Phosphate Deposits in Northern Alaska

EXPLORATION OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, NORTHERN ALASKA, 1944–53

PART 4, REGIONAL STUDIES

GEOLOGICAL SURVEY PROFESSIONAL PAPER 302-A

Prepared and published at the request of, and in cooperation with, the U.S. Department of the Navy, Office of Naval Petroleum and Oil Shale Reserves. This report also concerns work done in part on behalf of the U. S. Atomic Energy Commission and is published with the permission of the Commission

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PHOSPHATE DEPOSITS IN NORTHERN ALASKA

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ABSTRACT

Deposits of sedimentary phosphate rock were discovered on the Arctic Slope of Alaska during the geologic investigation of Naval Petroleum Reserve No. 4 between 1944 and 1953. They occur in at least two stratigraphic units, the Lisburne group (Mississippian) and the Shublik formation (Triassic), and have been found at widely scattered localities along the north front of the Brooks Range and in the adjoining foothills. The deposits in the Lisburne group in the central Brooks Range and Arctic foothills are of principal interest and have been examined in detail and systematically sampled at two localities, Tiglukpuk Creek and upper Kiruktagiak River.

The Tiglukpuk Creek and upper Kiruktagiak River areas are underlain by a thick sequence of highly deformed sedimentary rocks including the Wachsmuth limestone and Alapah limestone of the Lisburne group (Mississippian), the Siksikpuk formation (Permian?), the Shublik formation (Triassic), and the Tiglukpuk formation (Jurassic). The phosphate deposits are confined to the black chert and shale member of the Alapah limestone, near the top of the Lisburne group. This member, which ranges from about 40 to 100 feet in thickness, consists chiefly of dark shaly limestone, mudstone, and phosphate rock; it forms a distinctive lithologic unit within the massive light-colored fossiliferous clastic limestone that comprises the bulk of the Lisburne group which ranges in thickness from 2,000 to 2,500 feet.

The uraniferous phosphate rock from northern Alaska contains carbonate-fluorapatite as the phosphate mineral and, in general, is similar in mineralogy, phosphate, uranium, and minor element content to phosphates from the Phosphoria formation of Permian age in Northwestern United States. Other minerals identified are calcite, dolomite, quartz, and purple and colorless fluorite. Carbonaceous matter stains all the phosphate rock.

In the Tiglukpuk Creek area the phosphatic zone in the black chert and shale member is 36 feet thick and averages 8 percent P_2O_5. A 43-inch sequence of rock 16 feet below the top of the zone averages 21 percent P_2O_5. In the upper 20 feet of the zone 6 beds, from 1 to 5.5 inches thick, contain 30 percent P_2O_5. In the upper Kiruktagiak River area the phosphate zone is 38 feet thick and averages 12 percent P_2O_5. The upper 19 feet averages 19 percent P_2O_5; one 27-inch sequence of rock 16 feet below the top contains 27 percent P_2O_5. Because of the marked lateral variation in lithologic character and phosphate content in the black chert and shale member and the complex structure of the central Brooks Range and Arctic foothills, much work remains to be done before the phosphate deposits can be fully evaluated.

Samples containing as much as 35.8 percent P_2O_5 have been collected from the Shublik formation at several localities in the eastern Brooks Range. These deposits have not been sampled and measured systematically; therefore nothing is known of their thickness and extent.

INTRODUCTION

During the U. S. Navy's investigations of Naval Petroleum Reserve No. 4 and adjoining areas, between 1944 and 1953, deposits of sedimentary phosphate rock were discovered on the Arctic Slope of Alaska. The U. S. Geological Survey, as a cooperating agency, was chiefly responsible for the study and sampling of these deposits. The analytical work was done by the Geological Survey on behalf of the Division of Raw Materials, U. S. Atomic Energy Commission. A. E. Glover (written communication, October 1, 1948), of the Alaska Territorial Department of Mines, first authenticated the occurrence of phosphate in 1948 when he analyzed a prospector's sample from the Upper Anaktuvuk River valley.

Phosphate rock deposits in northern Alaska have been found at widely scattered localities and in two separate stratigraphic units, the Lisburne group of Mississippian age and the Shublik formation of Triassic age. The Lisburne group deposits in the central Brooks Range and Arctic foothills have received the most attention and are the best known. The present report is primarily concerned with detailed studies of these deposits at two specific localities, the upper Kiruktagiak River area and the Tiglukpuk Creek area. However, brief notes and analyses are given of samples collected from the phosphate deposits that have been found elsewhere on the Arctic Slope.

The phosphate deposits in the Lisburne group were first sampled by George Gryc, of the U. S. Geological Survey (oral communication), in 1945 during the course of a boat traverse down the Chandler River. In 1949 phosphate rock was found in the upper Kiruktagiak River area by a field party engaged in geologic mapping

along the mountain front using "weasels" (amphibious tractors) for transportation (W. W. Patton, Jr., and I. L. Tailleur, U. S. Geological Survey, written communication). The following year additional deposits were discovered near the head of Tiglukpuk Creek (H. N. Reiser, W. W. Patton, Jr., and A. S. Keller, U. S. Geological Survey, written communication). Also in 1950, deposits were noted on the Anaktuvuk River and at Chandler Lake by a field party engaged in detailed stratigraphic investigations of the Lisburne group using light plane and helicopter (W. P. Brosgé and H. N. Reiser, U. S. Geological Survey, written communication).

