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Alaska

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STRATIGRAPHY AND STRUCTURE OF SOME SELECTED LOCALITIES IN THE EASTERN BROOKS RANGE, ALASKA

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William P. Brosgé, J. Thomas Dutro, Jr.,

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INTRODUCTION

The report describes the stratigraphy and structure of areas in the eastern part of the Brooks Range. Detailed field work was done by U. S. Geological Survey Navy Oil Unit party 3 from base camps located between the 142nd and 149th meridians. In a north-south direction the camps extended from the front of the Range on the Echooka River (approximately lat. 69°20'N.) to the southern edge of the Range on the Sheenjek River (lat. 68°30'N.). Party 3 consisted of W. P. Brosgé, Chief; J. T. Dutro, M. D. Mangus, H. N. Reiser, geologists; and R. Olson, cook.

The objective of party 3 during the 1952 field season was the geologic mapping and stratigraphic study of rocks exposed in the eastern part of the Brooks Range. Detailed study of the Lisburne formation was to be made in an effort to extend the work of Survey parties in 1949 and 1950 and to determine potentialities of the Lisburne as a petroleum reservoir in structures to the north. The party also proposed to study and map the Kayak, Kanayut and Neruokpuk formations and to attempt a tie with the eastern Chandalar-Sheenjek River areas as mapped by J. B. Mertie, Jr., in 1927.

Base camps were located on the upper Echooka River, Wahoo Lake, Porcupine Lake, Lakes Peters and Schrader, the upper Sheenjek River, and Elusive Lake, all accessible to Norseman planes; all travel between field stations and camp was on foot. This restricted detailed studies in each area to an approximate radius of 6 miles. However, the formations are so distinctive that once the lithologic contacts were identified, they were easily traced on aerial photographs and a general geologic map of approximately 5,000 square miles of the eastern Brooks Range was made.

On June 11 party 3, consisting of Brosgé, Mangus, Reiser, and Olson, was landed on the ice at party 1's "Cache One Lake". On June 13 party 1 furnished weasels and moved party 3 to its first camp site on the Echooka River. The party worked in this area until June 20. Two sections of Lisburne formation and one each of Kayak and Kanayut were measured. On June 25 and 26 the party moved camp by boat 6 miles down stream to a gravel terrace large enough to accommodate a Norseman on wheels, and on June 27 and 28 all personnel were flown back to Umiat.

On July 2 Brosgé, Reiser, Olson and Dutro were flown from Umiat to Wahoo Lake by float Norseman. The party remained at Wahoo Lake measuring and mapping the Lisburne and Sadlerochit formations. On July 11 Mangus rejoined the party and on the 12th the Norseman shuttled the entire party to camp 3 at Porcupine Lake. The Shublik, Sadlerochit, and Lisburne formations were mapped and incomplete sections of Sadlerochit and Lisburne were measured.

On July 16 the party moved by Norseman to Lake Schrader, remaining there until August 4. Bad weather held up operations and accounted for a large portion of the time spent at this camp. At Lake Schrader a section of Lisburne and Kayak formations, measured in 1948 at Giraffe Creek (Whittington and Sable 1948, p. 6, 7), was studied and remeasured in greater detail; a section of Lisburne and Kayak formations was measured on Snake Creek and an estimated thickness for the Neruokpuk was determined at the south end of Lake Peters approximately 10 miles south of camp.

On August 5 the party was shuttled by Norseman float plant across the divide to Star Lake on the Sheenjek River drainage. Rocks exposed in this area are mostly of the Lisburne and Kayak formations. In order to make a further reconnaissance of the pre-Mississippian rocks and a more positive tie with Mertie's work, (Mertie, 1927) on August 9 Mangus and Dutro made a boat traverse 17 airline miles down the Sheenjek to its confluence with Old Woman Creek. Brosgé and Reiser continued work at Star Lake. On August 15 the Norseman shuttled Brosgé, Reiser, Olson and all equipment from Star Lake to camp 5a at a larger lake. On the following day Dutro and Mangus were flown back to Umiat. Brosgé, Reiser, and Olson went to Elusive Lake to measure a section of Lisburne mapped by party 2 in 1951. On August 21 they also returned to Umiat.

Party 3 was in the field a total of 72 days, of which 31 were spent in actual field work, the remainder being taken up by moving, bad weather, and waiting for planes to become available.

STRATIGRAPHY

Pre-Carboniferous rocks

Neruokpuk schist

The Neruokpuk schist, a great thickness of predominantly metasedimentary rock, was formerly thought to be entirely of pre-Cambrian age and tentatively was correlated with the Birch Creek schist of the Yukon-Tanana region (Whittington and Sable, 1948, p. 4). Leffingwell (1919, p. 105) had earlier considered it as correlative with the Totsen series (Silurian) of the John River area.

The main outcrop area is on an east-trending pair of west-plunging anticlinoria in the upper Canning River region. These anticlinoria coalesce south of Lake Peters to form a continuous belt of Neruokpuk

schist nearly 25 miles wide. The westernmost exposure of the northern anticlinorium is about 5 miles west of the Canning River where it plunges west beneath a cover of younger sedimentary rocks. This belt continues east to the Okpilak River, merging south of Lake Peters with the southern anticlinorium to form the major outcrop belt.

An isolated area of Neruokpuk schist lies between the Echooka and Shaviovik Rivers at the core of a doubly plunging, east-trending anticline approximately 16 miles long and 5 miles wide.

In the upper Sheenjek Valley, a sequence of chert, slate, limestone, and ultramafic rocks crops out in the vicinity of camp 5a near Old Woman Creek. Mertie (1927, p. 119-125) mapped these rocks as a single lithologic unit and considered it of possible Upper Devonian age. As a result of last summer's field work, these rocks are believed to be correlative with the upper part of the Neruokpuk schist.

Lakes Schrader-Peters area.--The Neruokpuk schist can be divided into at least three distinct lithologic units, of which the upper is considered Upper(?) Devonian in age, the middle unit, possibly of Middle Devonian age, and the lower unit, of pre-middle Silurian age.

Lower Neruokpuk unit.--This unit was examined several miles south of Lake Peters where there is a minimum of 2,000 feet of medium- to coarse-grained, gray-green quartz-mica schist with interbedded dark-gray and gray-black phyllites. The upper part is massively bedded and is predominantly schist with abundant vein quartz and quartz porphyroblasts. Gray phyllite, uncommon in this part of the unit, occurs as thin interbeds in the schist. In the lower part, thin interbeds of dark-gray to black "woody-textured" phyllite contain pyrite cubes as large as one-quarter inch in width.

Middle Neruokpuk unit.--At the south end of Lake Peters, the lower unit is overlain by 1,500 to 2,000 feet of interbedded phyllite and schist that has been thrust from the south to its present position. A normal contact with the lower unit was not observed, but this unit is believed to be younger in age. The middle unit is composed of about 60 percent gray-green, brownish-weathering, pencil-fracturing, pyritic phyllite and 40 percent gray-green, gray-brown-weathering, ferruginous, medium-grained, quartz-mica schist. Quartz veins are prominent and a minor amount of olive-green or maroon slate occurs with the phyllite. The different proportion of fine and coarse rocks, the presence of green and maroon slate, the absence of abundant quartz and pyrite porphyroblasts, and the generally finer grain size of the schist differentiate this unit from the lower one.

Imbricate thrust faults and overturned folds are features of the outcrop belt of the two lower units south of Lake Peters.

