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INTRODUCTION

The part of the Southern Foothills section, Arctic Foothills province, that lies between the Etivluk and Kiligwa Rivers was investigated by Navy Oil Unit party 6 during the 1950 field season. A belt about 16 miles wide and 60 miles long (approximately 800 square miles) was mapped in considerable detail (see index map, pl. 1). The mapped area is in the west-central part of the Arctic Foothills province, wholly within the boundaries of Naval Petroleum Reserve No. 4. Major drainage consists of the middle reaches of the Etivluk, Ipnavik, Kuna, and Kiligwa Rivers.

Principal objectives of the party, using previous geologic studies in the Okpikruak-Kiruktagiak Rivers area[1/] as an initial working base, were stratigraphic and structural studies of the outcrops in the interstream areas. In view of the former interest in possible Lisburne limestone plays, the Lisburne Ridge west of the Etivluk River and the northward nosing of the Triassic complex between the Ipnavik and Kuna Rivers were designated as areas for particular emphasis.

The party included six men: two geologists, two field assistants, a cook, and a weasel mechanic. Three weasels were available for transportation, two of which were maintained in operating condition for daily field use.

As many exposures as were pertinent or accessible were examined. Vertical photographs were used for plotting data and for areal control; relative vertical control was established with altimeters. The effective working radius from base camp was increased from 8 miles to 20 miles by making frequent 2- or 3-day spike trips.

The party was flown to the initial field camp on Smith Lake on May 22, but active field work was not begun until June 5 because of poor weather and a delay in caching operations. Approximately 20 percent of available working time was lost owing to weather, moving camp, and map work. However,

1/ Patton, W. W., Jr., and Tailleur, I. L., Stratigraphy and structure of the Okpikruak and Kiruktagiak Rivers area, Alaska: U. S. Geol. Survey Navy Oil Unit Rept. No. 34, 1950.

the complex geology required more time than was anticipated so that 2 weeks' work on the scheduled area remained when the field season was terminated on September 5. Near the close of the field season reconnaissance trips up the two forks of the Kiligwa River and up to the front of the Brooks Range on the East Fork of the Kiligwa River indicated exposures that warrant more detailed study than was possible in the remaining time. The weasels were driven to the Driftwood geophysical camp for caching and the party was flown to Umiat September 7.

Dr. Ralph W. Imlay visited the party for several days in early July to examine Lower Cretaceous strata. W. P. Brosge and C. J. Gudim joined the party on August 29 for a reconnaissance of the Paleozoic exposures on the headwaters of the East Fork of the Kiligwa River.

Previous geologic investigations include reconnaissance surveys along the Etivluk and Colville Rivers in 1925 and 1926 by P. S. Smith[2] and W. R. Smith, a boat traverse of the Ipnavik River from a point 4 miles south of Ekakevik Mountain to the Colville by Karl Stefansson[3] in 1947, and boat traverses of the Etivluk and Kuna Rivers from the headwaters to the mouths, by M. D. Mangus[4] and others in 1949. Except to verify parts of the interstream areas, none of the outcrops on the Etivluk or Kuna Rivers were reexamined in 1950. Other areas of overlap were remapped.

TOPOGRAPHY

The interstream areas of the Etivluk-Kiligwa Rivers lie entirely within the Southern Foothills section of the Arctic Foothills province. Three linear physiographic belts may be recognized within this area.

An east-trending tundra-covered region of monotonously low relief lies north of Smith Mountain and north of the Liberator Ridge. The Colville River forms the northern limit of this belt, which is 8 to 15 miles wide. Outcrops within this region are limited to a few low, linear, east-west rubble traces of lenticular sandstone and some cutbanks of sandstone and shale along the larger streams. The subdued topography is an expression of the underlying incompetent shale of the Torok formation. The southern margin of the lowland marks the northern interstream limit of geologic reconnaissance. To the east, another belt of similar subdued topography, 4 miles wide, lies between Smith Mountain and the Lisburne Ridge. A gravel pediment of late Tertiary age covers the southeastern part of this area.

The most southerly physiographic belt, 7 to 18 miles wide, has pronounced persistent ridges with a general N. 70° W. trend separated by intervals of tundra cover. The belt is correlative with the complex infolded

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2/ Smith, P. S., Geology and mineral resources of northwestern Alaska: U. S. Geol. Survey Bull. 815, 1930.

3/ Stefansson, Karl, Stratigraphy and structure of the area of the Ipnavik River, Alaska: U. S. Geol. Survey Navy Oil Unit Rept. No. 11, 1948.

4/ Mangus, M. D., Detterman, R. L., Lachenbruch, M. C., Jr., and Lachenbruch, A. H., Stratigraphy and structure of the Etivluk and Kuna Rivers area, Alaska: U. S. Geol. Survey Navy Oil Unit Rept. No. 35, 1950.

belt of the Okpikruak-Kiruktagiak Rivers area. Limestone and massive chert of Triassic or Mississippian age and mafic igneous sills are resistant rocks in the semi-arid climatic conditions of this Arctic province. They are commonly exposed in hogback ridges, cuestas, and low rubble ridges. They are made up of resistant conglomerate facies of the upper part of the Torok formation that were deposited in localized basins.

In the interstream area of the Etivluk-Kiligwa Rivers, a localized area of rugged topography arcs northward across the south-central part of the infolded belt. Flat or gently dipping escarpments and large buttes are capped by thick sills of mafic igneous rock. Talus cover on the slopes is extensive. Mount Bupto, a large overturned anticline of massive Mississippian chert and limestone, is the highest topographic feature. Resistant Mississippian limestone and chert, sandstone of the Okpikruak formation, and mafic igneous intrusives produce this belt of high relief.

To the south is an east-west belt of subdued outcrops that extends 8 to 15 miles south to the north front of the Brooks Range. Although geologic reconnaissance did not extend far into this area, indications are that less resistant Lower Cretaceous sandstone and shale crop out here.

The three physiographic units are similar in that they reflect the topographic features of a geomorphic cycle of late maturity. However, local areas of high relief and rugged topography reflect an apparent youthful to early mature stage and are due primarily to erosion of gently folded, more resistant strata overlying complexly folded less resistant rocks.

The major rivers are superimposed consequent streams. Large floodplains have been formed along their meandering courses. Tributary drainage is generally subsequent upon structural trends but numerous smaller streams cut across the regional strike along zones of weakness.

GENERAL GEOLOGY

Although rocks crop out in less than 50 percent of the area and only the more resistant rocks are exposed, field study has resulted in a fair understanding of the areal geology. Most noteworthy is the extreme degree to which the strata have been deformed. Considerably more than 50 percent foreshortening of beds older than the Torok formation is apparent and has produced a complex pattern of overturned to isoclinal folds and high-angle reverse faults. The preservation of an openly folded upper Paleozoic sequence in probable overthrust relationship to the underlying Mesozoic complex is also significant. Because the structural history could be more completely described for this region than elsewhere, the derived interpretations may well be extended or applied to other parts of the foothills structural belt. This is particularly true of the Okpikruak-Kiruktagiak Rivers area where a more complex structure was suspected but could not be demonstrated.

Much mapped detail was sacrificed in reducing the field map to the published scale of 1:96,000 (pl. 1). The structure sections (pl. 2) at a scale of 1:48,000, also have been necessarily simplified. Only the major structures are, therefore, represented. Although numerous faults and large folds have been inferred from obvious areal relationships adjacent to covered intervals, there are undoubtedly others of equal significance that are obscured by cover and lack of stratigraphic control. Although the geologic map and sections depict complex structure, it is emphasized that they are simplified versions of the actual conditions.

Recent evaluation of geologic data has led to the conclusion that erosional breaks and periods of nondeposition occurred throughout the formation of the sedimentary rocks of this area. Such conditions in numerous places may eliminate the apparent necessity for a proposed major fault, or greatly decrease the stratigraphic throw on such a major fault. Too little is known at present in regard to the nature and extent of unconformities, however, to warrant their use as alternate interpretations of anomalous areal relationships.

Stratigraphic studies were disappointing in that few complete, thick, or undeformed sections were available for measurement. Abundant exposures allow general knowledge of the various rocks but are not satisfactory for detailed study of the stratigraphy.

Maximum measured thicknesses are: Lisburne limestone, 2,400 feet; uppermost Paleozoic (?) and Triassic, 1,000 feet; Okpikruak formation, 2,000 feet; lowermost unit of Torok formation, 2,000 feet; middle unit of Torok formation, 2,100 feet; upper unit of Torok formation, 3,000 feet. Because local unconformities are present throughout the Mesozoic section and Cretaceous deposition was locally variable, the aggregate thickness is likely to be greater than the true thickness at any given position. The lithology of the rocks of this area is in general comparable to that described for the Okpikruak-Kiruktagiak Rivers area5/, an indication of fundamentally similar depositional environment for the two.

For this report, only the stratigraphic nomenclature developed by June 1950 is used on the map and structure sections. Further field work is needed before the revisions necessary because of recent faunal determinations may be incorporated in stratigraphic columns. Two new faunal zones, comparable to the Siksikpuk group and upper zones of the Kingak formation as described in the Nanushuk-Siksikpuk Rivers area6/, have been reported from macro-7/ and microfossil8/ collections in the Etivluk-Kiligwa Rivers area. The Siksikpuk group appears to be present in considerable thickness, but Jurassic rocks are limited in occurrence and are probably only the remnants left after pre-Torok erosion.

5/ Patton, W. W., Jr., and Tailleur, I. L., op. cit.

6/ Patton, W. W., Jr., and Keller, A. S., Stratigraphy and structure of the Nanushuk-Siksikpuk Rivers area: U. S. Geol. Survey Navy Oil Unit Prelim. Rept. No. 30, 1950.

7/ Imlay, R. W., personal communication.

8/ Bergquist, H. R., personal communication.

STRATIGRAPHY

Rocks ranging from Devonian to late Lower Cretaceous in age were identified in the Etivluk-Kiligwa Rivers area. A 1,500-foot section of Middle Devonian limestone and silicified limestone was briefly examined on the headwaters of the east fork of the Kiligwa River. These beds are described by Brosge.[9] Lithologic types that are correlative with or comparable to previously described sections are the Noatak formation (Devonian or Mississippian); the Alapah and Kiruktagiak members of the Lisburne limestone (Mississippian); the Shublik formation (Triassic); the Okpikruak formation (Lower Cretaceous, Neocomian); and the Torok formation (Lower Cretaceous, Aptian and Albian). Equivalents of two new lithologic units described by Patton and Keller[10] were recognized--the Siksikpuk group of Pennsylvanian or Permian age and a section equivalent to the upper zones of the Kingak formation (Upper Jurassic, Oxfordian).

Pre-Cretaceous sedimentary rocks reflect deposition under somewhat stable conditions, whereas the Cretaceous rocks derive their heterogeneous graywacke characteristics from deposition in an actively sinking geosyncline closely bordered by a rapidly rising foreland. Distinctive units in the pre-Cretaceous rocks are markedly persistent laterally over the mapped area and, in gross features, over adjoining areas of the Foothills province. In contrast, there are few distinctive units in the Cretaceous graywackes, and those that do exist are not extensive. Initial stages of the orogeny must have preceded deposition of the Okpikruak formation, but Lower Cretaceous deposition was, in large part, penecontemporaneous with deformation. Mafic igneous intrusives, generally sills, are widespread in pre-Okpikruak strata.

Devonian rocks

Unnamed formation.--A section of Middle Devonian strata was measured along the east fork of the Kiligwa River during a reconnaissance trip to the front of the Brooks Range. The section consists chiefly of fine-grained limestone with silicified zones and beds. An abundant fauna, for which age determinations are reliable, was collected. As no equivalents of these beds were recognized in the Southern Foothills section, a complete description is not given here, and the reader is referred to Brosge's[11] report for details.

Mississippian rocks

Noatak (?) formation

Several low ridges and rubble traces of sandstone of the Noatak formation are too small to show on the map. Two localities, 157°29'30" W., 68°35'30"-68°36'00" N., and 157°36'00" W., 68°35'30" N., carried an abundant though poorly preserved fauna. Two other exposures, one part way up the slope of Pimple Peak and the other one-half mile south of Pimple Peak, were barren.

9/ Brosge, W. P., and Reiser, H. N., Report on selected sections of the Lisburne limestone: U. S. Geol. Survey Navy Oil Unit Prelim. Rept. No. 31, 1950.

10/ Patton, W. W., Jr., and Keller, A. S., op. cit.

11/ Brosge, W. P., and Reiser, H. N., op. cit.

Bowsher[12] reports that the Chonetes and gastropod fauna has the same forms as a collection made by M. C. Lachenbruch from definite pre-Lisburne limestone which J. T. Dutro[13] designates as pre-Lisburne formation, Mississippian. Bowsher suggests that the stratigraphic unit be mapped as Noatak (?) formation and reports the following:

pentagonal crinoid columnal
radial plate of *Dichocrinus* ? sp.
Camarotoechia sp.
Chonetes sp. indet.
pelecypod indet.
productid indet.
Leiopteria ? sp. indet.
Retispira ? sp. indet.
Angyomphalus sp. indet.

No thicknesses could be estimated, except that 10 feet would be a minimum and considerably more is suspected. Some traces showed crenulation of the beds.

The relationships of the Noatak formation to adjacent beds could not be ascertained. At the western locality, chert of Siksikpuk (?) age completely surrounds the rubble expanse of Noatak, separated from it only by a narrow band of tundra cover. Exposures at the south-central locality are alined north-south in a north-trending (transverse) valley flat. Nearest outcrops, a few hundred feet east, are chert questionably assigned to the Kiruktagiak member of the Lisburne limestone. These exposures are near the northward projection of an intensely disturbed zone in which recrystallized and altered limestone of the Kiruktagiak member is in juxtaposition to the Okpikruak formation. The traces near Pimple Peak occur in a 4,000-foot covered interval between questionable Kiruktagiak chert and Shublik limestone in one place and stratigraphically beneath a postulated klippe of Lisburne limestone (Pimple Peak) in the other. These lie on a projection of the north-south line through the south-central exposures, but east-west structural trends under Pimple Peak are not interrupted. A minimum stratigraphic displacement of 2,000 feet is evident and a much larger displacement is suggested. Although a pre-Pennsylvanian erosional surface of high relief could account for the stratigraphic anomaly, evidence elsewhere precludes much erosion. The authors believe that major faulting is a more suitable explanation, particularly in view of the surrounding complex structural belt.

The lithology of the rocks in all the exposures is similar. The predominant type is sandstone that is very fine grained, dark to medium neutral in color with occasional greenish cast, argillaceous (?), dense, well-indurated, weathers pinkish gray to dark-reddish brown, and contains a few mica flakes. A minor amount of limestone, very fine grained, dark, with shaly partings, is interbedded.

12/ Bowsher, A. L., Sr., personal communication.

13/ Dutro, J. T., and Lachenbruch, M. C., Stratigraphy and structure of the Nimiuktuk, Kugururok, and part of the Noatak Rivers area: U. S. Geol. Survey Navy Oil Unit Prelim. Rept. No. 35, 1950.

Lisburne limestone

The Lisburne limestone is more extensively exposed in the Etivluk-Kiligwa Foothills section than in any other area outside the Brooks Range. The Lisburne limestone crops out over roughly 50 square miles of the high topography between the Ipnavik and Kuna Rivers. The Lisburne Ridge (see fig. 1, Prelim. Rept. 34[14]), essentially an overturned anticline with the Alapah member at the core, extends as a major topographic feature from the Etivluk River nearly to the Ipnavik. The same ridge extends west across the Ipnavik but with subdued expression. A series of strong ridges, a reflection of overturned isoclinally folded Kiruktagiak member chert, is present 2 miles south of the Lisburne Ridge. The trend is persistent over the middle part of the Etivluk-Ipnavik interstream area and is discontinuously present across the Ipnavik River halfway to the Kuna River. Another parallel trend of Lisburne limestone emerges from the covered interval at the northeast side of Ekakevik Mountain and extends westward along the north edge of Ekakevik Mountain, across the Ipnavik to Pimple Peak and into the complex area north of camp 7 on Cutaway Creek. This trend is marked by upper Alapah member (?) strata associated with mafic igneous sills that pinch and swell along the strike. Still another persistent trend, south of the Ekakevik trend, begins just east of the Kuna River, extends across the forks of the Kiligwa River and into the Nuka River drainage. Numerous similar trends of various zones of the Alapah member are apparent from inspection of plates 1 and 2, but are less obvious because of their discontinuity and smaller size.

This strikingly persistent alinement of exposures must reflect major structural control, and also indicates lateral persistence of zones within the Lisburne limestone. Smaller exposures of the formation are believed to have been inserted in the overlying rocks as thin slice blocks by some unexplained mechanism, probably faulting. The Lisburne limestone is present in appreciable thickness as far north as latitude 68°35' and crops out as far north as 68°41'. This evidence does not prove, but does make reasonable, the assumption that the Lisburne limestone underlies the younger beds to the north.

In spite of the large number of outcrops and a fair fauna, zonal determinations and correlations within the Lisburne are difficult to establish. Evidently the sequence present in the Etivluk-Kiligwa Rivers area represents a facies different from the typical section at Kanayut Lake, because Bowsher[15] reports that few zones have fauna in common with the subdivisions of the Lisburne recognized there. A comprehensive study of related sections would have to be made in order to establish the succession of beds that crop out. As far as could be demonstrated, lithologic or faunal equivalents of the lower or Wachsmuth member of the Lisburne limestone are not exposed in the area. After more careful study of a number of fossils of doubtful age, however, some zones may perhaps be assigned to the Wachsmuth.

14/ Tailleur, I. L., and Kent, B. H., Preliminary report on the stratigraphy and structure of the upper Etivluk-Kuna Rivers area: U. S. Geol. Survey Navy Oil Unit Prelim. Rept. 34, 1950.

15/ Bowsher, A. L., Sr., personal communication

Two distinct lithologic types or facies are apparent: a limestone facies and a bituminous phosphatic chert-shale facies. The two facies have been separately mapped; the limestone is the Alapah member and the chert shale the Kiruktagiak member. In the sections studied to the east in the Brooks Range, less of the Kiruktagiak member is exposed, whereas on the Kukpowruk River to the west the Kiruktagiak member comprises most of the section. Several zones of the chert-black shale facies that may be distinguished faunally and stratigraphically have been recognized in the Etivluk-Kiligwa Rivers area. This alternation of lithologic types is interpreted[16] as an intertonguing of the two facies. Little evidence of the direction of facies change was found in the mapped area.

Alapah member.--Extensive talus obscures most of the larger exposures of the Alapah member, so only gross lithologic characteristics could be determined. Most of the sections described below also appear in the columnar sections (pl. 4).

The south flank of the Lisburne Ridge is covered with a blocky talus of medium-grained, porous, dolomitic limestone. Although only 25 to 30 feet of massively bedded rocks are actually exposed, a thickness of 100 feet of dolomitic strata seems to be a conservative estimate. In hand specimen the dolomitic limestone appears porous; some of it has a saccharoidal texture. The rock weathers gray but is medium-neutral light-yellow red on fresh surfaces and emits a strong fetid odor when cracked. Many of the pore spaces are lined with fine "crystals" of asphaltum. No oil cuts have yet been made of samples from these beds; porosity and permeability properties (samples 50 ATr 29, 30, and 31, table 1) appear to be unfavorable.

The remainder of the underlying section on the Lisburne Ridge, except for a 20- to 30-foot zone of finer-grained dolomitic limestone similar to the above that crops out below an interbedded chert-limestone zone at the summit, appears to be a poor petroleum reservoir rock. Only small parts are exposed and consist of interbedded, very fine grained limestone and dense chert or silicified limestone. Color varies from dark to light neutral. Some of the rock has a fetid odor on cracking. The bedding varies from finely laminated "ribbon" appearance to coarse, irregularly banded. The proportion of calcareous to siliceous beds varies from 75 percent to 25 percent but over-all averages about 60 percent calcareous. Differential weathering on exposed areas produces a rough banded surface that has been termed "pagoda" weathering.

As only the interbedded limestone and chert appear in float, the lithology of the intervening beds is not known. Outcrops near the base of the north slope of the ridge are of black chert irregularly interbedded with dark, sandy-weathering limestone and, locally, black shale that probably belongs to the Kiruktagiak member of the Lisburne. The basal part of the normally overlying Siksikpuk group is also present. Faulting is therefore indicated. The estimated minimum thickness at the Lisburne Ridge is 800 feet.

16/ Brosge, W. P., and Reiser, H. N., op. cit.

Table 1. Porosity and permeability* of samples from the Etivluk-Kiligwa Rivers area, 1950

Sample Number	Location	Stratigraphic position	Porosity (percent)	Permeability (millidarcys)
50ATr 186	157°29'00" W. 68°36'00" N.	Noatak formation (Devonian or Mississippian	8.85	Impermeable
50ATr 100	156°52'30" W. 68°36'00" N.	zone 9 Alapah (arenaceous limestone)	1.83	Impermeable
50ATr 100	156°52'30" W. 68°36'00" N.	zone 9 Alapah (calcareous quartz sandstone)	1.75	Less than 1
50ATr 100	156°52'30" W. 68°36'00" N.	zone 9 Alapah (limestone)	1.33	Impermeable
50ATr 109	156°54'00" W. 58°36'00" N.	zone 9 Alapah (quartz granule cong.)	12.2	15
50AKt 119	156°59'00" W. 68°36'00" N.	zone 9 Alapah (coarse quartz sandstone)	4.85	Less than 1
50AKt 121	156°59'00" W. 68°36'00" N.	zone 9 Alapah (calcareous, fine quartz sandstone)	0.94	Impermeable
50ATr 223	157°05'30" W. 68°40'00" N.	zone 9 Alapah (coarse quartz sandstone)	2.77	Impermeable
50AKt 319	158°16'30" W. 68°38'00" N.	zone 9 Alapah (calcareous quartz sandstone)	4.41	Impermeable
50AKt 319	158°16'30" W. 68°38'00" N.	zone 9 Alapah (feldspathic quartz sandstone)	13.8	372
50ATr 29	156° 41'00" W. 68° 38'00" N.	upper Alapah (upper crystalline dolomitic limestone)	5.32	Impermeable
50ATr 30	156° 41'00" W. 68° 38'00" N.	upper Alapah (middle crystalline dolomitic limestone)	5.00	Impermeable
50ATr 31	156°41'00" W. 68°38'00" N.	upper Alapah (lower crystalline dolomitic limestone)	4.95	Impermeable
50AKt 69	156°37'30" W. 68°37'30" N.	Upper Alapah (finely crystalline limestone)	4.41	Impermeable
50AKt 259	157°34'00" W. 68°37'30" N.	Alapah (fine-grained limestone)	1.27	Impermeable
50AKt 82	156°52'00" W. 68°37'30" N.	Kiruktagiak member (finely crystalline, bituminous limestone)	1.48	Impermeable
50AKt 99	156°56'30" W. 68°40'00" N.	Kiruktagiak member (sandy-weathering, dark limestone)	0.96	Impermeable
50AKt 107	157°01'10" W. 68°41'00" N.	Kiruktagiak member (shaly limestone)	2.14	Unsuitable
50AKt 189	157°30'30" W. 68°36'30" N.	Okpikruak(?) formation (moderately clean, fine-grained sandstone)	1.59	Impermeable

*As reported by Fairbanks Laboratory, Navy Oil Unit.

At Mount Bupto, in the south-central part of the Ipnavik-Kuna Rivers area, a minimum thickness of 2,400 feet of Lisburne limestone is suggested. This prominent mountain is anticlinal with 60° S. dips on the south flank and vertically dipping, somewhat crumpled beds on the north flank. Resistant beds cap the mountain and a stream cuts the underlying beds from the axis of the structure through the south flank. However, talus effectively covers most of the valley walls, so the rocks described below are known principally from discontinuous exposures along the creek bed. Undoubtedly a more careful examination of these exposures would yield additional useful detail.

Two hydroclastic fossiliferous limestone zones 200-250 feet below the base of the Kiruktagiak member of the Lisburne limestone at the top of the section (pl. 4) carry a fauna correlative with zones 8 and 9 of the Alapah member of the Lisburne limestone in the Kanayut Lake area. The collected fauna includes indeterminate corals and fenestellid bryozoans, crinoid columnals and Stenoschisma ? sp. indet.[17] A chert zone occurs about 700 feet below the fossiliferous zones. Talus covers the intervening section but shaly, buff-weathering limestone occurs in the float along with the hydroclastic and fine-grained limestone. About 70 feet of the chert zone is exposed along the creek. It is dark neutral in color and weathers black. Massively bedded, it overlies a section of "pagoda"-weathering, interbedded limestone and chert. Although the thick dolomitic limestone of the Lisburne Ridge was not recognized, broadly lenticular beds as much as 5 feet thick of hydroclastic limestone and medium crystalline limestone are present in the upper part of the "pagoda"-weathering unit. More typical development of the interbedded limestone and chert occurs about 100 feet below the crest of the mountain. The last exposure is 15 feet of medium crystalline, light yellow-red limestone, that appears to be nonfossiliferous. The limb of the anticline is computed to include 2,600 feet of strata, of which 2,000 feet is partially exposed. No evidence of the age of the lower beds was observed. By tentatively correlating the lithology of the "pagoda" limestone and chert here with the grossly similar lithology of the "pagoda" type on the Lisburne Ridge, as is shown on the columnar section (pl. 4), a considerable thickness of the Alapah member of the Lisburne limestone is demonstrated.

Exposures of the Lisburne limestone on the possible thrust sheet are limited to the interbedded limestone and chert of the "pagoda"-weathering type. A lower diabase sill, 100 to 150 feet thick, persistently intruded the basal part of the sequence. An upper, irregular, and less persistent sill occurs near the top. The lower sill intrudes a shaly zone that may be near the base of the section. Although exposures of this zone usually produce fine talus slopes, float fragments and isolated outcrops indicate a well-indurated dark shale and siltstone sequence. Several horizons with worm-trail markings were observed; thin beds of crinoidal limestone are also present.

Crinoidal beds from the "pagoda"-weathering limestone and chert contain a fairly abundant fauna that has some affinities to faunas collected elsewhere. Bowsher[18], however, believes that they represent Upper Mississippian

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17, 18/ Bowsher, A. L., Sr., personal communication.

forms and are probably contained in strata equivalent to zone 5 of the Alapah member. A partial faunal list is given below:[19]

"Spirifer" sp. indet.	Chonetes sp. indet.
Productina sp. indet.	Echinoconchus (?) sp. indet.
Productus sp. indet.	indet. sponge spicules
Mourlonia sp. indet.	indet. pleurotomarid gastropod
Retispira sp. indet.	indet. straparollid gastropod
Glabrocingulum (?) sp. indet.	indet. trilobite pygidium.

On the north flank of the anticline south of camp 6 a covered interval separates the top of the bedded limestone and chert from the bottom of a diabase sill and the Siksikpuk group above. The total thickness exposed is more than 1,200 feet. The lower 200 feet are argillaceous thin-bedded siltstone and limestone intruded by the lower sill. The upper 1,000 feet are composed of interbedded limestone and chert of the "pagoda"-weathering type. Fossils collected from the upper part of the section have been compared to zone 5 of the Alapah:[20] Eumetria ? sp. indet., Productella sp. indet., Loxonema ? sp. indet., Mourlonia, Michelinia sp. indet., Chonetes sp. indet., indeterminate sponges, and sponge spicules.

On the thrust sheet also, just north of Mount Bupto, a thin band of Siksikpuk group and remnants of Lower Cretaceous (?) sandstone overlie only 500 feet of the "pagoda" limestone and chert. Phanerotinus and Straparollus collected from a thin crinoidal bed in argillaceous strata at the base of this section, believed to be just above the thrust contact, indicate probable lower Alapah age.[21] Less information is available about the beds associated with diabase sills in the linear trends. The lithology of these rocks is generally comparable to the "pagoda"-weathering zones of other sections. This correlation is substantiated by several fossil collections correlative to zone 5 of the Alapah member.

Several outcrops of a new facies of the Lisburne limestone are 1 to 3 miles north of Ekakevik Mountain in the eastern part of the Etivluk and Kiligwa Rivers section and near the southern margin of the mapped area just east of the Kiligwa River. Characteristically this type is a coarse, quartzose sandstone composed of rounded white quartz grains and minor fresh feldspar granules, locally encrusted with chlorite. Carbonate appears to range from a trace to predominant. The outcrops are all isolated; therefore the stratigraphic relationships can only be inferred.

An outcrop of limestone in the eastern part of the mapped area directly underlies, perhaps by fault contact, varicolored chert of some part of the Siksikpuk group, and contains a large suite of silicified fossils. Bowsher[22] reports that this zone has close affinities with zone 8 and the lower part of zone 9 of the Alapah member in the Kanayut Lake area. A similar silicified fauna is contained in the limestone and intercalated arenaceous limestone lenses $2\frac{1}{2}$ miles to the east. The sandstone is exposed again 1 mile to the south in a rubble ridge several hundred yards long and 100 feet wide. The sandstone is only slightly calcareous, has no interbedded carbonate rock, and has local facies of quartz-pebble conglomerate with pebbles three fourths of an inch in diameter.

19, 20, 21, 22/ Bowsher, A. L., Sr., personal communication.

Near the Kiligwa River, at approximately the same latitude, the same faunal zone occurs in medium- to coarse-grained feldspathic quartzose sandstone. Abundant chlorite is present. The sandstone is associated with shaly limestone and calcareous clay shale. These rocks, similar to others in this zone, weather light gray and are medium-yellow red on fresh surfaces. The sample with a permeability of 372 millidarcys was collected from this locality. Other permeability results from this zone were not as promising (samples 50ATr 100, 109, 186, 223; 50AKt 119, 121, and 319, table 1).

The fauna from this zone is abundant and well preserved by silicification. A partial list is given below:[23]

Several indet. corals
Platycrinites sp. indet.
Stenoschisma sp.
Orthotetes ? sp. indet.
"Spirifer" of the Fusella ? type
Choristites ? sp. A
Phricodothyris sp. indet.
Overtonia sp.
Linoproductus ovatus (McChesney)
Gigantella ? sp.
Dictyoclostus cf. D. hindi (Muir-Wood)
Dictyoclostus sp.
Dictyoclostus inflatus
Eumetria sp.
Tetracamera ? sp. indet.
Tropidostrophia ? sp. indet.
Straparollus cf. S. savagei Knight

No reliable thickness estimates were possible. A minimum of 30 feet of sandstone is indicated. The sandstone-limestone sequence near the Kiligwa River is at least 100 feet thick.

Samples from isolated outcrops of a similar sandstone were recognized in other areas of the Foothills province: 1 mile north of Fortress Mountain in the Okpikruak-Kiruktagiak Rivers area; near the south edge of the infold belt of the Oolamnagavik-Etivluk Rivers area; and in the Utukok-Kokolik Rivers area. This coarse facies must then be present over much of the foothills province but in a narrow band. Its southward extent is probably limited because the sandstone was apparently absent from the Mount Bupto section and has not been reported from areas studied along the front of the Range. A northward limitation is suggested by the outcrop north of Ekakevik Mountain where the strata are essentially calcareous, in contrast to the carbonate-free sandstone 1 mile to the south.

Kiruktagiak member.--Rocks having the lithology of the Kiruktagiak member are widely distributed across the infold belt. None, however, were recognized in the possible thrust sheet. The greatest areal extent of the Kiruktagiak member outcrops is in the south Lisburne ridges that trend west from the Etivluk River to the middle of the interstream area. Here, a thick section of chert has been isoclinally folded to produce several sharp, craggy ridges.

23/ Bowsher, A. L., Sr., personal communication.

Two units of distinct lithology are recognized and are believed to represent two zones of the Kiruktagiak member. These two zones are shown on the columnar section as lithologic equivalents of zones 5 and 9 of the Alapah member. On Mount Bupto the upper zone overlies beds containing a fauna of the zone 9 of the Alapah member. The assignment of zone 5 of the Kiruktagiak on the flanks of the north Lisburne Ridge is based on less firm evidence: (1) resemblance of the lithology here to the lithology of the zone 5 type locality on the Kiruktagiak River24/; (2) gross similarities of the Alapah member underlying the Kiruktagiak member in both places; (3) comparison to a black chert zone overlying "pagoda"-weathering limestone-chert sequence in the Mount Bupto section.

At the Lisburne Ridge the lowest exposed beds are an 8-foot sequence of black paper shale with two 6-inch colloform phosphate layers, saccharoidal to cinder limestone, shaly bituminous limestone, and black chert. The next higher exposure is of dark, bituminous fine-grained limestone (sample 50 ATr 32, table 2) irregularly interbedded with black chert.

A 100-foot covered interval follows, below a 10-foot exposure of interbedded black clay to paper shale and black chert. A similar zone of shale and chert probably underlies the covered interval. Evenly bedded black chert at least 5 feet thick caps the exposed section and lies no more than 100 feet below the first exposure of Permo-Carboniferous (?) beds. Thickness is estimated to be slightly over 200 feet. Subdued exposures of this zone along the Lisburne Ridge projection to the west is expressed by low ledges and rubble of shaly limestone, the so-called "musical limestone." These beds contain Leiorhynchus sp. B and Bellerophon sp. indet.25/

In the south Lisburne ridges the sequence contains at least 60 feet of interbedded black shale, black occasionally sooty chert, and black bituminous limestone at the base. In this unit chert becomes more abundant in a gradational upward change from shale to chert and contains a Goniatite fauna. Above this unit is at least 200 feet of evenly bedded black chert. Talus fragments weather light gray, striped or banded with darker tones. Extended weathering bleaches the surface to a near white. Limonite stains extend into the interior of the bleached rock along minute cracks. Above the chert is black siliceous shale of undetermined thickness. The shale contains scattered finely crystalline calcareous and phosphatic concretions. A few thin beds of black sooty chert are present and pyritic stringers are scattered through the section. A strong fetid odor is emitted by the calcareous material when cracked (samples 50 ATr 55 and 98, table 2).

Still younger beds are exposed along the ridge trend to the west: brittle shaly limestone and black shale with sooty chert underlie a 5- to 10-foot zone of carbonate rock that weathers to a finely banded light and dark chocolate brown and is usable as a marker of the uppermost beds. The thickness of this unit is well over 200 feet. The section on the south Lisburne ridges differs from those previously described by having a massive zone of bedded chert in the middle of the sequence.

24/ Patton, W. W., Jr., and Tailleur, I. L., op. cit.
25/ Bowsher, A. L., Sr., personal communication.

Table 2. Summary of oil-cut determinations for samples collected in the Etivluk-Kiligwa Rivers, Southern Foothills section, as reported by the U. S. Geological Survey Fairbanks Laboratory.

Sample No.	Location	Formation or member	Cut	Residue
50AKt 203	157°35'30" W. 68°36'00" N.	Upper Alapah, fine-grained limestone	very light straw	light yellow
50ATr 32	156°41'00" W. 68°38'00" N.	Kiruktagiak (Lisburne Ridge) black chert and limestone	yellow	yellow
50ATr 55	156°49'00" W. 68°37'30" N.	Kiruktagiak (south Lisburne ridges) black shale	yellow	light yellow
50ATr 98	156°52'00" W. 68°37'00" N.	Kiruktagiak (south Lisburne ridges) bituminous limestone	black	heavy dark-brown or black asphaltic material
50ATr 145	157°31'30" W. 68°34'30" N.	Kiruktagiak crackled chert	black	yellowish brown
50ATr 159	157°33'00" W. 68°30'00" N.	Kiruktagiak bituminous limestone and black shale	very light straw	very light yellow
50AKt 207	157°38'00" W. 68°36'30" N.	Kiruktagiak crackled chert	dark brown	dark-brown asphaltic
50ATr 25	156°43'00" W. 68°38'00" N.	Shublik formation, Halobia oil-shale zone, bituminous limestone	very pale straw	very pale
50AKt 196	157°34'30" W. 68°35'30" N.	Shublik formation, Halobia oil-shale zone, bituminous limestone	light straw	yellow
50AKt 221	157°36'00" W. 68°37'00" N.	Okpikruak (?) formation, clean sandstone, distinct odor	none	very light yellow film

Fossils collected from the upper shaly zones of this unit compare to the fauna of the type section of the Kiruktagiak member, equivalent to zone 5 of the Alapah member, on the Kiruktagiak River: Cravenoceras ?, Goniatites cf. G. choctawensis Shumard, Pseudometacoceras ? sp. indet., Mooreoceras cf. M. crefiliratum (Girty), Sulcaretopora ?. However, the evidence is not strong enough to exclude an upper zone (?) determination for the sequence in the south Lisburne ridges.[26]

Comparison of the section in the south Lisburne ridges with the upper Kiruktagiak zone at Mount Bupto shows a fair correlation. The Kiruktagiak member at the north Lisburne Ridge overlying the "pagoda"-weathering limestone appears to be roughly correlative with the heavy chert near the middle of the section at Mount Bupto. These correlations are tentative at best and are not presented as conclusive.

Where well exposed, both zones have abundant hydrocarbons (samples 50ATr 33, 55, 98, 145, 159; and 50AKt 207, table 2). Crackled cherts have a sooty appearance, because of carbonaceous material deposited on the surfaces. At one locality, a thin slice of the Kiruktagiak member lies between Triassic and Permo-Carboniferous (?) beds and has, apparently, been folded into an overturned anticline (see fig. 2, Prelim. Rept. 34).

The cherts of the Siksikpuk group have been fractured and veins of asphaltum introduced as fracture fillings (just to left of upper bedding trace of C-Pe?; fig. 2, Prelim. Rept. 34). Several veins are wider than 5 inches; the maximum is 14 inches. (Fragments from one of the veins are shown in figure 3 in Prelim. Rept. 34.) The fractured chert and limestone of the Kiruktagiak at this locality have abundant asphaltic material in pore spaces and apparently contained considerable syngenetic bituminous material (sample 50 ATr 145, table 2). The close proximity of a possible source, the Kiruktagiak slice, to the asphaltum veins strongly suggests that the petroliferous fluid (?) was generated in the Kiruktagiak member and introduced into nearby voids.

Two samples of similar solid bitumen occurring as fracture fillings in the Torok formation were analyzed and determined to be the pyrobitumen grahamite. The analyses are given below:[27]

Field sample No.	Color and streak	Fracture	Lustre	Specific gravity	Hardness (Moh)	Fusing temperature	Fixed carbon (ash free) (percent)	Ash (percent)
50AKt 237 (Lab. No. 50-2052C)	black	conchoidal to hackly	very bright	1.52	2-3	approx. 280° C.	37	30
49ATr 643 (Lab. No. 50-2053C)	black	hackly	very bright to dull	1.16	2-3	approx. 290° C.	49	0.6

26/ Bowsher, A. L., Sr., personal communication.
27/ Analyses by Michael Fleischer, Branch of Geochemistry and Petrology.

Units of the Kiruktagiak member were observed near the Brooks Range along the east fork of the Kiligwa. Black chert is abundant and is accompanied by normally associated black shale and limestone. Another section with some dark chert but characterized by medium-neutral calcareous clay shale and silty, flaggy-bedded limestone crops out near the type locality. This sequence contains a cephalopod that is similar to a genus from Russia older than the *Goniatite* fauna collected from the typical Kiruktagiak.[28] No detailed section measurement was attempted but the thickness was estimated to be 150 to 200 feet.

Although evidence is insufficient to evaluate this new occurrence of the Kiruktagiak member, it is presented for incorporation into the interpretation of the relationship of the Kiruktagiak member to the Lisburne limestone as a whole.

The strata in the belt of outcrops immediately north of the Range are not as contorted as in the infold belt. Further field investigations of the relationships of the Kiruktagiak member to the rest of the Lisburne limestone and of other problems in this part of the Foothills province would achieve more conclusive results if studies were extended to include this belt adjacent to the Range.

The persistent outcrops of various zones of the Lisburne limestone near or in contact with younger strata without obvious fault relationship has no ready explanation. If the suggested correlations are valid, beds underlying the Siksikpuk group at the north edge of the infold are older than those along the central part. Older horizons of the Lisburne limestone are also in contact with the overlying Siksikpuk group south of the center of the infold belt. On the possible thrust sheet a pre-Siksikpuk regional dip to the north is indicated. Careful analysis of data collected from other outcrops would test this concept of a gentle warping prior to deposition of the Siksikpuk group.

Permo-Carboniferous (?) rocks

Identification of conodonts of Permo-Carboniferous (?) age[29] from beds formerly considered to belong to the Shublik formation (Triassic) necessitates reclassification of the post-Lisburne pre-Okpikruak complex. The microfauna is the same as that collected from beds tentatively designated as Siksikpuk group by Patton and Keller in 1950.[30]

As lithologic studies are not complete, the exact location of the Siksikpuk-Shublik contact cannot be ascertained. An unfossiliferous interval of 230 feet of beds separates the lowest occurrence of Triassic macrofossils from the highest occurrence of Permo-Carboniferous (?) microfossils, but these unfossiliferous beds have a marked lithologic affinity with the underlying strata. Therefore the Siksikpuk-Shublik contact in the columnar section (pl. 3) is shown at the base of the *Halobia*-bearing

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28/ Bowsher, A. L., Sr., personal communication.

29/ Bergquist, H. R., personal communication.

30/ Patton, W. W., Jr., and Keller, A. S., op. cit.

zone of the Shublik formation, which is also the top of the lithologic zone that contains red- and green-weathering shales.

The Siksikpuk group probably unconformably overlies several zones of the Alapah and Kiruktagiak members of the Lisburne limestone in different places. In the Etivluk-Kiligwa Rivers area the Siksikpuk group is represented by approximately 700 feet of section.

The stratigraphic sequence of the Siksikpuk group was pieced together from several exposures. Horizons or zones assumed to be correlative may not actually be so, but the gross zones are fairly well established and have the stratigraphic positions indicated in the column (pl. 3). The lower 200 feet consists of interbedded, dark-neutral medium-green chert that weathers green and dark red, and dark calcareous clay shale that generally weathers dark red in hackly fragments. The middle part, as it occurs in the "thrust" area between the Ipnavik and Kuna Rivers, is composed of approximately 120 feet of dark-neutral, gray to black bedded chert that weathers a black and dull orange. This weathering makes a distinctive color pattern when viewed from a distance. The upper 250 feet of this section is interbedded dark clay shale and dark chert. The lower part of the upper unit commonly weathers red and green. Permo-Carboniferous (?) microfossils were collected from the middle shale.

The section on the north flank of the Lisburne Ridge is not more than 500 feet thick. The middle 120 feet of dark-weathering chert is missing. This unit appears to be absent over the northern half of the mapped area. Its lateral persistence in the southern half of the area is demonstrated, however, by its occurrence on the west fork of the Kiligwa River where it is separated from the overlying Halobia zone of the Shublik formation by several hundred feet of beds that are predominantly shale.

Triassic rocks

Triassic rocks comprise a large proportion of the outcrops in the infolded belt but they have been so much folded and faulted that no complete sections are exposed. Also, recent erosion has generally stripped the upper, relatively weak shale beds of the formation from the bedded chert and limestones of the middle part of the section, thus leaving good outcrops of the resistant beds only. In order to estimate the thickness of the Shublik in this area, a composite columnar section was prepared from data obtained from several small measured sections, and the thickness of 230 feet shown (pl. 3) in this section is only approximate. The lithology and fauna of the Shublik formation are persistent over the 60-mile lateral extent of the mapped area, and they appear to be persistent over wide areas of the Arctic Foothills province.

As discussed in the section on Permo-Carboniferous (?) rocks, the lower contact of the Shublik formation has been established somewhat arbitrarily as the lowest occurrence of Triassic macrofossils. The character of the upper contact is not known. Where remnants of Jurassic rocks are preserved, the relationships with the underlying Shublik formation are obscured. A pre-Okpikruak erosional break of considerable magnitude is recognized. The uplift responsible for this break was not, apparently, accompanied by strong folding, so the overlying *Aucella*-bearing beds lie conformably upon either the Shublik formation or Siksikpuk group.

The only unit of the Shublik that consistently crops out is a zone containing abundant *Monotis subcircularis* Gabb. It is composed of about 60 feet of limestone, cherty limestone, and chert. The limestone and cherty limestone are dense to fine-grained, locally light-yellow red, and generally contain abundant *Monotis subcircularis* and related pelecypods. Beds as much as 10 inches thick are common. Beds of the chert are thinner, seldom over 4 inches thick. The three types are interbedded in variable proportions and are usually separated by thin shale beds. The several zones in which limestone predominates usually stand in relief above the adjacent beds.

A 60-foot zone underlies the *Monotis* zone and is characterized by dark paper shale or oil shale in beds as much as 5 inches thick. Thin-bedded ripple-marked dark limestone is associated with the paper shale. It usually has a strong fetid odor (samples 50 ATr 25 and 50 AKt 196, table 2), and is highly fossiliferous; practically all bedding surfaces are covered with spread valves of *Halobia* sp. and others. Beds of dark chert 2 to 4 inches thick also occur with the shale. The light and dark stripes developed on weathering are diagnostic features of this chert. Scattered "golf ball" and larger concretions of black bituminous limestone are scattered through the upper shale. These bear a fauna of diminutive pelecypods and cephalopods. Locally, at least, the fossiliferous beds are underlain by 20 to 25 feet of bedded dark chert that is barren of macro-fossils. A thin zone of *Monotis*-bearing limestone and oil shale appears to underlie this sequence and to mark the base of the Shublik formation, which, as previously explained, is drawn just below the lowest occurrence of Triassic fossils.

The upper 120 feet of the Shublik formation is exposed at only one locality. There this upper unit is composed of dark carbonaceous clay shale, siltstone, thick-bedded dark chert that bleaches white on weathering, and dark calcareous shale that weathers red and green. Interbeds of black paper shale and minor amounts of chert are also present. At another locality, 30 feet of black carbonaceous shale containing sideritic concretions directly overlies the *Monotis*-bearing limestone zone. This shale carries a calcareous microfauna typical of the Shublik.31/ It is possible that equivalent strata have been seen elsewhere, but have mistakenly been identified as part of the Siksikpuk group. Vertebrate remains were found at two localities. Ichthyosaur teeth, probably of the genus *Mixosaurus*,32/ were contained in *Monotis*-bearing limestone. Vertebral fragments and outlines of a chest cavity, about 8 feet long and 4 feet deep, occur on a bedding surface in a section of thinly interbedded chert and siliceous shale of doubtful Triassic age.

31/ Bergquist, H. R., personal communication.
32/ Hough, Jean, personal communication.

Jurassic rocks

Isolated exposures of chert of questionable age, not included in the Shublik formation, occur throughout the area. Most of these are associated geographically with the Okpikruak formation. The unfossiliferous nature of this varicolored chert, together with the complex structure involved, makes the stratigraphic position very difficult to determine. The chert is generally considered to overlie the Shublik formation and underlie the Okpikruak formation and may best be considered Jurassic in age. They have not been included in stratigraphic columns because of insufficient data.

The following lithologic sequence is recognized, described from top to bottom:

(3) Conglomeratic sandstone, light-neutral-colored matrix, highly calcareous, poorly sorted, angular to subround inclusions of black chert, pyrite nodules, and colorless to green chert fragments.

(2) Interbedded fine-grained neutral-colored sandstone and impure greenish chert.

(1) Black-, red-, and green-weathering carbonaceous fissile clay shale, containing an extensive microfauna:

50AKt 228: Bathysiphon B (7)
Peloxina fragment
Glomospira B ? (8)
Gaudryina n. sp. (abundant)
Trochammina cf. Trochammina M. (1)
Nodosaria fragment
reptile tooth

Bergquist[33/], in discussing the above microfauna, compares them to similar types found in Patton's samples (50APa 84, 214, 216, 239, 241, etc.) which are designated faunal zone 4 and thought to be of Jurassic age.

This section occurs on the south flank of a small syncline where it underlies conglomeratic sandstone and sandstones containing Aucella crassicolis of Lower Cretaceous (Neocomian) age. No estimate of relative thickness or definite stratigraphic relationships could be made for this sequence, and it was not, therefore, included in the stratigraphic columns.

A coquinoid limestone composed of Aucella bronni occurs also in obscure stratigraphic relationship. Imlay, 34/ in discussing the above species of Aucella, suggests that it is characteristic of the Upper Jurassic (Oxfordian stage). The isolated outcrops of this horizon are generally in close association with the Shublik formation.

33/ Bergquist, H. R., personal communication.
34/ Imlay, R. W., personal communication.

Several inferences may be made from the brief data above:

(1) Rapidly changing conditions of sedimentary environment are evident from the diverse lithologies represented.

(2) Erosional unconformities of varying local extent and periods of nondeposition appear to have been present throughout Jurassic time.

Cretaceous rocks

Lower Cretaceous

The Lower Cretaceous rocks in the Etivluk-Kiligwa Rivers area are graywacke sandstones and shales that are Neocomian to Albian in age. The Nanushuk group (Albian and possibly younger) does not crop out within the limits of the mapped area.

On the basis of gross lithology and faunal control, these sedimentary rocks are divided into the Okpikruak formation and the Torok formation. Although the contact between the two formations is gradational and locally represents a continuous sequence of deposition, the authors feel that the two formations are sufficiently distinctive and that each has sufficient lithologic homogeneity to warrant separate mapping; ultimately, smaller units of the Lower Cretaceous rocks may prove to be mappable.

Okpikruak formation.--Exposures of the Okpikruak formation in the area between the Etivluk and Ipnavik Rivers are confined to small infolds southwest of the northern Lisburne ridges, and in narrowly elongated synclines within the structural complex northeast of Ekakevik Mountain. In the south-central area along the Ipnavik River, outcrops of the Okpikruak formation are extensive. Exposures for the most part occur in broad faulted synclines closing to the west on the complex area and opening to the east to form the perimeter of the structural basin of Ekakevik Mountain. High fault-block ridges of Okpikruak formation lie to the south of the south-central structural complex. They extend west to the Kuna River and northward along the Kuna River in faulted and infolded association with chert of Triassic and Jurassic age. North of the south-central structural complex a broad valley is cut in shale of the Okpikruak formation, and north of this valley are numerous exposures in narrow elongate, overturned synclines flanked by chert of Triassic or Jurassic age. Exposures of the Okpikruak formation are extensive, characteristically in broad faulted synclinoria, within the infold complex east of the Kiligwa River. Cutbanks along the Ipnavik River show that shale and very fine sandstone of the Okpikruak formation have been infolded and infaulted with the Jurassic and Triassic to a much greater extent than is apparent from outcrops in the interstream areas. The covered intervals between the chert-limestone ridges are underlain by the incompetent Okpikruak formation.

At the present time the authors are unable to determine any basis for further subdivision of the Okpikruak formation. There are no recognizable major lithologic breaks and fossils are scarce and not diagnostic of any horizon. The fauna is limited to Aucella crassicolis Keyserling. Aucella crassicolis is now believed to be characteristic of Lower Cretaceous (Neocomian) age[35] and is thus an age determinant for the Okpikruak formation, but the presence or absence of this diagnostic species does not warrant further subdivision of the formation. Samples collected from apparently favorable shales contain no diagnostic microfossils.

The most complete well-exposed sequence of the Okpikruak formation is in the area on the south flank of a broad syncline southwest of camp 6. This section consists of 2,000 feet of beds (pl. 3) which are in erosional though conformable contact with the underlying Siksikpuk group, and are conformably overlain by a sharpstone conglomerate that is believed to mark the base of the Torok formation.

The lower 1,000 feet consists mainly of fine- to coarse-grained graywacke sandstone, medium green to dark gray, interbedded with shale, siltstone, and clay. The siltstones are somewhat calcareous. Lenticular beds of poorly sorted granule conglomerate, consisting of subround chert grains and oil-shale pebbles in a poorly indurated matrix, are present in the lower part. Scattered carbonaceous material is abundant and silt-clay inclusions are common in the coarser beds. Silty limestone that weathers dark-red brown is common. Fossil fragments thought to be Aucella crassicolis are disseminated throughout the coarser clastic beds. Zones having a high ratio of sandstone to shale alternate with zones having a low sandstone-shale ratio. In general, the sandstone beds predominate and are coarser and more numerous toward the base of the section.

The same monotonous sequence of interbedded sandstone and shale occurs in the overlying 1,000 feet but with shale generally predominant. The Okpikruak formation thus becomes more shaly upward; it also seems to become more shaly from south to north.

Fossil plants were found in shale and siltstone of the Okpikruak formation that underlies the southwest scarp of Ekakevik Mountain on the east bank of the Ipnavik River. Aucella crassicolis was found 200 yards to the south of this locality. Mr. Roland Brown of the U. S. Geological Survey reports that the plants are similar to collections from the Corwin area and from Oregon. These collections had been previously referred to the Jurassic.

In the area along the east bank of the Kuna River and extending east to the structural complex, the Okpikruak formation has slightly different characteristics. The same monotonous sequence of graywacke sandstone, siltstone, and shale persists, but the graywacke sandstone is in general finer-grained, better-sorted, and somewhat lighter in color. Hassock bedding is common, and while this type of bedding was not apparent in the measured stratigraphic section, its presence in this and other areas is characteristic of the Okpikruak formation; Aucella crassicolis occurs throughout the section.

35/ Imlay, R. W., personal communication.

The lithology of the Okpikruak formation in infolds farther north differs little except that grains are generally smaller and the proportion of shale to sandstone is greater, as much as 80 percent shale in some places. Monotonously regular series of shale with scattered interbeds of very fine sandstone and zones of interbedded, very fine sandstone, siltstone, and shale are characteristic. Aucella crassicolis is common but less frequent than in exposures to the south. Apparently these beds reflect deposition by less vigorous currents and at a greater distance from the source.

Isolated exposures of metamorphic quartzite, probably the basal Okpikruak formation, are limited to the southern infold belt where deformation has been very intense. These quartzites have been bleached and somewhat recrystallized to a hard dense rock that weathers medium-yellow red. Scattered carbonaceous fragments and impressions of Aucella have been preserved. At one locality on the west fork of the Kiligwa River, conglomeratic quartzitic beds are composed of subround white quartz and dark chert pebbles. Regional deformational stresses are believed to be responsible for the low-grade metamorphism of the Okpikruak formation in the southern infold belt.

Graywacke sandstones briefly examined at the front of the Brooks Range resemble those at the southern margin of the infold belt, except that the propostion of shale is considerably less and the degree of induration is greater. Coarser beds are also more common.

Facies changes noted between the southern edge of the area and the northern infold exposures were probably more gradual than is indicated by the 8 to 15 miles now separating them. If the openly folded Okpikruak formation to the south is part of an overthrust sheet, as is believed, then the observed facies changes have been telescoped by the overthrust movements.

Torok formation.--A thick section of coarse clastics and equivalent shale of the Torok formation overlies the Okpikruak formation. A minimum aggregate thickness of 6,800 feet has been computed for the coarse facies. These strata exhibit the common characteristics of graywackes deposited in a geosynclinal basin.

Although similar over-all, the Torok formation has been divided into three units. The contacts established were used with some satisfaction in field mapping. The lower unit is shown separately on the accompanying geologic map (pl. 1), however, and the middle and upper units are not differentiated.

The lower unit, comparable to the shale unit of the Torok formation in the Okpikruak-Kiruktagiak Rivers area, consists of at least 1,000 feet of dark clay shale with scattered septarian calcareous concretions in a prismatic calcite layer. This unit is conformable (?) with the underlying Okpikruak formation and is separated from that sequence of shale and very fine graywacke sandstone only by a zone of sharpstone conglomerate which is thought to mark the base of the Torok formation.

The upper contact is indeterminate. At Ekakevik Mountain, where the distinct lithology was recognized, the uppermost shale grades into a zone of chert-pebble conglomerate and fine- to coarse-grained graywacke sandstone. On the southeast side of Ekakevik Mountain the coarse-grained beds unconformably underlie the heavy conglomerates of the upper unit and differ by 20° of dip and 10° to 15° of strike. A few hundred feet of shale overlying the sandstone-conglomerate zone of the middle unit is unconformable with the heavy conglomerate above it on the flanks of the large syncline, but conformably underlies the conglomerate at the axis of the structure.

Elsewhere shale of the lower unit was not readily distinguished from the shale of other units. Locally this unit, together with the Okpikruak formation, is absent below strata of the middle unit. Although the lower unit may not have been deposited in certain areas, it is more likely that it has been removed by pre-middle unit erosion.

The middle unit of the Torok formation may be separated from the other units by several characteristics. The most obvious, as observed in the field, is a difference in degree of deformation and angular discordance with the overlying unit. These strata are commonly folded into asymmetric structures ranging from one quarter to three quarters of a mile wide and seldom over 3 miles long. Vertical to steeply overturned beds are common, whereas beds dipping 60° to 75° are typical.

These structures and attitudes are in contrast to the broad open folds with 10° to 30° dips that have been developed in the upper unit conglomerates (see fig. 4, Prelim. Rept. 34). It should be emphasized, however, that the apparent difference in degree of deformation is undoubtedly due in part to the more competent nature of the upper unit conglomerates and their greater resistance to folding and compressive stresses. Although differences in relative competency are thus a factor in considering the relative degree of deformation, angular discordance is nevertheless apparent in the truncation of the beds of the lower unit by the upper unit conglomerates.

In the places where typical lithology of the two units is recognizable, the middle unit is distinguished from the lower shale unit by the presence of a thick zone of coarse clastics. The shale associated with and (or) equivalent to the coarse beds is characteristically silty and is variably interbedded with siltstone, fine to medium graywacke sandstone, and, occasionally, granule conglomerate. The ammonite Lemuroceras[36] is at present considered to mark the basal section of the middle unit, but the basal section at Smith Mountain is the only locality within the area where this ammonite was found.

The zone of coarse clastics, medium to coarse sandstone, granule to pebble conglomerate, and rare lenticular beds of cobble conglomerate, is extremely variable laterally. At Smith Mountain a 2,100-foot thickness was computed for the zone. There sandstone, fine- to medium-grained, dark to medium green in color, and with poorly sorted, subangular particles, is apparently the main constituent. The beds "tongue out" laterally into shale,

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36/ Imlay, R. W., personal communication.

so continuations of the zone from either end of Smith Mountain are very much reduced in thickness. In the Ipnavik-Kuna area this zone is marked by 1,000 feet of pebble to cobble conglomerate. About 400 feet of medium to coarse graywacke sandstone and granule to cobble conglomerate makes up the ridges south of Liberator Lake. The thickness of the zone may range from 700 to 800 feet with accompanying increase in proportion of conglomerate southward to the vicinity of Swayback Mountain.

An undetermined thickness of interbedded dark silt shale and fine sandstone overlies the coarse clastic zone. The contact between the two zones is indefinite as the lower facies grades into the upper by a more or less alternating series of the two facies.

A thick zone of cross-bedded, very fine sandstone is present in a thick sequence of shale on the lower reaches of the Kiligwa River. It is tentatively correlated with the upper cross-bedded siltstone of the Torok formation described by Sable.[37] It is suggested that this zone is correlative in part with the middle unit of the Torok formation as described above.

At several localities, sharpstone conglomerate is present near the base of the middle unit. Where best developed it includes blocks of Lisburne limestone and Shublik formation as much as 10 feet in dimension. This conglomerate is tectonic in origin.

The beds of the middle unit crop out close to Triassic rocks along the northern margin of the infold belt. At the northernmost exposure of Triassic, 2 miles northwest of Swayback Mountain, a basal calcareous granule conglomerate is in disconformable contact with a Halobia zone of the Shublik formation. The unique appearance of an associated diabase sill may be interpreted as due to pre-middle unit weathering. Nearby sources of material are implied for the basal part of the unit. Other highs could have been developed to the north in the basin of deposition. Possibly, then, the basal part of the middle unit was deposited on actively growing structures.

Remnants of the upper unit are recognized in the Ekakevik Mountain and Swayback Mountain synclines. A maximum remaining thickness of 1,000 feet was computed at Swayback Mountain. Variable thicknesses were measured at Ekakevik Mountain: 3,000 feet on the northwest end; 2,200 feet on the northeast, and 1,700 feet on the southern margin of the infold. Conglomerates composed of subround pebbles and cobbles of quartzite, mafic igneous rock, chert, and Lisburne limestone are predominant at Swayback Mountain and in all but the upper 400 to 500 feet at Ekakevik Mountain. The two sequences of conglomerate have been correlated because they are folded in the same degree, project into one another along the regional trend, and are composed of similar types of conglomerate. They differ slightly in that the Ekakevik Mountain series has a marked predominance of quartzite pebbles as contrasted to the more typical chert, mafic igneous rock, minor quartzite, Lisburne limestone, and white quartz that make up the series at Swayback Mountain. The series at Ekakevik Mountain overlies the folded

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37/ Sable, E. G., and Mangus, M. D., op. cit.

lower unit of the Torok formation and the Okpikruak formation, whereas the series at Swayback Mountain overlies the folded middle unit of the Torok formation.

IGNEOUS ROCKS

Diabase[38] and closely related types are the only igneous rocks recognized. Most of these are sills and sill-like masses enclosed by pre-Cretaceous strata. Relatively thin sills 5 to 50 feet thick, and averaging 15 to 20 feet, intrude the Shublik formation and the Siksikpuk group. Local coalescence of several closely spaced sills results in a thicker mass of igneous rock. Sills of generally greater thickness occur in the Lisburne limestone. The lower sill on the "thrust" sheet is 150 feet thick.

The diabase is probably identical to the mafic igneous rock described in the Okpikruak-Kiruktagiak Rivers area[39]. The texture depends mainly on the thickness of the intrusive body. On chilled contacts, from 2 to 12 inches wide, the rock is dense but grades through fine to medium grain in the thinner sills. Maximum grain size was observed in the thick lower sill where mineral grains are one half inch long or more. The composition varies little. Apparent assimilation of host rock has locally produced a slight change in appearance.

Little metamorphic effect of the intrusives was noted and none extended more than 2 or 3 feet from the contact. On contacts with the larger masses chert is locally bleached and limestone recrystallized. A few epigenetic sulfides were found in the country rock; several zones of witherite (?) ($BaCO_3$), barite ($BaSO_4$), and gypsum[40] ($CaSO_4$ $2H_2O$) occur in the limestone-chert of the infold belt.

Several outcrops of igneous rock appear to be surface flows. Microscopic studies of samples from these outcrops have not been made.

The intrusives were nowhere proved to cut the Okpikruak formation or younger beds. In a few places, Cretaceous outcrops are very closely associated with outcrops of the igneous rock but no alteration was evident. Mafic igneous fragments and pebbles in the Okpikruak formation megascopically resemble the diabase. The authors feel that, in view of the numerous faults and stratigraphic displacement, conclusive proof of intrusion in Cretaceous rocks must come from an exposed igneous contact, preferably one with contact alteration. Intrusive activity cannot be definitely dated closer than between post-Jurassic and pre-Torok time.

Although the sills were probably injected into the strata along zones of weakness, generally parallel to the bedding, they have been subsequently folded and faulted with nearly the same intensity as the enclosing rock. The intrusion must, then, pre-date the major part of the deformation. But concentration or occurrence of the diabase is often closely associated

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38/ Stefansson, Karl, op. cit.
39/ Patton, W. W., Jr., and Tailleur, I. L., op. cit.
40/ Milton, Charles, Branch of Geochemistry and Petrology.

with post-diabase zones of weakness. It is probable, therefore, that zones of disturbance that initiated at the beginning of the deformation have been locii of later stages of adjustment.

STRUCTURE

The area mapped has been intensely deformed. Structural patterns and some details are shown on the geologic map and structure sections (pls. 1 and 2).

Regional compressional forces resulted in failure of large units by faulting; however, these forces produced overturned isoclinal folds in smaller units. Faults of considerable displacement are associated with the tight folds (see fig. 5, Prelim. Rept. 34). Combined folding and faulting of this type may account for the occurrence of thin slice blocks of older rocks within younger. The major fault zones are laterally persistent and in some places are associated with large overturned folds.

In the infold belt, the Okpikruak formation has been contorted only slightly less than the underlying strata, but the competent strata of the Torok formation have been involved in considerably less intense deformation.

Complicated folding of the incompetent shale sequences of the Torok formation (see fig. 6, Prelim. Rept. 34) probably is an expression of drag folding between more competent zones rather than relief of compressional stresses. Effect of waning compression is shown by the gentle folding of the upper member of the Torok formation.

An anomalous structural situation in the south-central Ipnavik-Kuna Rivers area has been referred to frequently above. Along the headwaters of Cutaway Creek, an obvious thrust-fault relationship exists between gently folded strata of the Lisburne limestone and associated diabase sills (in topographic highs) and the infold complex (forming the lowlands) (see fig. 7, Prelim. Rept. 34). This fault cannot be traced to the north and east, however, because it is obscured by a swarm of high-angle reverse faults that cut more steeply dipping Mississippian strata and diabase sills.

The fault trace eastward must pass just north of Ekakevik Mountain where the basal conglomerate of the upper unit of the Torok formation is faulted against a diabase mass. The fault plane dips 30° S. Moreover, the openly folded beds on the west side of the Ipnavik-Kuna Rivers area are broken by a series of reverse faults that destroy the postulated western projection of the thrust plate. Opposed to the interpretation of a low-angle thrust fault in the area in question is the present reasonable position of Ekakevik Mountain in relation to Swayback Mountain. As Ekakevik Mountain strata are closely associated with the beds on the possible thrust sheet, its restored location, before faulting, would be several miles to the south. However, other evidence supports the thrust-fault concept: (1) the Lisburne limestone at Mount Bupto has no diabase, as contrasted to the persistent sills occurring in correlative (?) strata on the "thrust" sheet; (2) possible correlation of the beds on the "thrust" sheet with "pagoda"-weathering beds and diabase sills that occur at the Range front;

and (3) apparent missing section on top of the "thrust" sheet as contrasted to a complete section up to zone 9 of the Alapah member of the Lisburne limestone at Mount Bupto. At present the authors believe that the evidence favors the interpretation of a low-angle thrust fault.

The thrust plate has been folded since its development in about the same degree as Swayback Mountain. It was broken later by numerous high-angle reverse faults. The strong suggestion of a flat thrust 10 to 20 miles north of the Range front lends support to the interpretation that the infold belt is part of a low-angle thrust present at depth. Many similarities exist between the Etivluk-Kiligwa section and the Albertan Foothills province where the presence of these subsurface low-angle thrusts has been established. Numerous complex structures that seem to have no reasonable explanation from the data available might be successfully interpreted as structural adjustments on a thrust sheet.

The structural history of the basin from which the strata were folded is complex. Down-warping and shortening of the basin was initiated during or shortly before deposition of the Okpikruak formation and must have continued intermittently throughout deposition of the Torok formation. Active upfolds, from which previously deposited strata were eroded, appear to have been present near the local axis of deposition. The accumulated effect of deformation has produced complicated structure in the older strata. Therefore, structures in the younger rocks exposed at the surface may only broadly reflect the conformation of older beds at depth.

PETROLEUM POSSIBILITIES

1. No favorable source or reservoir beds are present in the Okpikruak or Torok formations.

2. Possible source beds occur in the Kiruktagiak member of the Lisburne limestone and also in the Shublik formation.

3. Possible reservoir beds occur in the upper Alapah member of the Lisburne limestone in the quartzose sandstone facies which has, locally, high permeability and porosity, and in the dolomitized limestone that is exposed on the Lisburne Ridge.

4. The presence of at least 2,400 feet of Lisburne limestone in the infold belt of the Southern Foothills section and an additional 1,500 feet of Devonian limestone at the Brooks Range front indicates a thick section of beds, susceptible to development of secondary permeability, that may underlie the Northern Foothills section.

5. Surface structures in the infold belt would not warrant exploration because of probable complexity of structure at depth.

6. The probable anticlinorium area to the north of the mapped area would have the most favorable sites for testing the potentialities of the Paleozoic section.

7. Presence of grahamite as fracture fillings within strata in the infold belt as well as surface linings in voids, present in the Lisburne limestone, attest that petroleum, at least in small quantities, has migrated from its places of accumulation.

SUMMARY

1. Rocks of Devonian (?), Mississippian, Permo-Carboniferous (?), Triassic, Jurassic, and Lower Cretaceous age are exposed in the area.

2. Thicknesses for the stratigraphic units are as follows: Noatak formation (Mississippian or Devonian), indeterminate; Alapah member and older (?) rocks of the Lisburne limestone (Mississippian), 2,400 feet; Kiruktagiak member of the Lisburne (Mississippian), 400 feet or more; Permo-Carboniferous (?), approximately 700 feet; Shublik formation (Triassic), approximately 280 feet; Jurassic, indeterminate; Okpikruak formation (Lower Cretaceous), 2,000 feet; Torok formation (Lower Cretaceous), a total of more than 5,000 feet.

3. Several local unconformities are recognized: a disconformity at the base of the Okpikruak formation; an unconformity at the base of the middle unit of the Torok formation; and an angular unconformity at the base of the upper member of the Torok formation. The unconformity at the base of the middle unit of the Torok formation may represent erosion on an actively growing high in the depositional basin.

4. An area of structural complexity with isoclinally overturned folds and high-angle reverse faults is typical of all strata except the Torok formation. The younger beds are less intensely folded because deformation began at some time previous to initial Torok deposition and was decreasing at the end of Torok deposition. A low-angle thrust fault brings essentially flat-lying Lisburne limestone and overlying strata over Triassic and other beds in the south-central complex.

5. Small amounts of petroleum have been derived from beds that underlie the Okpikruak formation, principally the Kiruktagiak member of the Lisburne limestone. A quartzose sandstone facies and dolomitized zones in the Alapah member of the Lisburne limestone, in addition to 3,900 feet of rocks that may have secondary permeability, indicate reservoir possibilities in the Paleozoics.