In 1953 two localities, the upper Kiruktagiak River area and the Tiglukpuk Creek area (pl. 1), were selected for detailed examination of the phosphate deposits in the Lisburne group. On June 3, 1953, W. W. Patton, Jr., and A. L. Bowsher landed on the ice at White Lake in the Chandler River valley in a "bush plane" mounted on skis. They packed their camping equipment 6 miles across the divide to the Kiruktagiak River where a food cache had been airdropped earlier. Six days were spent in the area, 3 of which were devoted to measuring and sampling the phosphate zone on the Kiruktagiak River and Monotis Creek. A total of 42 samples was collected for analysis. On June 11 the samples and equipment were back-packed to White Lake and the party was picked up and returned to the base camp at Umiat.

On June 23, Patton and M. V. Carson, field assistant, landed on Natvakruak Lake in a "bush plane" mounted on floats. They walked 5 miles west to the confluence of Tiglukpuk and Skimo Creeks where food had been cached by airdrop. Fieldwork in the area was cut short by a snow and sleet storm lasting from June 28 to July 3, and only 3 out of 10 days could be devoted to an examination of the phosphate deposits. Thirty samples were collected for analysis. On July 4 the men returned to Natvakruak Lake and were picked up by plane.

All the samples from the upper Kiruktagiak River and Tiglukpuk Creek areas were given a rapid field test for phosphate by Matzko in the U. S. Geological Survey laboratory at College, Alaska; subsequently, some of these samples were sent to the U. S. Geological Survey laboratory in Washington, D. C., for more refined analyses. In addition, 38 samples from several stratigraphic units, including the Lisburne group, which were collected between 1945 and 1951 from widely scattered localities across almost the entire length of the Arctic Slope, were submitted to the laboratory in Washington for phosphate and radiometric analyses.

The sections of this report on character and composition of the phosphate rock were written by John J. Matzko. The rest of the report was prepared by W. W. Patton, Jr., with the aid and advice of other geologists who have been engaged in the petroleum investigations of the Arctic Slope, particularly H. N. Reiser, W. P. Brosgé, and A. L. Bowsher.

GEOGRAPHY

The Arctic Slope of Alaska is subdivided (Payne, 1951) into three physiographic provinces, the Brooks Range, the Arctic foothills, and the Arctic coastal plain (pl. 1). The Brooks Range province extends east across northern Alaska from the international boundary to near Cape Lisburne on the Arctic coast. The Arctic foothills province adjoins the Brooks Range province on the north and is divisible into a northern foothills section and a southern foothills section. All known occurrences of phosphate rock are in the southern foothills section and along the northern margin of the Brooks Range province (pl. 1).

The southern foothills section has a maximum relief of about 2,000 feet and is characterized by scattered groups of irregularly shaped ridges and knobs separated by extensive tracts of gently rolling uplands (pl. 5). The northward-flowing rivers cross the foothills through broad, mature valleys. The major river valleys are mantled with glacial debris, which produces an uneven, hummocky, morainal topography and hundreds of small lakes. Except for ridgetops and steep declivities, the foothills are everywhere cloaked by a heavy growth of mosses, lichens, grasses, and sedges. There are no trees except for patches of stunted willows along the creek bottoms.

From altitudes of from 2,000 to 3,000 feet along the southern margin of the foothills, the Brooks Range rises abruptly to 5,000 feet at the western end, 7,000 feet in the central part, and over 9,000 feet near the eastern end. The larger rivers, such as the Killik and Anaktuvuk, head near the center of the range and meander northward through deep flat-floored U-shaped glacial valleys. Small lakes, which are impounded behind dams of morainal debris, are common along the valley floors. The smaller streams, such as Tiglukpuk and Skimo Creeks, have not been as extensively glaciated. They head high in the mountains a few miles from the north front, flow down through steep-walled canyons over cataracts and waterfalls, and then, with an abrupt decrease in gradient, meander out across the foothills. The north flank of the mountains is notably barren and rugged. Tundra growth extends up the mountain slopes a few hundred feet but then gives way to bare rock or talus. There are no trees.

Aircraft provide the only practical means of access to this region. Livengood and Circle, the northern termini of the Alaska road system, are 250 miles to the south. Fairbanks and the nearest railroad are nearly 300 miles

to the south. The closest settlements with permanent airfield facilities are Bettles, 100 miles to the south, and Umiat, 80 miles to the north. The phosphate deposits at Tiglukpuk Creek and the Kiruktagiak River are accessible during the summer from nearby lakes that are suitable for the landing of a "bush plane" mounted on floats.

GEOLOGY

REGIONAL SETTING

The northern slope of the Brooks Range and the adjoining foothills are underlain by a thick succession of sedimentary rocks that range in age from Devonian or older to Cretaceous. (See correlation chart.) The rocks are predominantly Paleozoic in the mountains and Mesozoic in the foothills. In the eastern part of the Brooks Range-Arctic foothills belt, the rocks are deformed principally by eastward-trending folds, some of which are overturned to the north. Faults of relatively small displacement occur locally. The intensity of deformation increases westward so that in the central and western part of the belt imbricate faults and large-scale overthrusts are the predominant structural features.

Schematic correlation of the principal stratigraphic units exposed on the north flank of the Brooks Range and in the adjoining Arctic foothills

Age	West and central		East
Cretaceous	Fortress Mountain formation: Graywacke sandstone, conglomerate, and shale Okpikruak formation: Graywacke sandstone and shale		Ignek formation: Shale, siltstone, and sandstone
Jurassic	Tiglukpuk formation: Graywacke sandstone, shale, and chert		Kingak shale: Black shale
Triassic	Shublik formation: Dark shale, limestone, and chert		Shublik formation: Dark limestone, shale, siltstone, and sandstone
Permian(?) and Permian	Siksikpuk formation: Red and green shale, siltstone, and chert (Permian?)		Sadlerochit formation: Shale, siltstone, sandstone and conglomerate (Permian)
Mississippian	Lisburne group: Alapah limestone: Limestone, dolomite, shale, and chert Lisburne group: Wachsmuth limestone: Limestone, dolomite, shale, and chert		Lisburne group: Limestone, dolomite, and chert
	Kayak shale: Black shale, limestone, and sandstone		Kayak shale: Black shale, quartzite, conglomerate, and limestone
Devonian	Kanayut conglomerate: Conglomerate, sandstone, and shale		Neruokpuk formation: Schist, phyllite, slate, limestone, and quartzite
Devonian and older	Shale and sandstone		

UPPER KIRUKTAGIAK RIVER AND TIGLUKPUK CREEK AREAS

STRATIGRAPHY

Rocks ranging in age from Mississippian to Jurassic are exposed in the upper Kiruktagiak River and the Tiglukpuk Creek areas. Their stratigraphic relationships are shown on plate 2. The column for the upper Kiruktagiak River area was compiled from measured sections on Monotis Creek, the Kiruktagiak River, and Chandler Lake. The column for the Tiglukpuk Creek area was compiled from measured sections on Tiglukpuk and Skimo Creeks. In addition to bedrock, there are surficial deposits of glacial gravels (Pleistocene) and alluvium (Recent).

ROCKS OF MISSISSIPPIAN AGE

LISBURNE GROUP

The Lisburne group underlies the southern half of the Tiglukpuk Creek area (fig. 1) where it forms the steep northward-facing front of the Brooks Range. In the upper Kiruktagiak River area it also occurs along

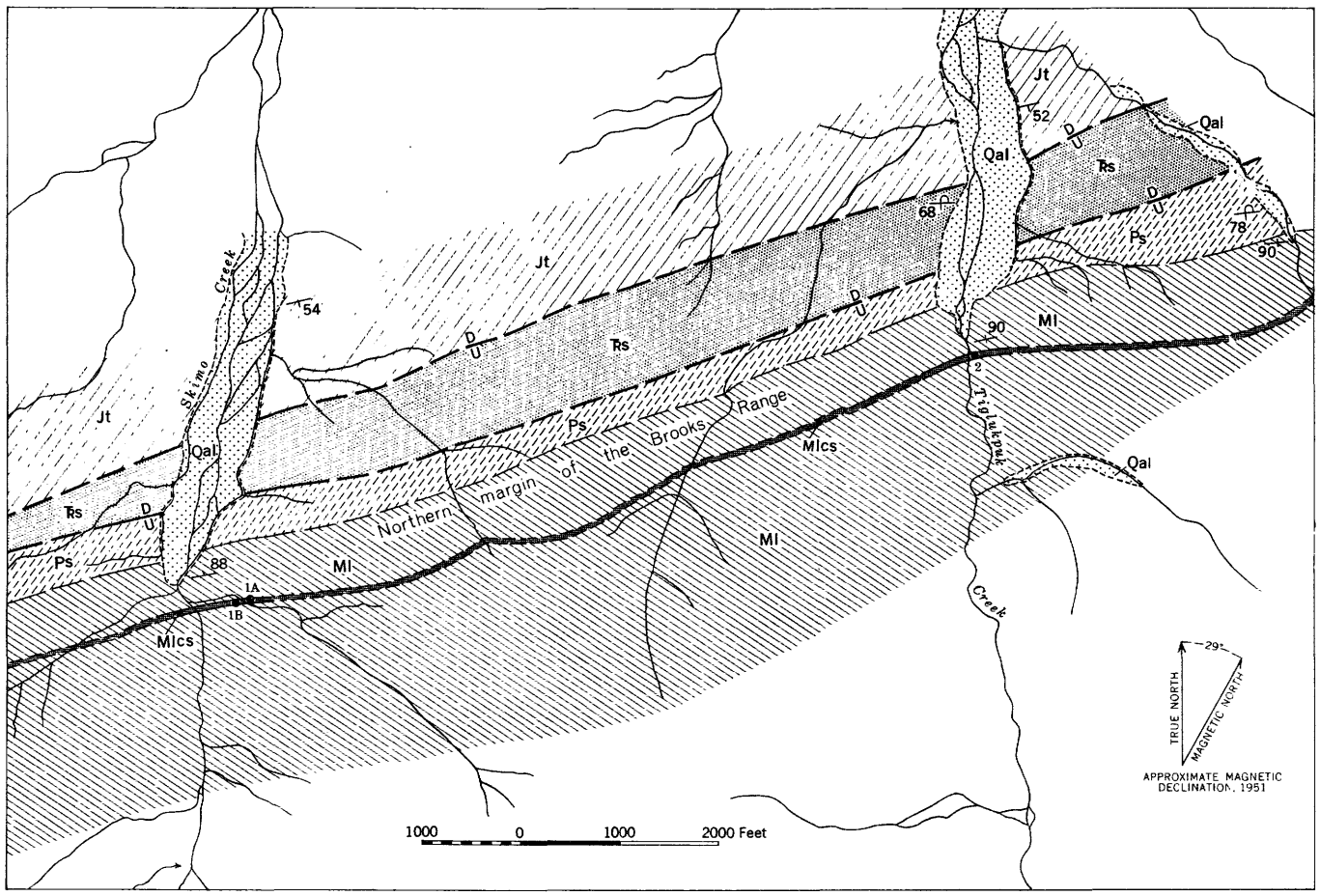


FIGURE 1. Sketch map showing geology and location of measured sections in Tiglukpuk Creek area.

UPPER KIRUKTAGIAK RIVER AREA, NORTH FRONT OF BROOKS RANGE

Low-angle oblique view west. Mountain front, paralleled by Monotis Creek in center background, is underlain by Lisburne group (Mississippian). Foothills are underlain by complexly folded and faulted strata of late Paleozoic and Mesozoic age. Photograph by U. S. Navy, 1949.

A

B

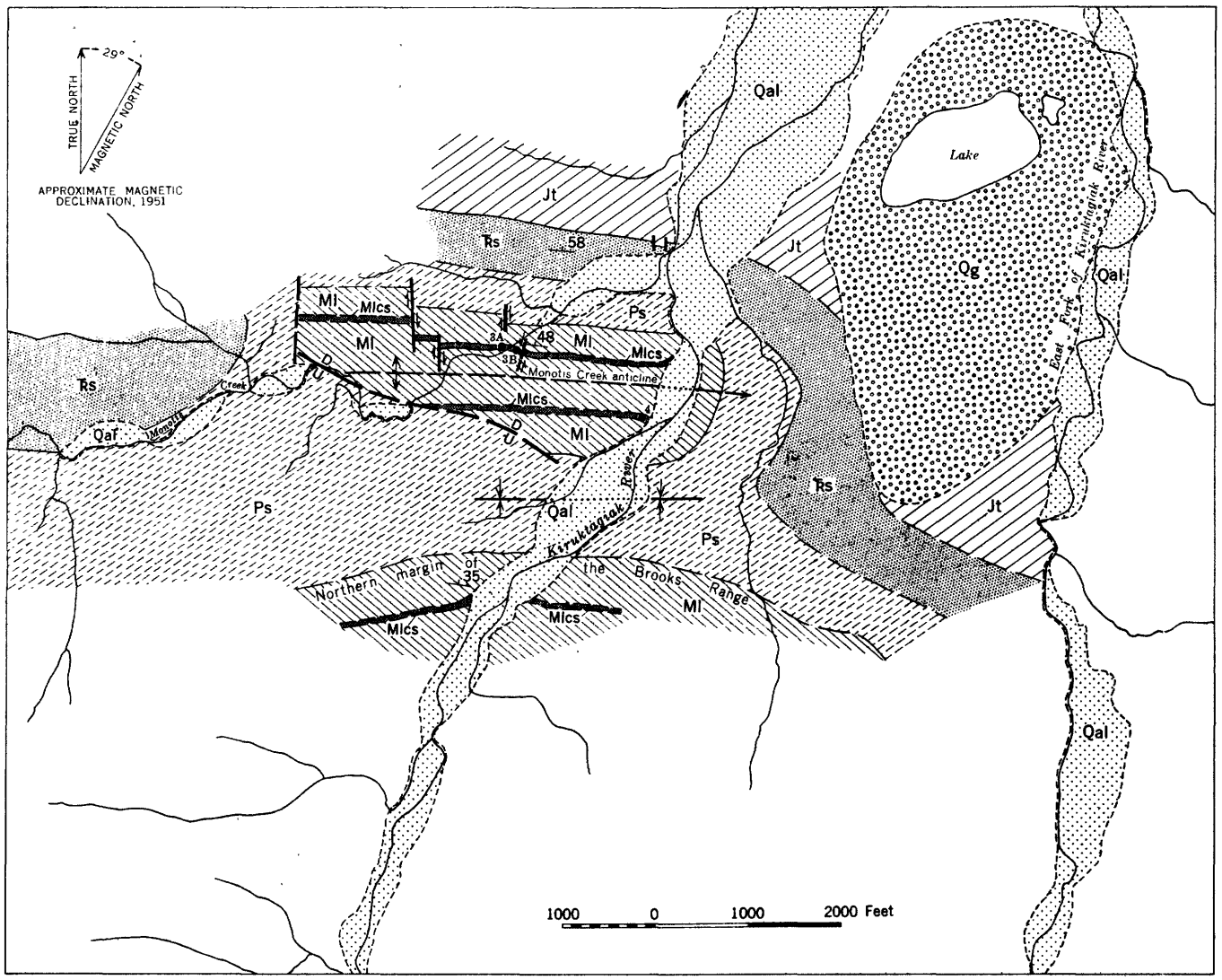
C

EXPOSURES OF THE PHOSPHATIC ZONE OF BLACK CHERT AND SHALE MEMBER, ALAPAH LIMESTONE, IN THE UPPER KIRUKTAGIAK RIVER AND TIGLUKPUK CREEK AREAS

A. Looking east toward valley of Kiruktagiak River in background. Black chert and shale member of the Alapah limestone (Mac) on north flank of Monotis Creek anticline. Location of measured sections 3A (A) and 3B (pl. 4) near center of picture. Strata dip about 50° N. *B*. Exposure of interbedded phosphate rock and phosphatic limestone in the black chert and shale member at locality of measured section 4 (pl. 4) on Kiruktagiak River. *C*. Looking west at an exposure of black chert and shale member in Tiglukpuk Creek area near locality of measured section 1 (pl. 3). The dark nonresistant beds at the top of the black chert and shale member on the left are overlain by massive ledges of light-colored limestone on the right. Strata dip very steeply north. Saddle on ridge in background is underlain by black chert and shale member.

the mountain front, but, in addition, it is exposed a short distance north of the mountain front along the axis of the Monotis Creek anticline (fig. 2).

The Lisburne group was originally described in 1902 by F. C. Schrader (p. 233–252). Schrader named it Lisburne limestone after the exposures at Cape Lisburne on the Arctic coast, though he designated a type locality on the upper Anaktuvuk River in the central



Base map compiled from aerial photographs

Geology by W. W. Patton Jr., 1949, 1953, and I. L. Tailleur, 1949

EXPLANATION

- Qal — Alluvium — QUATERNARY
- Qg — Glacial gravel — QUATERNARY
- Jt — Tiglukpuk formation — JURASSIC
- Rs — Shublik formation — TRIASSIC
- Ps — Siksikpuk formation — PERMIAN(?)
- Ml, Mlcs — Lisburne group, Black chert and shale member of Alapah limestone, Mlcs — MISSISSIPPIAN
- Contact — *Long dash where approximately located; short dash where projected*
- Indefinite contact
- Fault — U, *upthrown side;* D, *downthrown side; dashed where inferred or approximately located*
- Fault, showing relative movement
- Anticline, showing direction of plunge — *Dashed where approximately located; dotted where concealed*
- Syncline — *Dashed where approximately located; dotted where concealed*
- 48 — Strike and dip of beds
- 3A — Location end number of measured section

FIGURE 2. Sketch map showing geology and location of measured sections in upper Kiruktagiak River area.

Brooks Range. As a result of recent stratigraphic studies in the Shainin Lake area, A. L. Bowsher and J. T. Dutro, Jr. (1957) have elevated Schrader's Lisburne limestone to the status of a group and have subdivided the group into two formations: the Wachsmuth limestone and the Alapah limestone. In the upper Kiruktagiak River and Tiglukpuk Creek areas the Lisburne group has not been mapped in sufficient detail to permit delineation of the Wachsmuth and Alapah limestones (figs. 1, 2). However, the thickness and character of the two formations are shown on plate 2.

The bulk of the Lisburne group is composed of a brownish to grayish fossiliferous clastic limestone and varying but subordinate amounts of light-gray coarsely crystalline dolomite, dark-gray to grayish-black argillaceous limestone, grayish-black shale, and dark-gray nodular and bedded chert. The clastic limestone is fine to coarse grained, occurs in beds several inches to several feet thick, and consists largely of an aggregate of fossil fragments including brachiopods, corals, echinoderms, bryozoans, gastropods, and trilobites. Nodules and lenses of dark chert are an important constituent at many levels where they may make up as much as 40 percent of the rock.

The base of the Lisburne group is not exposed in either of the two areas. However, a few miles south of the upper Kiruktagiak River area the Lisburne group was found, as elsewhere in the central Brooks Range, to rest upon the Kayak shale (Mississippian). The total thickness of the group is probably between 2,000 and 2,500 feet (Brosgé and Reiser, written communication, 1954).

Bowsher and Dutro (1957) have assigned the Wachsmuth limestone an Early Mississippian age and the Alapah limestone a probable Late Mississippian age.

BLACK CHERT AND SHALE MEMBER OF THE ALAPAH LIMESTONE

The phosphate deposits are confined to the black chert and shale member of the Alapah limestone near the top of the Lisburne group. The black chert and shale member, composed predominantly of dark soft shale, shaly limestone, and phosphate rock, forms a discrete lithologic unit within the light-colored massive fossiliferous clastic limestone that characterizes the rest of Alapah limestone. In the Tiglukpuk Creek area the black chert and shale member occurs 530 feet below the base of the Siksikpuk formation (Permian?). In the Kiruktagiak River area, however, it is only 185 feet below the Siksikpuk (pl. 2). The difference in thickness of the overlying limestone sequence is attributed at least in part to differential erosion before deposition of the Siksikpuk. The black chert and shale member in the Tiglukpuk Creek and upper Kiruktagiak River areas is correlated with the type section in the Shainin Lake area in figure 3.

The upper part of the black chert and shale member has an abundant and distinct goniatite-brachiopod faunal assemblage. The following collections from the upper Kiruktagiak River area were identified and assigned a late Mississippian age by J. T. Dutro, Jr., and Mackenzie Gordon, Jr.

49APa384 (USGS U. Paleozoic loc. 10862), Monotis Creek:
Nudirostra cf. *N. carbonifera* (Girty)
Moorefieldella? sp.
Productella cf. *P. hirsutiformis* Walcott
Martinia aff. *M. glaber* (J. Sowerby)
Pleurotomarid gastropod, n. gen. n. sp.

49APa390 (USGS U. Paleozoic loc. 10864), Kiruktagiak River:
Moorefieldella cf. *M. eurekensis* (Walcott)
Caneyella cf. *C. percostata* Girty
Bactrites? sp. indet.
Knightoceras pattoni Gordon
Beyrichoceras (*Bollandoceras*) cf. *B. micronotum* (Phillips)
Goniatites crenistria Phillips (wide form)
Girtyoceras arcticum Gordon
Entogonites borealis Gordon
Dimorphoceras algens Gordon

ROCKS OF PERMIAN(?) AGE

SIKSIKPUK FORMATION

In the Tiglukpuk Creek area the Siksikpuk formation crops out along a narrow northeastward-trending band that borders the mountain front (fig. 1). At the south edge of the band, vertical beds of the Siksikpuk formation are in contact with the underlying Lisburne group, and at the north edge they are in fault contact with the overlying Shublik formation. The soft, nonresistant rocks of the Siksikpuk formation and the overlying Shublik formation have been deeply eroded so that the nearly vertical massive beds of the Lisburne group form a steep escarpment at the north front of the mountains.

In the upper Kiruktagiak River area the Siksikpuk formation also crops out adjacent to the mountain front. In addition, it is found a short distance north of the mountains on the flanks of the Monotis Creek anticline (fig. 2).

The Siksikpuk formation derives its name from the Siksikpuk River of which Tiglukpuk Creek is a major tributary. The type locality is on Tiglukpuk and Skimo Creeks (Patton, 1957).

The chief components of the Siksikpuk formation are variegated shale and siltstone that, locally, are notably calcareous, cherty, or ferruginous. There are all gradations from thin fissile clay shale through platy silty shale to 6-inch beds of siltstone. Shades of green, gray, and dark red are the predominant rock colors. The variegated nature of the fresh rock and the bright-yellow and red weathering of the ferruginous beds serve

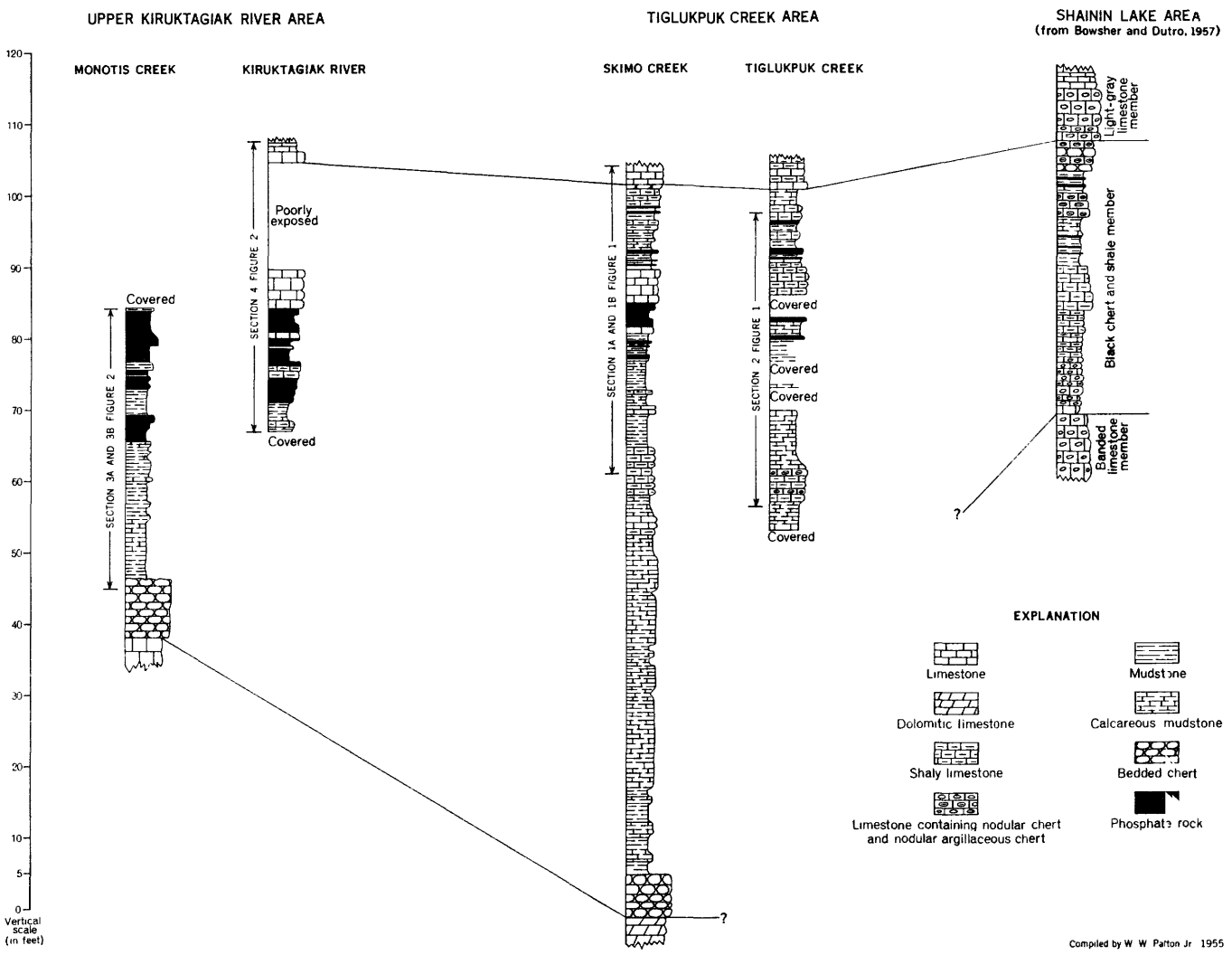


FIGURE 3. Correlated columnar sections of black chert and shale member, Alapah limestone, Lisburne group.

to distinguish, even at a distance, the Siksikpuk formation from the gray limestone and black shale which characterize the underlying Lisburne group.

In the Tiglukpuk Creek area the Siksikpuk formation is about 350 feet thick. It thins to 250 feet in the upper Kiruktagiak River area as a result, at least in part, of pre-Shublik erosion.

The Siksikpuk formation has been assigned tentatively to the Permian, based upon a coral, brachiopod, and gastropod faunal assemblage from the basal 50 feet (Patton, 1957).

ROCKS OF TRIASSIC AGE

SHUBLIK FORMATION

In the Tiglukpuk Creek area, the Shublik formation bounds the Siksikpuk formation on the north and crops out along a narrow northeastward-trending band (fig. 1). In the upper Kiruktagiak River area, the Shublik crops out in a narrow band that swings north from the mountains at the east side of the area, wraps around the eastward-plunging end of the Monotis Creek anticline, and then trends westward along the north flank of the Monotis Creek anticline (fig. 2). Like the Siksikpuk formation, the Shublik is not resistant to erosion and is characteristically expressed at the surface by subdued topography.

The Shublik formation was originally described and named by E. de K. Leffingwell (1919, p. 115–118) in the Canning River region of the eastern Brooks Range. Because of its remarkably uniform and distinctive lithologic character and the abundance of diagnostic fossils, it can be mapped and correlated with confidence over most of northern Alaska.

The Shublik formation is composed principally of highly carbonaceous grayish-black shale, chert, and limestone. The dark color distinguishes it from the variegated rocks of the underlying Siksikpuk formation. In the Tiglukpuk Creek and upper Kiruktagiak River

areas the Shublik formation can be subdivided into three members: (a) a lower member of black, gray, and greenish-gray shale with minor intercalated dark limestone; (b) a middle member of dark siliceous limestone, black paper shale, and dark calcareous shale; and (c) an upper member of dark fossiliferous limestone capped by dark shale. The lower member is about 100 feet thick in the upper Kiruktagiak River area but more than 500 feet thick in the Tiglukpuk Creek area. The middle and upper members are about the same thickness in the 2 areas, that is, 130 to 150 feet and 60 to 80 feet, respectively.

The lower member has an ammonite-pelecypod fauna which has been dated as early Middle Triassic by Bernhard Kummel (written communication, April 7, 1952). The middle and upper members have a typical Late Triassic assemblage including *Monotis subcircularis* (Gabb) and *Halobia*.

ROCKS OF JURASSIC AGE

TIGLUKPUK FORMATION

The Tiglukpuk formation crops out along the north edge of the upper Kiruktagiak River and the Tiglukpuk Creek areas (figs. 1, 2). It is exposed in cutbanks along Skimo and Tiglukpuk Creeks and the Kiruktagiak River. In the interstream areas it is typically expressed at the surface by discontinuous low rubble-covered ridges.

The type section and type locality of the Tiglukpuk formation (Patton, 1956, p. 213–218) are on Tiglukpuk Creek 2 to 3 miles north of the mapped area (fig. 1).

Probably not more than the basal 400 feet of the nearly 1,500 feet of the Tiglukpuk formation is exposed in either the upper Kiruktagiak River or Tiglukpuk Creek areas (pl. 2). This basal section rests disconformably upon the Shublik formation and is composed dominantly of greenish-gray graywacke, dark-gray shale and siltstone, variegated shale and siltstone, and green bedded chert.

The Tiglukpuk formation includes rocks of both Middle and Late Jurassic age. The Middle Jurassic rocks are limited in areal distribution on the Arctic Slope. The bulk of the formation, including the exposures in the Tiglukpuk Creek and upper Kiruktagiak River areas, is Late Jurassic in age.

DEPOSITS OF QUATERNARY AGE

The northeast corner of the upper Kiruktagiak River area is mantled by glacial gravel that appears to have been derived chiefly from the rocks of Paleozoic age of the Brooks Range. These deposits are largely obscured by a heavy growth of tundra; however, their distribution is outlined by low morainal ridges and disrupted drainage.

North of the mountain front, stream gravels fill the valleys of the Kiruktagiak River, the east fork of the Kiruktagiak River, and Tiglukpuk and Skimo Creeks. The abrupt decrease in gradient where the streams leave the mountains has caused the valleys to become choked with gravel, and the streams have been diverted into a network of braided channels (figs. 1, 2).

STRUCTURE

TIGLUKPUK CREEK AREA

The rocks of the Tiglukpuk Creek area lie along the north flank of a broad eastward-trending anticline. The axis is about a mile south of the southern edge of the mapped area (fig. 1). At the mountain front the Lisburne group stands vertically or nearly vertically and strikes N. 75° E. For the most part, the massive Lisburne group is free from minor folds and faults. North of the mountain front, however, the less competent Siksikpuk, Shublik, and Tiglukpuk formations have been intensely crumpled and broken. Two reverse faults along the contact of the Siksikpuk and Shublik formations and along the contact of the Shublik and Tiglukpuk formations are shown in figure 1; other faults, most of which have relatively small displacement, have not been shown. At the mountain front the strata dip principally southward, though north from the front the succession of progressively younger rocks indicates a northward regional dip. The southward dip of the strata at the mountain front is the result of isoclinal folds that are overturned to the north and southward-dipping imbricate faults. The northward regional dip north of the mountain front is reversed along a major synclinal axis that crosses Tiglukpuk Creek near the confluence of Skimo Creek, 1½ miles north of the mapped area.

UPPER KIRUKTAGIAK RIVER AREA

At the mountain front in the Kiruktagiak River area the rocks dip northward at an angle of about 35°. A short distance north of the mountain front the northerly regional dip is interrupted locally by a small syncline and the Monotis Creek anticline (fig. 2). The westward-trending belts of the Siksikpuk, Shublik, and Tiglukpuk formations, that parallel the mountain front at the east edge of the mapped area, wrap around the eastward-plunging end of the Monotis Creek anticline and continue a westerly trend along the north flank. On the south flank, the Siksikpuk formation has been thrust northward onto the Lisburne group, and, less than a mile west of the Kiruktagiak River, the anticline appears to terminate against this fault and a northward-trending strike-slip fault. The Lisburne group and Siksikpuk formation are offset in several places on the north flank of the anticline by other northward-trending strike-slip faults.

The broad structural features of the upper Kiruktagiak River area are complicated, locally, by many faults and folds too small to be shown on the map. Furthermore the entire mapped area appears to be part of a large folded overthrust sheet which has been thrust northward across the foothills from the general region of the Brooks Range. As evidence of this, half a mile south of the mapped area, the Lisburne group forming the north flank of the mountains has been eroded, revealing younger rocks in fault contact below.

PHOSPHATE DEPOSITS

UPPER KIRUKTAGIAK RIVER AND TIGLUKPUK CREEK AREA

In the upper Kiruktagiak River and Tiglukpuk Creek areas the phosphate deposits occur in the middle and upper parts of the black chert and shale member of the Alapah limestone, Lisburne group (fig. 3). Columnar sections, lithologic descriptions, P_2O_5, V_2O_5, and equivalent uranium analyses are given on plates 3 and 4 for those parts of the black chert and shale member that were logged and sampled in detail. The rocks comprising the phosphatic zone are composed chiefly of a mixture of phosphate mineral, calcium carbonate, silt and clay. Depending upon which is the predominant component, they are called phosphate rock, limestone or mudstone (as used in this report, "mudstone" includes shale, siltstone, and claystone). The common rock names are modified by the adjectives "phosphatic," "calcareous," or "argillaceous" if one or both of the other principal components are present in appreciable amounts.

Because of the necessity for back-packing the samples several miles to a place where they could be picked up by an airplane, they were limited in size and number. Only those parts of the black chert and shale member which appeared to be phosphatic were sampled. The samples weighed about 1 pound each and consisted of representative chips from each bed or zone of similar lithologic character. In those parts of the section where two different rock types occur in thin alternating layers, only one representative sample of each type was collected.

All 81 samples collected in the upper Kiruktagiak River and Tiglukpuk Creek areas were tested for P_2O_5 content and equivalent uranium. Twenty of the samples were analyzed for P_2O_5 in the U. S. Geological Survey laboratory in Washington, D. C., by accurate laboratory methods. The remainder were analyzed by a simple field test (Shapiro, 1952) by the U. S. Geological Survey at College, Alaska. According to Shapiro, the simple field test for phosphate is capable of an accuracy to the nearest 5 percent.

CHARACTER AND COMPOSITION OF THE PHOSPHATIC ROCK

The phosphate rock is dark gray or black but where it has been exposed it weathers light gray or brown and generally is coated with a characteristic bluish-white bloom. In some places secondary purple fluorite is visible on bedding surfaces and in veinlets. Thickness of beds ranges from a fraction of an inch in the highly argillaceous rock to 2 feet in the highly calcareous rock.

The texture of the rock is usually pelletal, that is, granular, oolitic, or pebbly. The size of the pellets is generally between 0.1 and 2 mm but may be as much as 10 mm. Most of the pellets are elliptical and oriented with the long axis parallel to the bedding plane. Some of the pellets, however, are fragmented and disoriented and many contain calcite veinlets. This suggests some postdepositional movement and crushing. In thin section, the concentric structure is indicated in some of the phosphatic pellets by alternating light- and dark-brown rings due to variations in the carbonaceous content, but most of the pellets do not show any recognizable structure. No nuclei have been identified in them.

In the present report phosphatic samples are classed as phosphate rock if they contain more than 13.8 percent P_2O_5. If they contain less than 13.8 percent but more than 5 percent P_2O_5, the adjective "phosphatic" is applied to the common rock name, that is, phosphatic mudstone, phosphatic limestone.

Samples of the phosphate rock from the Lisburne group were examined by X-ray analysis, and the phosphatic pelletal material was identified as a carbonate-fluorapatite. The d-spacings are similar, in general, to those of the phosphate mineral from the Phosphoria formation in Northwestern United States (C. A. Gulbrandson, written communication, 1954). The apatite in the Alaskan phosphate rock is generally either colloform or cryptocrystalline, isotropic appearing, and usually highly stained by carbonaceous matter.

Other minerals identified in the samples are calcite, dolomite, fluorite, and quartz, All the samples contain these minerals in varying amounts. Calcite occurs as secondary large clear crystals with prominent twinning, as small grains interstitial to the phosphate, and as a secondary filling or replacement in shattered pellets. Some specimens contain dolomite rhombs. Most of the samples contain purple and colorless fluorite as (a) veinlets cutting the phosphatic pellets, (b) blebs in the center of the pellets and frequently closely related to carbonaceous matter, or (c) between the pellets. In the latter specimens, veinlets of phosphatic or carbonaceous matter generally are associated with the fluorite. The quartz is most commonly fine grained,

angular to subrounded, and is dispersed throughout the phosphatic pellets or confined to interstices between the pellets.

Spectrographic analyses of a few selected samples indicate that the phosphate rock from the Lisburne group contains as many as 30 different elements besides fluorine and uranium. The results of these analyses are shown in the table below.

Semiquantitative spectrographic analyses, in percent, of selected samples from the Lisburne group, northern Alaska

[Samples 120,731 and 120,738 analyzed by Katherine E. Valentine; all other analyses by Joseph Haffy. All samples from the upper Kiruktagiak River and Tiglukpuk Creek areas]

Sample No.	Laboratory No.	10	5–10	1–5	0.5–1	0.1–0.5	0.05–0.1	0.01–0.05	0.005–0.01	0.001–0.005	0.0005–0.001	0.0001–0.0005
53APa7	120,677	Si	------	Ca, Al, P	Fe, K	Mg, Na, Cr	Ti, Ni, V	Cu, Y, B, Zn, Ba, Sr	Mo	La, Ag, Ga, Mn, Pb, Sn, Zr, Yb	----------	Be
53APa10	120,680	Si	------	Ca, Mg	Al, Fe	P	Cr, Ni, Cu	Na, B, Mo, Ti	Zn, Sr	Ba, Mn, Pb, Sn, V, Y	Zr	Ag, Yb
53APa17	120,687	Si	------	Ca, P, Al	Fe	Mg, Na, V, Cr	Ni, Cu, Sr	Ti, B, Mo, Y, Zn, Ba	Cd, Pb	Ag, La, Sn, Mn, Zr, Yb	----------	----------
53APa18	120,689	Si	------	Ca, P	Al, Fe	Mg, Cu, Cr	Ni, Na, V	B, Mo, Zn, Co, Sr	Sn, Ti, Ba, Pb, Mn	Y, Ag, Zr	----------	Yb
53APa21	120,692	Ca, P	------	Si	----------	Fe, Al, Mg, Na	Cu, