to predict these important lithologic changes from one thrust sheet to the next in the subsurface. In minerals exploration, the large lead-zinc-silver and (or) barite deposits that are found within a wide area of the western Brooks Range are known to occur only in Devonian and Mississippian rocks of allochthon one. The allochthon map and cross sections (plates 1 and 3) should aid in the exploration of these favorable rocks by showing where they occur at the surface, and where they are expected to occur in the subsurface.

The palinspastic synthesis of the western Brooks Range is a stratigraphic framework which should provide additional insight into the geologic history of adjacent regions in northern and central Alaska. In the central Brooks Range where most rocks occur in thrust sheets that correlate with structurally lower allochthons in the western Brooks Range, hundreds of kilometers of thrust displacement should have occurred during Late Jurassic and Early Cretaceous time, and the palinspastic stratigraphy, much of which is now apparently eroded away, should have been similar to the stratigraphy described in this report. In the Seward Peninsula where mostly Lower Paleozoic and Precambrian rocks are exposed, important similarities of structural style and metamorphism with the southwestern Brooks Range suggest closely related Late Jurassic and Early Cretaceous tectonic histories. South of the Brooks Range in the Yukon-

Koyukuk province, models for the origin of Cretaceous volcanic rocks and granitic plutons will need to take into account the possibility that the Arctic Alaska plate underthrust this province.

The tectonostratigraphic model leaves many important geologic problems unresolved. The early Paleozoic geologic history and the character and structural style of the Devonian Ellesmerian orogeny in northern Alaska is still poorly understood. The late Paleozoic geologic history of northern and central Alaska is incomplete without knowledge of what happened to the granitic rocks of Nukaland. An important uncertainty about the character of the southern edge of the Arctic Alaska plate just prior to the Brooks Range orogeny could be resolved if the crustal setting of the pillow basalts in the Copter igneous sequence of allochthon six were known. Determination of the origin of these basalts might provide added insight into the origin and process of obduction of the Brooks Range ophiolites. The model for the tectonic evolution of the Brooks Range also is incomplete without better evidence for what happened to the missing subducted(?) sialic crust in the Brooks Range and whether or not the deflection of the mountain trends at the east and west ends of the Brooks Range were formed by oroclinal bends. The answers to these questions will greatly improve our understanding of the tectonic processes that helped shape northern Alaska.

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