Upper Neruokpuk unit.--In the vicinity of Snake Creek, about 1,200 feet of thin-bedded quartz-mica schist, schistose sandstone, phyllite, chert, slate, and limestone lies unconformably beneath the basal conglomerate of the Kayak formation. From top to bottom the section includes:

		(feet)
1.	Interbedded quartzite, chert, and phyllite; quartzite is fine-grained, medium gray, brownish weathering, schistose; chert is dark gray to black and thin-bedded; phyllite is dark gray, olive and maroon, and constitutes about 60 percent of the thickness	300
2.	Fine-grained gray-green quartz-mica schist which is thick-bedded, cliff forming, red brown weathering, and has a tendency to split into thin cleavage plates; thin interbeds of medium-gray, slightly calcareous, gray-brown-weathering phyllite comprise less than 10 percent of the thickness	400
3.	Interbedded maroon and olive phyllite and gray-green fine-grained quartz-mica schist	100
4.	Olive and maroon, thin, platy, pyrite-bearing phyllite (these beds appear lithologically similar to those in the basement complex at Simpson).	400
	Total	1,200

This is a minimum thickness because the lower part of the section is talus-covered. At least 100 feet of thin-bedded, dark-gray, fine-grained limestone and calcareous siltstone, which occurs in the upper part of the Neruokpuk formation near the base of Kayak formation on Giraffe Creek east of Lake Peters, appears to have been eroded away in the vicinity of Snake Creek. It can be demonstrated that no less than 200 feet of relief was present on the Neruokpuk surface before deposition of the conglomerate of the Kayak formation. In addition, basal Kayak beds lie with angular unconformity on upper Neruokpuk beds in this area.

Upper Sheenjek Valley.—Upper(?) Devonian strata, described as the chert-slate formation by Mertie (1929, p. 119-125) and considered by him to be either Upper Devonian or early Mississippian in age, are thought to be correlative with the upper Neruokpuk unit described above.

About 5 miles southwest of camp 5a, exposures of slate, chert, shale, and ultramafic intrusives were examined. As no continuous section is present, only the roughest estimate of thickness can be made. There is at least 500 feet of beds composed of dark-gray, black and banded chert; gray-brown, maroon, and olive-green shale and slate; medium-gray, saccharoidal, recrystallized, thin-bedded limestone, and finely crystalline ultramafic rocks.

The maroon slate forms a thin persistent band which can be traced for a considerable distance along strike west from Old Woman Creek, as noted by Mertie (1927, p. 120). The limestone is very finely crystalline with a marmoritic texture and crops out as a 30-foot zone bounded by 20-foot bands of light-gray, orange-weathering hornfels. Both above

and below the hornfels bands are 25- to 50-foot sills of finely crystalline, dark-green, chocolate-weathering, ultramafic rocks. The strike of these beds is generally east or a few degrees north of east.

No fossils were found in this sequence, but it is correlated with beds of similar composition that occur above the Middle Devonian Salmon-trout limestone on the Porcupine River (White, 1952, p. 6). In that area lower Mississippian sandstone and shale lie above this similar sequence; in the upper Sheenjek Valley the Kayak conglomerate lies unconformably above the chert-slate sequence. These rocks could be partially equivalent to either the Kanayut formation or the Devonian shale-slate series (Patton, Brosgé, Mangus 1951, pp. 2-4) that crops out in the central Brooks Range. As the Kayak formation lies unconformably above these beds, a correlation with the Devonian shale-slate strata is more probable. A possible Kanayut equivalent in this area is the Devonian (?) quartzite formation of Mertie (1927, pp. 115 to 118).

Upper Echooka Valley.--The westernmost exposure of the Neruokpuk schist occurs near camp 1 on the Echooka River. At least 1,500 feet of quartz-mica schist, phyllite, and limestone form the core of a doubly plunging anticline. From top to bottom the section consists of:

		(feet)
1.	Gray-brown phyllite and interbedded gray, thin-bedded, ledge-forming chert with medium-gray, fine-grained, thin-bedded limestone near the top . .	300 ±
2.	Gray-brown to gray-green, fine-grained, red-brown-weathering, thin-bedded, moderately calcareous quartz-mica schist with interbeds of gray-brown, pyrite-bearing, pencil-fracturing slate and phyllite	700
3.	Gray-brown, fine-grained, cross-bedded, platy, red-brown-weathering, schistose sandstone with a few interbeds of gray-brown slate and phyllite . .	500
	Total	1,500 ±

These strata are considered partly equivalent to the upper Neruokpuk unit of the Lake Peters area. Similar lithologic types occur at both localities but much of the upper part of the unit near Lake Peters has been eroded away.

Kanayut formation

The Kanayut formation crops out in a belt approximately one-half mile wide along the south limb of the large anticline on the upper Echooka River. Although much thinner and showing some differences in composition from the type section, this is a distinct lithologic unit, separate from the Neruokpuk schist which it overlies.

In the vicinity of camp 1, the Kanayut formation is composed of 900 to 1,000 feet of thin, platy, schistose sandstone, quartzite, and granule-pebble conglomerate with interbeds of siliceous siltstone, slate, and phyllite. Here the contact with the Noruokpuk schist is talus-covered but appears to be conformable.

From top to bottom the exposed section consists of:

		(feet)
1.	Gray-green, coarse-grained, medium-bedded, ledge-forming quartzite; about 40 percent of the thickness consists of gray-brown, bronze-weathering, noncalcareous slate and phyllite	400
2.	Gray-brown, thin-bedded, noncalcareous phyllite and silver-gray, translucent slate with interbedded dark-gray chert	150
3.	Black, plant-bearing clay shale with interbeds of black, ropy, pencil-fracturing mudstone and coal seams 2 to 12 inches thick	40-50
4.	Interbedded gray-brown, red-weathering phyllite and medium-gray to dark-gray, thin-bedded chert . . .	150 +
5.	60 percent gray-brown, medium-grained, red-brown-weathering, thin-bedded, slightly calcareous, limonitic, cross-bedded schistose sandstone; 20 percent light-gray to gray-green, medium-bedded, schistose granule-pebble conglomerate with subrounded to rounded pebbles as much as 1 inch in diameter; 20 percent gray-brown phyllite. Stretched pebbles in the conglomerate have their long axes parallel to the cleavage in some places . . .	200
	Total	950 +

The upper beds are similar in appearance to exposures of the Kanayut formation near Howard Pass and the entire sequence closely resembles the Stuver member of the type area near the Kanayut River 1/.

The Kanayut formation was not examined on the ground in the southeastern Brooks Range, but was traced by aerial reconnaissance east to the confluence of the East Fork of the Chandalar and Junjik Rivers. Here the lower contact coincides with the bottom contact of the quartzitic sandstone and slate mapped as Upper-Middle Devonian (Mertie, 1927, pp. 115-118). It is thought that these sandstones and slates are in part or entirely equivalent to the coarser Kanayut formation sediments farther west.

1/ As the name of Kanayut Lake has been changed to Shainin Lake, the type section of the Kanayut formation will be considered to be at the Kanayut River, where it enters Shainin Lake.

Mississippian rocks

Kayak formation

The Kayak formation, one of the most distinctive lithologic units in northern Alaska, is from 400 to 1,200 feet thick in the eastern Brooks Range where it is composed of black clay shale, quartzite, pebble-cobble conglomerate, and minor amounts of argillaceous arenaceous limestone.

In the upper Echooka Valley the Kayak formation is underlain with no apparent unconformity by the Kanayut formation, and is conformably overlain by the Lisburne formation. In the vicinity of Lake Peters it overlies the Neruokpuk schist with angular unconformity and is disconformably overlain by the Lisburne formation. In the upper Sheenjek Valley it unconformably overlies the Upper Devonian (?) chert-slate formation (Mertie, 1927, pp. 119-125) and is conformably overlain by the Lisburne formation.

Upper Echooka Valley.—In the vicinity of camp 1 (see pl. 1) about 1,200 feet of black clay shale, siliceous fine-grained sandstone, and minor amounts of arenaceous limestone are exposed on both flanks of a major east-trending anticline. From top to bottom the section here exposed consists of:

		(feet)
1.	Black clay shale with calcareous concretions and platy arenaceous limestone interbeds containing abundant bryozoans, brachiopods, trilobites, and crinoid debris	180 ±
2.	Black hard clay shale with thin sandstone interbeds.	500 ±
3.	Shale, as in unit 2, with ironstone concretions . .	200 ±
4.	Interbedded dense gray sandstone and medium-gray, fine-grained, dense, thin- to medium-bedded quartzite with conchoidal fracture	100
5.	Gray-black, hard clay shale and slate	100 ±
6.	Gray, fine-grained, medium-bedded quartzite as in unit 4	100
	Total	1,180 ±

This sequence, especially the upper 900 feet, is quite similar to the type section of the Kayak formation near Kanayut River (Dutro, 1952, pp. 27-30). In the lower 300 feet the Echooka River section is considerably silicified and the resultant quartzites differ from the lowest beds of the type section. In both areas, however, the basal

clastics are composed of clean, clear, rounded quartz grains and there seems to be no doubt about the correlation. Preliminary identifications of the fossils from the upper unit indicate that the fauna is very similar to that of the argillaceous limestone member in the type area.

The Kayak is conformably overlain by the Lisburne formation, but a normal lower contact was not seen in the Echooka region. On the north flank of the anticline the Kayak formation is in high-angle reverse-fault contact with the Neruokpuk schist, and on the south flank of the anticline the lower contact is talus-covered.

Lakes Schrader-Peters area.—West of Lake Peters the Kayak formation is 400 to 500 feet thick and consists of about 300 feet of interbedded, gray, medium- to thick-bedded pebble-cobble conglomerate and dark-gray, coarse sand-sized quartzite overlain by about 200 feet of black clay shale with thin interbeds of arenaceous limestone and black chert.

The conglomerate varies from light gray to dark gray and contains subround to round granules, pebbles, and cobbles of gray, black, and white chert and dense gray siltstone. Though massively bedded, the coarse material is sporadically distributed in lenses and thin zones throughout the lower part of the unit. The conglomerate grades upward into dark-gray thin-bedded quartzite. The overlying shale and limestone are similar to those in the upper part of the Kayak formation in the Echooka Valley and in the type area near Kanayut River.

The Kayak lies disconformably below the Lisburne formation and rests with angular unconformity on the Neruokpuk schist where it crops out along Snake Creek, just west of Lake Peters. West of Snake Creek the Kayak formation crops out in an east-trending band that ranges in width from 1,000 feet to nearly 2 miles. The resistant lower unit forms a north-dipping escarpment with the shales cropping out on the dip slope. Varying relationships between topography and this resistant layer produce the marked difference in outcrop pattern.

On Giraffe Creek, about 4 miles east of Lake Peters, about 250 feet of gray-black clay shale, containing thin interbeds of limestone and bedded black chert near the top and fine-grained quartzitic sandstone near the base, lies disconformably beneath the Lisburne formation. The basal conglomeratic beds are absent at this locality, and the shale lies directly on the Neruokpuk schist.

Fossils collected from the upper half of this section are similar to those described from the type area (Dutro, 1952, especially p. 36) though they may also be related to faunas of the lower part of the Wachsmuth member of the Lisburne formation. The lithologic sequence is similar to the upper Kayak of the Kanayut River region. The basal conglomerate reappears in the Hulahula River Valley several miles to the east where it lies beneath the black shales, as described west of Lake Peters.

Upper Canning River Valley.---In this region the Kayak formation crops out in two belts, a southern one at the main fork of the Canning River and a northern one about 8 miles north of that fork. These exposures were examined by Gryc and Mangus in 1947 and discussed as Noatak formation (1947, p. 5).

The northern belt is a westerly continuation of the outcrops west of Lake Peters. Pebble-cobble conglomerate extends west from Snake Creek to within 5 miles of the Canning River. Near the head of the Sadlerochit River, Whittington and Sable (1948, p. 5) report that these coarse clastics are about 125 feet thick. Where the Kayak formation crosses the Canning River, however, the conglomerate is missing and the basal part of the formation is composed of 10 to 25 feet of light-gray, coarse-grained, medium- to thick-bedded clean quartzite. Here the quartzite is overlain by black clay-silt shale with interbeds of dark-gray, medium-grained, ferruginous, platy, fossiliferous limestone near the lower contact of the Lisburne limestone. The shale contains Mississippian plant fossils (Gryc and Mangus 1947, p. 5). The total thickness of the Kayak on the Canning River is probably no more than 500 feet (Gryc and Mangus 1947, p. 5), this being in line with measured thicknesses further east. Stratigraphic relationships in this area are obscured by bedding-plane faults but the Lisburne is thought to rest conformably on the Kayak formation. No definite evidence regarding the upper Kayak contact has been set forth.

At the forks of the Canning River the lithology of the Kayak formation is quite similar to that described above and the relationships to older and younger formations are again obscured by what probably are bedding-plane thrust faults.

On the basis of lithologic similarities, continuous tracing westward from the Lake Peters area, and stratigraphic position there is little doubt that the beds exposed on the Canning River can be correlated with the Kayak formation. They are so mapped on plate 1. Fossils present do not contradict this hypothesis, though it is possible that faunas from the eastern area are slightly younger than those of the type section near Kanayut River.

Upper Sheenjek Valley.---Although no complete section was examined in the vicinity of camp 5, the Kayak formation is estimated to be 1,200 to 1,500 feet thick. Two hundred to 300 feet of light-gray, medium- to thick-bedded, pebble-cobble conglomerate and quartzite are overlain by 800 to 1,000 feet of black clay shale with thin interbeds of medium-gray, ferruginous, red-brown weathering, fossiliferous limestone in the upper part. This is the quartzite-conglomerate-slate formation of Mertie (1927, pp. 119-125) and is similar to the section west of Lake Schrader, though considerably thicker where cropping out in the upper Sheenjek Valley.

The basal conglomerate lies with angular unconformity on the Upper Devonian (?) chert-slate formation, whereas the upper contact with the Lisburne formation is a conformable one. Faunas from the upper part of the formation have been tentatively correlated with those from the upper part of the Kayak formation in the Kanayut River area.

Lisburne formation

Three complete and three partial sections of the Lisburne formation were measured by party 3. These six sections plus the Katakturuk River section measured by George Gryc in 1951 (personal communication) and the Galbraith Lake sections measured by Brosgé and Reiser in 1950 are shown on plate 5. Correlative horizons are shown on the section with solid lines. Interpreted changes in carbonate facies from section to section are shown by lithologic patterns bounded by broken lines. The members and some of the zones established in the type section at Kanayut River were traced in 1952 into the eastern Brooks Range. Contacts between members are based principally on fossil control; zone boundaries principally on lithologic breaks. All are subject to revision after paleontologic work on the collections has been completed.

Because only a few of the zone boundaries (the base of zone 9, the top of zone 4, and the base of zone 3 of the Alapah member) have been traced, individual zones will not be described in detail.

Wachsmuth member.—The Wachsmuth member was seen in only two of the six sections. It is not exposed at Wahoo Lake, Porcupine Lake, or Elusive Lake, where the incomplete Lisburne sections were measured. At Lake Schrader the Wachsmuth is missing, and Lithostrotion-bearing, red-weathering limestone of the Alapah member rests disconformably on shale of the Kayak formation. At the Echooka River the Wachsmuth member is only 120 feet thick, and at the Sheenjek River it is 630 feet thick, both thicknesses being considerably less than that of the Wachsmuth member farther west. At both places the contact with the Kayak formation appears to be conformable. Black shale and red, argillaceous, bioclastic limestone of the topmost Kayak formation give way to a zone of red- and yellow-weathering, black, shaly limestone and course bioclastic limestone in the basal part of the Wachsmuth member. This zone, 80 feet thick at the Echooka River and 160 feet thick at the Sheenjek River, corresponds lithologically to zone 1 of the type section.

Plate 2 is an isopachous map of the Wachsmuth member based on sections measured by the Lisburne field parties of 1949, 1950, and 1952, by Whittington and Sable in 1948 on the Okpilak River, and by Keller and Detterman on Flood Creek in 1951. It has been assumed that the Wachsmuth member is thin in the incomplete sections at Wahoo Lake and Porcupine Lake. The lowest exposed limestones of the Alapah member at Wahoo Lake are red weathering and shaly, a feature typical of the basal Lisburne formation whether it be Wachsmuth as at the Echooka and Sheenjek Rivers or Alapah as at Lake Schrader. Therefore, the base of the

measured section at Wahoo Lake is assumed to be close to the base of the formation. Because the Porcupine Lake section is quite similar to that of Wahoo Lake, it is assumed that the unexposed parts of the two sections are also similar. As mapped, (pl. 2), a linear belt of maximum thickness trends slightly north of east from the Kanayut-Chandler Rivers area; its thickness probably decreases eastward, and decreases northward to zero at the latitude of Lake Schrader.

Alapah member.---The Alapah member comprises most of the Lisburne formation exposed in the eastern sections. The basal contact of the Lisburne formation is exposed in only three of these sections. At Lake Schrader the Alapah member rests disconformably on the Kayak formation. At the Echooka River it is only 50 feet above zone 1-type Wachsmuth member limestone; the disconformity at the base of the Alapah member may account for the absence of zones 2, 3, and 4 of the Wachsmuth member. At the Sheenjek River the contact seems conformable.

Only a few of the 10 zones into which the Alapah member has been divided in the type section at Kanayut River can be traced to the eastern sections. The rocks are mostly dark and dominantly fine grained. The most prominent break in lithology is approximately at the base of zone 9, and is indicated on plate 5 by a heavy line that separates a zone of mostly light- to medium-gray carbonates at the top of the Alapah from predominantly dark- to medium-gray carbonates in the lower part. Almost all the coarser-grained limestones, as well as most of the lithographic and sublithographic limestone, and about half the dolomites are included in the lighter-colored zone. According to Krynine and Folk, (1950, p. 4) lightness of color in the Lisburne indicates that fine dark organic debris has been winnowed out, and thus correlates with coarseness of grain size of the calcite fragments. This is borne out in the Sheenjek River, Porcupine and Wahoo Lakes sections where coarse- to medium-grained limestones are concentrated in the lighter-colored zone. In the sections along the northern edge of the mountains, however, coarser rocks are rare, and lithographic and sublithographic limestone is common in this light zone.

Chert and silicified limestone are common to abundant throughout each of the sections. Although in the western sections previously studied, almost all the chert is dark gray, in the eastern sections there is much light-gray chert. Most of this light-colored chert occurs in the zone of lighter carbonates; most of the dark chert occurs in the zone of darker carbonates. Dolomite is present within two stratigraphic intervals in the Alapah member: one, in the lower part of the lighter zone where it is restricted to the northern section; two, at the middle and lower part of the darker zone where dolomite is more widespread, but tends to pinch out northward. Except for some coarse-grained dolomitic limestones near the top of the Katakturuk section, the dolomite is almost entirely fine-grained, much is dense and black. About 20 percent is impure, pale red to yellow-weathering, and about 50 percent partly silicified.

At the Echooka River and at Wahoo, Schrader and Elusive Lakes, the lowest part of the Alapah is more argillaceous than the rest of the member. The lower limestone and dolomite beds are gray black, partly red, yellow, and brown weathering and include many beds of shaly limestone, in this respect being similar to the basal part of the Wachsmuth member. However, Lithostrotion colonies and Gigantoproductus are especially abundant in these more argillaceous rocks.

Boundaries of the type zones of the Alapah member have been drawn as follows: the base of zone 9 is approximately at the base of the zone of lighter-colored carbonates, to include in zone 9 the coarser limestones, the upper dolomites, and most of the lithographic limestones; the top of zone 4 is at the top of the lower dolomite zone; and the base of zone 3 at the base of the dolomite. Although these zones do not include dolomite in the type section at Kanayut River, much dolomite is present in these zones at Alapah Creek and Chandler Lake. Zones 1 and 2 include the more argillaceous limestones and dolomites.

The Alapah member is overlain disconformably by the Sadlerochit formation, with the contact exposed in all but the Sheenjek River section. The upper 50 feet of limestone is limonitic to pyritic, partly yellow weathering, and includes black, nodular to bedded chert. Except at Lake Schrader the topmost bed is coarse- to medium-grained limestone. On Giraffe Creek near Lake Schrader, the topmost 50 feet is black, fine-grained, pyritic limestone that includes clay shale breaks, and overlies sublithographic limestone. One-quarter mile east of the creek the black shaly limestone and part of the sublithographic limestone are missing from the top of the section, indicating 50 to 100 feet of relief on the disconformity. At each of these exposures pyrite is restricted to the topmost strata, even though they are at different horizons, so the pyritization seems to be related to the erosional surface rather than to a depositional environment of the Lisburne. At Elusive Lake, the topmost 8 feet of medium-grained limestone has been replaced almost entirely by massive chert. Locally at Porcupine Lake the coarse-grained limestone from 15 to 65 feet below the contact has been replaced by rust-colored, glassy chert. Associated with the chert is limestone containing some fluorite and azurite.

Another possible disconformity is at the top of zone 4. In sections measured on the east and west sides of Lake Schrader there is a 5 foot thick intraformational conglomerate in the dolomite about 50 feet below the top of zone 4. At the Echooka River the topmost dolomite bed of zone 4 contains silt particles and fresh pyrite.

Thicknesses of the Alapah member are shown by an isopachous map (pl. 3). The narrow linear basin that coincides with the northern slope of the Brooks Range west of Galbraith Lake was defined by field work of 1950 and 1951. Stations in the foothills northwest of Chandler Lake are from Patton and Tailleur's work in 1949 (Patton and Tailleur, 1950, p. 5). The 1952 field work, plus sections measured by Keller and Detterman on Flood Creek in 1951, Gryc on the Katakturuk River in 1951, Whittington and Sable on the Okpilak River in 1948, and Gryc and Mangus

on the Shaviovik River in 1947, defines a broad northward extension of the basin coinciding with the northward bulge of the Range in the Canning River area. The maximum thickness of the Alapah member in this part of the basin is 3,310 feet and exceeds that in the western part by 700 feet. Control is lacking to prove whether the thickening is continuous from west to east, but the sharp bend in the isopachous lines near the 148th meridian suggests that it is discontinuous.

Control is also lacking for the rate of northward thinning in the Shaviovik River area; the dashed isopachous lines there are based on extrapolation (pl. 3). In the eastern part, as in the western part of the basin, the greatest and most rapid changes of thickness from north to south are in the lower four zones of the Alapah member. The limestones above the base of zone 9 maintain an almost constant thickness from the Sheenjek River northward across the basin to the Echooka River and Lake Schrader. From there they thin northward toward the Katakturuk River. Accordingly, northward extrapolations of thickness have been made zone by zone and then added to give the total thickness of the member. These extrapolations indicate that the lower zones of the Alapah pinch out rapidly in the foothills area, but that the 9th and younger zones are fairly widespread.

Lake Schrader section.--The Lisburne formation at Lake Schrader disconformably overlies the Kayak formation. The measured 1,835-foot section is overlain disconformably by the Permian Sadlerochit formation. Three separate Lisburne sections served as a basis for the composite section shown on plate 5.

The section is mostly fine grained limestone and dolomite, coarse-grained rocks comprising less than 4 percent of the exposed sequence. Fine-grained, dark- to medium-gray, silicified dolomite constitutes approximately 35 percent of the section. The change from dark to light-colored rocks, so apparent above zone 9 in Lisburne sections to the south, is lacking here. Silica, present in silicified limestone and chert, comprises approximately 8 percent of the thickness. At Lake Schrader the earliest Lisburne was deposited in Alapah time; lithostrotioncid corals occur in the lowest beds. The first lithologic break, between the zones 2 and 3 of the Alapah, is 280 feet above the base. The lower 280 feet is dark, fine-grained, mostly red-weathering limestone with the basal 145 feet thin-bedded and shaly and the upper 135 feet thicker-bedded. Black nodular chert occurs 100 feet below the top of zone 2 and constitutes less than 1 percent of the rocks.

Zones 3 and 4, 570 feet thick and approximately 50 percent dolomite, can be correlated with dolomitic zones 3 and 4 of the Echooka and Wahoo Lake sections. This dark-colored, fine-grained dolomite is characteristic of known low-porosity dolomite zones elsewhere in the Lisburne. The remainder of the section is dark, reddish-weathering, fine-grained, medium-bedded limestone. An intraformational conglomerate, possibly correlated with the intraformational conglomerate in the Echooka section, occurs 500 feet above the base, but does not mark a change in the lithologic continuity of the zone. The conglomerate is 4 feet thick and is arenaceous dolomite containing particles of gray chert and clay shale. Zones 5 through 8, 330 feet thick, include a more

cherty, medium-gray, sublithographic limestone. Approximately 5 percent of this sequence is chert, black chert nodules occurring in the bottom 40 feet of the section, white chert nodules comprising the silica present in the upper part.

From the base of zone 9 to the Lisburne-Sadlerochit contact, 920 feet of carbonate rock is fine-grained and predominantly medium gray. The lower 480 feet is almost entirely silicified dolomite; the next 420 feet is predominantly thick-bedded lithographic limestone; the top 20 feet of Lisburne consists of medium-bedded, dark-gray, fine-grained, yellow-weathering limestone that contains pyrite granules.

Upper Echooka River section.--The Echooka River section (pl. 5) is a composite of two sections, one measured upward from the Kayak formation contact on the west side of the river at Camp One, the other measured downward from the Sadlerochit formation contact east of the river about 3 miles downstream. Although both locations are on the north flank of the major anticline exposing Neruokpuk schist, they are separated structurally by several minor folds and faults. The total thickness of Lisburne formation is 2,535 feet, of which 85 percent is limestone, 12 percent is dolomite, and 3 percent is chert and silica.

About 130 feet of the Wachsmuth member is present at the bottom of the section. Black shale of the Kayak formation, immediately beneath the Wachsmuth beds, contains thin beds of coarse-grained, yellow-weathering, fossiliferous limestone, and one bed of fine shaly limestone. Similar rocks are present in the Wachsmuth member. The contact was drawn at the top of the highest black shale and the base of the lowest thick unit (30 feet) of shaly limestone. This shaly limestone is overlain by 55 feet of coarse, yellow-weathering fossiliferous limestone which in turn is overlain by about 100 feet of thin-bedded to shaly limestone. The lowest Lithostrotion is just above the thin-bedded to shaly zone. The Alapah-Wachsmuth contact has been drawn at a bed of banded chert near the middle of the thin-bedded to shaly limestone, putting the shaly limestone in the basal part of the Alapah member.

Zones 1 and 2 of the Alapah member are 700 feet thick. The lower half consists of 55 feet of dark shaly limestone overlain by dark, fine-grained, thick-bedded, yellow-weathering limestone with some black chert and clay partings and one thin dolomite bed. The upper half is dark-gray, thick- to massive-bedded, fine-grained limestone of which the top 75 feet is reddish-weathering lithographic limestone. Massive beds just below the lithographic limestone are separated by shaly partings. Lithostrotion and Gigantoproductus are common through this upper half of zones 1 and 2.

Zones 3 and 4 together are 370 feet thick and are mostly dark, fine-grained limestone. Chert and silica are rare. Three thin dolomite beds serve to correlate these zones with zones 3 and 4 of Wahoo Lake and Lake Schrader. The lowest and highest of these dolomites are pyritic and all are red to yellow weathering; the upper dolomite is silty.

From the top of zone 4 to the base of zone 9 are 490 feet of fine-grained medium-bedded limestones. The lower part contains a little black chert. Beds 270 to 430 feet above the top of zone 4 contain 15 to 20 percent of white to pink and yellow chert. The change from dark to medium-gray limestone occurs 40 feet above the lowest of these light cherts, and they are overlain by 50 feet of light-gray lithographic limestone just below the base of zone 9.

The sequence above the base of zone 9 is 860 feet thick. The lower half of the unit is light- to medium-gray, fine-grained limestone and dolomite. Silicified limestone and white chert are abundant throughout. About 50 percent of the dolomite weathers yellowish. The bed of limestone immediately below the dolomite is pyritic. The upper half of the unit is medium to dark gray, with fine-grained massive limestone at the base and two zones of coarse- to medium-grained limestone, separated by a zone of sublithographic limestone, at the top. The limestone just below the basal quartzite of the Sadlerochit formation is coarse-grained and limonitic. Twenty feet below the quartzite are three thin beds of black chert in yellow-weathering limestone. A bed of pyritic limestone 260 feet below the contact is at about the same horizon as similar pyritic limestones at Lake Schrader and Wahoo Lake.

Wahoo Lake section.--This section was measured in cutbanks of the Dry Fork of the Echooka River where it crosses the south flank of a large anticline in the Lisburne formation about 3 1/2 miles south of Wahoo Lake. The Sadlerochit formation flanks the anticline. The structure has not been breached deeply enough to expose the base of the Lisburne. Near the axis is a zone of conspicuous minor folds and faults about 400 feet above the base of the measured section. Beds could not be traced through this zone, but about 500 feet of correlated section is duplicated on each side.

About 700 feet, stratigraphically, above the fault zone 1,200 feet of silicified dolomites is exposed. The lower 600 feet of these dolomites includes five brecciated zones that cross bedding planes. These are assumed to be tectonic breccias and the lower 600 feet of dolomite duplicates the upper 600 feet.

The total exposed section, taking into account duplication by faulting, is 3,310 feet. All this is in the Alapah member. The lowest 950 feet, comprising zone 2 and probably zone 1, is dark-gray to gray-black limestone, dolomite, and dolomitic limestone. Except for 70 feet of gray-black lithographic limestone at the top, the upper half of this unit is mostly dolomite and dolomitic limestone and is about 50 percent red to yellow weathering. Shaly limestone occurs near the top and bottom of the unit. Black chert is abundant, making up 6 percent of the rock. Lithostrotion and Gigantoproductus are restricted to this unit and are very abundant; many beds composed almost entirely of coral colonies.

Zones 3 and 4 together are 700 feet thick. Except for 100 feet of limestone at the base, these zones are almost entirely gray-black, fine-grained dolomite. The dolomite is silicified throughout and contains about 10 percent ragged silica, and 3 percent light-gray nodular chert and some black chert.

The limestone in the 740-foot interval between zones 4 and 9 is fine-grained and dark to medium gray, except for 40 feet of light-gray lithographic limestone at the top. This marks the base of the zone of lighter-colored rocks. One 20-foot bed of coarse-grained limestone is near the center of the unit. All beds are cherty or silicified; white chert amounts to 5 percent, black chert, 3 percent, and silicified limestone, 2 percent. A few very thin beds of dolomite are present in the lower half.

The limestone above the base of zone 9 is mostly light to medium gray, but there are scattered dark limestone beds in the upper half. The unit is 960 feet thick, with four zones of coarse-grained limestone comprising about one quarter of the thickness. One coarse zone is at the very base, two at the middle and one at the very top of this unit. Just below the coarse limestone in the middle of the unit is 90 feet of light-gray lithographic limestone. This, and the overlying 100 feet of limestone, contains about 5 percent white chert. The upper half of the unit has scattered black chert nodules. A 10-foot dolomite near the base of the unit has been correlated with the base of the zone 9 dolomites of the Echooka and Lake Schrader sections.

The top of this unit is 35 feet of medium- to dark-gray, coarse-grained, limonitic, yellow-weathering fossiliferous limestone. This is underlain by 5 feet of clay shale followed by 5 feet of black bedded chert and 20 feet of cherty, fine-grained limestone, and is overlain by 40 feet of pyritic siltstone and silty limestone of the Sadlerochit formation. Fifty feet of silty to conglomeratic quartzite overly the siltstone.

A thin-bedded, pyritic, shaly limestone, interbedded with silt shale 300 feet below the top of the Lisburne, has been correlated with pyritic limestone at a similar position in the Lake Schrader and Echooka River sections.

Porcupine Lake section.--In the 1,670-foot section near Porcupine Lake, zone 4 of the Alapah member, is the lowest exposed stratigraphic horizon. From zone 4 to the base of zone 9, the Lisburne is predominantly a dark-gray, fine-grained, medium- to thick-bedded limestone. Above the base of zone 9 the strata are lighter-colored and practically all the coarse-grained limestone (11 percent of the entire section) are present in this interval. Predominantly light-colored chert comprises 5 percent of the section. Silicified limestone, in nodules and beds, comprises less than one percent of the section; no dolomite is present.

From the base of the section to the top of zone 4 (190 feet) the limestone is fine-grained, dark gray, thick- to medium-bedded. A few black chert nodules occur near the base and about 130 feet above the base of this interval.

In the 900-foot interval from the top of zone 4 to the base of zone 9, the same dark-colored, fine-grained limestone prevails. A 40-foot dark-gray lithographic limestone bed, occurring 220 feet above the base of the section, is correlated with a similar unit at Wahoo Lake. The only coarse-grained limestone below zone 9 is 20 feet thick and occurs 385 feet above the base of the section. This interval is correlated with similar horizons in the Wahoo and Sheenjek sections. From the base of zone 9 to the top of the section (Sadlerochit contact) the rocks are distinctly lighter colored and approximately 55 percent is coarse-grained. This coarse-grained facies is correlated with coarse zones in the Sheenjek and Wahoo sections, as shown on plate 5.

The bottom 100 feet of zone 9 is predominantly a coarse- to medium-grained limestone with only a few large gray chert nodules present. This is overlain by 120 feet of medium-gray, fine-grained limestone with approximately 7 percent chert. In the interval from 1,050 to 1,260 feet above the base of the section, the predominant rock type is medium- to thick-bedded, massive, coarse-grained, medium-gray limestone. Chert, which constitutes 5 percent of the beds, is gray to white and occurs in beds as well as nodules. From 1,260 to 1,315 feet above the base of the section the limestone is thick-bedded, lithographic, and light to medium gray with about 7 percent gray chert nodules. This is overlain by 65 feet of shaly limestone containing lenses of white chert and coarse limestone. From 1,380 to 1,575 feet above the base of the section the limestone is a homogenious, medium-gray, medium-bedded, lithographic limestone that weathers a mottled brown and gray. From 1,575 to 1,655 feet above the base of the section a medium-gray, medium- to fine-grained limestone occurs with 35 percent of brown and gray chert. The top 15 feet of the Lisburne formation is thick-bedded, medium- to dark-gray, coarse-grained limestone. This coarse-grained unit is correlated to similar ones at the top of the Wahoo Lake and Echooka River sections. The Sadlerochit beds that disconformably overlie the Lisburne are dark-gray clay shale.

Sheenjek River section.---Near camp 5 on the Sheenjek River 2,050 feet of Lisburne conformably overlies the Kayak formation. The thickest Wachsmuth sequence measured during the 1952 season is included in this section. The Wachsmuth-Alapah contact is 690 feet above the base of the Lisburne. The top of the formation is not exposed and the section is incomplete. The section is composed predominantly of dark-gray, fine-grained limestone, with black chert constituting 15 percent of the thickness. Limestone beds lacking chert are usually silicified to some extent. A sequence of fine-grained, medium-gray dolomitic beds approximately 20 feet thick occurs in the Wachsmuth member. A few thin beds of coarse-grained limestone are scattered throughout the section.

The yellow-weathering limestone in the lower 160 feet of section may be correlative with similar yellow-weathering, though much thinner, limestone beds that are at the base of the Lisburne formation at the Echooka River.

Zone 1 of the Wachsmuth member is 160 feet thick. The lower 50 feet is interbedded dark calcareous shale and coarse-grained, limonite-flecked, dark-gray limestone. The upper part is predominantly medium- to fine-grained, medium-gray limestone with about 10 feet of dark-gray fine-grained shale on top. The combined zones 2, 3, and 4 consist of shaly, laminated limestone containing 40 percent black chert. An intraformational conglomerate 2 to 3 inches thick is present 408 feet above the base. This suggests a minor disconformity during Osagian time in this area. Zone 1 of the Alapah member consists of thick-bedded, fine-grained, dark-gray limestone. Large irregular black chert nodules that comprise 25 percent of the unit serve as a good marker for the zone. Zones 2 through 4, 140 feet thick, consist of dark, fine-grained massive limestone with black chert stringers and silicified lime nodules composing 25 percent of the sequence. Lithostrotions, which are not abundant, occur through 730 feet of section beginning 55 feet above the base of zone 2. Zones 4 to 9 are considered together and include 350 feet of predominantly dark-gray, fine-grained, thick-bedded limestone. One conspicuous break occurs 150 feet below the base of zone 9 where there is a 20-foot bed of medium-gray, coarse-grained limestone that is tentatively correlated with a similar horizon in the Porcupine Lake section.

Above the base of zone 9, the top 720 feet of limestone is generally light-colored and coarse-grained. There are, however, several noticeable occurrences of dark, fine-grained rocks. A dark-gray lithographic limestone, correlated with a similar lithographic limestone at Porcupine Lake occurs 270 feet above the base of zone 9. A shaly, dark gray, fine-grained phosphatic (?) limestone marks the top of the lighter-colored sequence about 200 feet below the top of the Lisburne formation. This interval, approximately 50 feet of thick-bedded black chert and clay-silt shale, resembles Kiruktagiak member of the Lisburne formation and possibly represents an easterly extension of that member. From the Kiruktagiak-like beds to the top of the section, bedrock is almost completely covered by talus, and steep dips suggest the possibility of a fault. The section is capped by 30 feet of fine-grained, dark- to medium-gray siliceous limestone containing approximately 15 percent of chert.

An interesting feature of the Lisburne in this area are caves, which are roughly restricted to horizons at and above the intraformational conglomerate, 490 feet above the base of the section. They occur about 1,000 feet above the valley floor. The caves, widest at their mouths, are approximately 9 feet across, and rapidly decrease in size, ending within 20 or 30 feet of the entrance.

Elusive Lake section.—This section was measured in an overturned anticline about 2 miles southeast of Elusive Lake. The base is not exposed, and the entire 1,300 feet of measured section is in the Alapah member. There is only 50 feet of dolomite, in thin beds near the base of the section. About 2 percent black chert and 2 percent silicified limestone occur throughout the section.

The lower 145 feet is dark-gray to gray-black, fine-grained, chert-free, brownish-weathering limestone containing zones in which Lithostrotion and Gigantoproductus are abundant. These strata have been placed in zone 2.

Zones 3 and 4 together are 400 feet thick. The rocks of the lower half of this unit are dark, fine-grained, thin-bedded to shaly, and include all the dolomite in the section. A thin, pyritic, coarse-grained limestone is at the top of the lower part. The upper half of the unit is largely thick-bedded, dark, fine-grained to sublithographic limestone. The lower half of the unit contains black chert; the upper half has silicified limestone.

The 550 feet of limestone between the top of zone 4 and the base of zone 9 is all dark and fine-grained and about 50 percent is sublithographic. All is thick-bedded except for three thin zones of very finely and evenly laminated limestone interbedded with the sublithographic limestone in the lowest third of the unit. About 10 percent of the laminae have been replaced by silica. Nodules of silicified limestone occur throughout the unit and are found together with black chert nodules on the upper half. The top 35 feet contains 10 percent of black layered chert.

The base of zone 9 coincides with the break between the dark and the medium-gray limestones. Two hundred and eighty feet of limestone, mostly lithographic to sublithographic, is above this boundary. The lower half contains about 2 percent black chert, the upper half about 5 percent silicified limestone and light chert. Five feet of limestone just below the Sadlerochit shale has been largely replaced by limonitic chert. Beneath this is 10 feet of coarse-grained limonitic limestone and 25 feet of fine-grained, pyritic limestone with 5 percent white chert and silica.

Permian rocks

Sadlerochit formation

The lower Permian Sadlerochit formation ranges from about 600 feet to nearly 1,800 feet in thickness in the area studied by party 3 in 1952. Sections were measured just south of Wahoo Lake, near Porcupine Lake, and about one-half mile west of camp 4 near Lake Peters (see pl. 6).

Wahoo Lake area.—At Wahoo Lake more than 1,200 feet of medium-gray to brownish-gray, fine- to medium-grained, ferruginous sandstone, gray-black siltstone, and gray-black clay shale lie disconformably above the Lisburne formation. A thin zone of light-gray, orange-weathering limestone occurs at the base and contains an invertebrate fauna identical to that listed from the type area of the Sadlerochit formation (Leffingwell, 1919, p. 114). This fauna is now considered of lower Permian age (Mertie, 1929, p. 124). Because contacts with younger formations are not exposed in this area, the complete thickness is not known. Fifteen hundred feet is a reasonable estimated thickness for the Sadlerochit formation in the Wahoo Lake area.

Keller and Morris (1952, p. 3-8) divide the Sadlerochit formation into three units where it crops out along the front of the Range between the Echooka and Canning Rivers. In the Wahoo Lake section, a unit comparable to their lower unit is about 540 feet thick. A middle shale-siltstone unit is 360 feet thick and an incomplete upper unit is 300 feet thick. If the upper unit in the Wahoo Lake area is comparable in thickness to that along the Range front, the total Wahoo Lake section may be 1,300 to 1,800 feet thick.

Porcupine Lake area.—The Sadlerochit formation crops out in a complex east-trending synclinorium in the vicinity of camp 3. Incomplete sections indicate that at least 600 feet of gray siltstone and gray-black, pyritic clay shale with a few thin beds of fine-grained limestone overlies the Lisburne formation with apparent disconformity. This sequence is more finely clastic, more pyritic and more calcareous than the typical Sadlerochit formation and contains some thin-bedded dark-gray chert. In general, this section lithologically resembles the lower part of the Sadlerochit formation as described farther west by Keller and Detterman (1951, p. 6). These sections southwest of the Ivishak River were correlated with the Siksikpuk group by Keller and Detterman (1951, p. 7). Ammonites, found near Porcupine Lake about 400 feet above the base of the Sadlerochit formation, have been tentatively correlated with similar fossils collected by Keller and Detterman in 1951 and are considered to be middle Permian in age. (Mackenzie Gordon, Jr., personal communication).

Lakes Schrader-Peters area.—At least 1,600 feet of fine-grained, gray, ferruginous sandstone, dark-gray siltstone, and gray-black silt shale crop out along the front of the main mountain range both east and west of camp 4. This thickness is considerably greater than previously reported for the eastern area (Leffingwell, 1919, pp. 113-115: Whittington and Sable, 1948, pp. 8-9).

The three major units recognized farther west are apparently unrecognizable in this region. Basal sandstone grades upward into silt shale within 250 feet of the bottom of the section. This shale, with interbedded siltstone, is about 300 feet thick and is overlain by approximately 300 feet of ferruginous sandstone. The upper 800 feet is composed of silt slate with a few thin beds of siltstone and sand-

stone. Because the section illustrated on plate 6 is a composite one, it is possible that the Sadlerochit formation is not as thick as postulated. However, the general succession of beds is correct and the thickness is of the right order of magnitude.

No fossils were collected here but the age of the Sadlerochit formation has been fairly well established as indicated above. Available evidence demonstrates that the basal beds of the Sadlerochit formation were deposited on a post-Lisburne erosion surface that had at least 50 to 100 feet of relief in the vicinity of Lake Schrader.

Triassic rocks

Shublik formation

The Shublik formation, a distinctive lithologic unit, crops out in a large synclinorium in a complex series of tight folds and faults. In the vicinity of Porcupine Lake, approximately 250 to 300 feet of black shale, phosphatic siltstone, and dark-gray-black limestones occur. Near what was thought to be the base of the section is a black iron-stained shale containing fossiliferous limestone nodules. These nodules contain several types of pelecypods, including Monotis. At another location, which was also thought to be near the base, is about 20 feet of thin-bedded, (2-4 in.) hard, dense, fine-grained, noncalcareous, orange-yellow-weathering, medium-gray siltstone. Directly overlying the siltstone is thin-bedded, black, pyritic, chert-bearing shale, which is overlain by thin- to medium-bedded, silty, creamy-weathering, Monotis-bearing, medium-gray limestone.

The black shales, phosphatic siltstones, and sandstones slake to a distinctive black, silty, hard-packed earth which is commonly covered by a white efflorescent salt.

In general, the lithology of this sequence compares very well with the type locality at Shublik Island (Leffingwell, 1919, pp. 115-118).

Igneous rocks

Ultramafic rocks crop out as thin sills in the Upper Devonian (?) metasedimentary sequence in the region southwest of Old Woman Creek near camp 5a. These dark-green, chocolate-weathering, pyrite-bearing, aphanitic intrusives are approximately 25 to 50 feet thick and are bounded by 20-foot zones of light-gray, orange-weathering hornfels.

The granite mass shown on plate 1 in the vicinity of Mt. Michelson east of the Hulahula River, was mapped in 1948 (Whittington and Sable, p. 14) and was not examined by party 3 in 1952.

STRUCTURE

The main structural features in the eastern Brooks Range fall into two major patterns. Fold axes and fault systems strike east, in general, whereas regional highs and lows strike north. It appears that the east-trending structures have been superimposed on the north-trending ones. The former are, at least in part, late-Tertiary in age since the Eocene (?)-Paleocene Kavik formation is folded along with Mesozoic and Paleozoic rocks. Major north-south structures are reflected in the outcrop pattern of the Neruokpuk schist and are probably of pre-Carboniferous age.

Pre-Carboniferous (?) structures

Two regional highs have been delineated as a result of field work in 1952. Plate 1 shows these north-trending highs as located at the latitudes of Lake Peters and the Echooka River (approximately 145°10'W. and 147°10'W. respectively). The highs are separated by a north-south structural low at about 146°40'W. A possible third high is present in the longitude of Mt. Michelson (144°10'W.), extending southward toward the upper Sheenjek Valley.

Neruokpuk beds were folded and faulted before deposition of the lower Mississippian Kayak formation. In the vicinity of Lake Peters a thrust fault trace appears to be truncated by the basal Kayak beds. Along Snake Creek, west of Lake Peters, basal Kayak clastics unconformably overlie various parts of the upper unit of the Neruokpuk schist.

The age of the formation of these early structures is not definitely known. It is possible that they were associated with mid-Paleozoic diastrophism. Prior to recent investigations by geologists of the Navy Oil Unit, only one such period of diastrophism was suggested.

The absence of Lower Devonian rocks over all of Alaska led earlier workers to postulate a period of diastrophism in the late Silurian or early Devonian (Smith and Mertie, 1930, p. 267; Smith 1939, pp. 18-19).

It is now known that the early Mississippian Kayak formation, in the eastern Brooks Range, unconformably overlies the upper Neruokpuk unit, considered to be early Upper Devonian in age. However, during late Upper Devonian time in the central Brooks Range, more than 5,000 feet of Kanayut conglomerate was deposited. This suggests that late Upper Devonian diastrophism took place in the eastern Brooks Range area, with concurrent coarse clastic deposition to the west and southwest. The Mt. Michelson granite could have been emplaced at this time. Foliation in this gneissic granite is parallel to that in the surrounding Neruokpuk schist. Field relationships suggest that the granite is a syntectonic one. White (1952b, pp. 1-4) states that the granite is relatively rich in uraniferous biotite. A radioactive age determination would provide extremely valuable information regarding the possible age of Paleozoic diastrophism.

Pre-Permian diastrophism

The Lower Permian Sadlerochit formation unconformably overlies the Mississippian Lisburne formation throughout the eastern Brooks Range. In any one place the contact is a disconformable one, but over a short distance along strike the basal Sadlerochit lies upon various units in the upper Lisburne formation. Near Lake Peters, where proof of this erosional unconformity has been carefully documented, there was at least 100 feet of relief on the pre-Sadlerochit land surface.

This evidence suggests uplift during the Pennsylvanian period, but no pronounced folding or faulting is implied. Absence of Pennsylvanian rocks in this region is additional evidence in support of this hypothesis.

Post-Paleozoic structures

The pronounced east-trending structural grain of the eastern Brooks Range may have been produced in the late Tertiary. North of 68°45'N. the dominant features are folds with axes trending east or slightly north of east.

Some folds are overturned toward the north, with faulted crests, the south limbs being upthrown and pushed northward. High-angle reverse faults are most common, though several thrust faults, with displacement of only a few hundred feet, have been mapped.

At about 68°45'N., just south of Porcupine Lake, an imbricate thrust-fault pattern predominates. This zone of imbricate thrusting extends west to south of Elusive Lake and appears to join with the imbricate thrust zone near the mountain front in the central Brooks Range. An eastward continuation of this thrust zone reaches the upper Sheenjek Valley about 15 miles north of camp 5.

Structures characteristic of this imbricate thrust zone are overturned folds and thrust faults with several thousand feet of northward displacement. Generally, several thrust slices are piled one above another. Detailed mapping of these features was possible south and southwest of camp 3 at Porcupine Lake (see pl. 1) and the general thrust zone was traced east and west by use of aerial photographs.

As indicated above, diastrophism took place in the late Tertiary, as the Early Tertiary Kavik formation is folded with Upper Cretaceous rocks and earlier formations. Stratigraphic evidence of unconformities within the Mesozoic section suggests the possibility that some of the folding and faulting may have occurred in late Mesozoic time. These unconformities occur at the base of the Ignek formation, between the two members of the Ignek, and at the base of the Kavik formation. Keller has indicated that he considers one major period of folding and possible faulting to have taken place in post-Ignek, pre-Kavik time (Keller and Morris, 1952, pp. 16-17).

Considering all the available evidence, this diastrophic period consisted of several phases. Earliest activity occurred in the middle Lower Cretaceous with subsequent periods of folding in lower Upper Cretaceous and late Upper Cretaceous. A final epoch of folding followed deposition of the Kavik formation, probably in Middle or Late Tertiary time.

GEOLOGIC HISTORY

The Neruokpuk schist is a thick series of metasediments and previously was suggested as being of pre-Cambrian age (Whittington and Sable, 1948, p. 4). The formation is now tentatively divided into three lithologic units; two lower units are thought to be pre-middle Silurian to Middle Devonian, the upper unit, however, is now thought to be correlative to the Upper (?) Devonian chert-slate sequence mapped by Mertie (Mertie, 1927, pp. 119-125) 5 miles southwest of Old Woman Creek.

It seems quite evident that a pronounced uplift occurred in the eastern Brooks Range in late Upper Devonian or early Mississippian time. This argument can be upheld by the following:

1. The Kayak formation in the eastern Brooks Range (upper Sadlerochit-Sheenjek Rivers area) rests with angular unconformity on the Neruokpuk schist; here the basal Kayak is a pebble-cobble conglomerate, which suggests a proximal facies.

2. The uplift is much more pronounced in the eastern area. As the Kayak formation is traced westward the conglomeratic facies gives way to quartzite and the unconformity disappears east of Galbraith Lake.

3. No Kanayut formation or high upper Neruokpuk schist was recognized east of the Echooka River on the north slope of the Brooks Range; thus it is assumed that these rocks were eroded away during uplift or that uplift was occurring during Kanayut time.

In the Lake Peters-Schrader area the Kayak formation becomes very thin (200-450 feet) and the conglomerate in places is absent where the formation rests unconformably on the Neruokpuk schist. To the southeast in the Sheenjek Valley the Kayak becomes quite thick (1,200-1,500 feet).

In all localities the basal part of the Kayak formation is either clean quartzite or quartzitic conglomerate. This clean lithology suggests a period of long quiescence, allowing time for the less resistant rock fragments to be winnowed away.

The eastern area, thought to be uplifted in Late Devonian time, was a relatively less sinking area through the early Mississippian. This is reflected by the thinning of the Kayak formation and the absence of the Wachsmuth member of the Lisburne near Lake Schrader. Tentative

identification of fossils indicates that the upper Kayak shale at Lake Schrader is of the same age as the lower part of the Wachsmuth at Shainin Lake. From Shainin Lake east to Galbraith Lake the Wachsmuth thins slightly but gains greatly in percentage of shaly to nodular limestones. Both lines of evidence suggest that the eastward loss of Wachsmuth limestone is through a change to a shale facies. This does not rule out the possibility that part of the upper Wachsmuth member is absent because of a pre-Alapah disconformity. In any case the total thickness of early Mississippian rocks on Giraffe Creek and Lake Schrader is only 250 feet.

The area of minimum deposition of the Wachsmuth member in early Mississippian time was close to the area of maximum deposition of the Alapah member in late Mississippian time. Sinking of the center of the basin, relative to the more stable areas to the north, south, and east, was most rapid during deposition of the lower half of the Alapah member. The more conspicuous amounts of clay material in the lowest Alapah as compared with that in equally dark and fine-grained rocks higher in the section indicate some overlap or disconformity at the beginning of the late Mississippian.

The widespread uniform thickness of the upper Alapah member shows a more uniform sinking of the entire area of deposition. The relative lightness of color of even the finest-grained limestone shows that land was either far to the north, or if nearby, was low-lying and stable, permitting the deposition of fairly clean lime muds in some of the northern sections. The widespread tongues of coarse-grained limestone at the very top of the Lisburne show a shallowing of the sea preceding the general emergence necessary to account for the lack of rocks of Pennsylvanian age.

The nature of the Sadlerochit formation in the areas visited by party 3, especially at Porcupine and Schrader Lakes, suggests that basal beds were deposited on a post-Lisburne erosional surface, and the evidence at Lake Schrader indicates a relief of at least 50 to 100 feet.

Although no normal contacts were seen, it is believed that the Shublik formation is conformable with the Sadlerochit.

PETROLEUM POSSIBILITIES

In 1950 Krynine (Krynine and Folk, 1950, p. 10) determined that the only good reservoir rocks in the Lisburne were the clean, light-colored dolomites. These dolomites are inherently coarse grained. In the following seasons, field study in the Lisburne was to determine more exactly the range and persistence of these "good" dolomites. Investigation revealed that the light, coarse-grained dolomites constitute a minor percentage of the thickness, and are entirely absent from several of the measured sections. It is now evident that in testing the Lisburne formation, favorable reservoir characteristics may be more dependent on fractures, jointing, and possible secondary porosity than on presence of porous dolomites.

Limestone and dolomite seen in the eastern area are mostly fine grained and contain abundant silica. No systematic study was made of the character of the jointing, but in general the joints exposed in outcrop are calcite-filled. Cleavage fractures, on the other hand, are mostly open and are fairly common near faults, near fold axes, and near the Sadlerochit formation contact, where there seems to have been bedding-plane slippage during deformation.

In addition to rock types seen in outcrop, more favorable facies may be present below the surface in the foothills. In western areas, sandy to conglomeratic limestone occurs at the top of the Lisburne formation north of the Range. In this eastern area there is evidence that although the Wachsmuth and lower Alapah members may pinch out rapidly north of the Range, the upper Alapah is more extensive. Almost all the coarse-grained limestone in the east is in these upper zones, with a thin but very extensive unit of coarse grained limestone at the very top. Closer proximity to a northern shoreline, coupled with lowering of wave base at the end of the Mississippian, make it possible that in the eastern foothills a coarse shoreline facies, which might include land-derived clastics, may be found in the upper part of the Alapah member.

Possible stratigraphic traps may be at the Sadlerochit-Lisburne disconformity and at the less demonstrable Alapah-Wachsmuth disconformity. If the zones of the Alapah overlap progressively northward as postulated, various pinch-outs could provide other traps beneath the foothills.

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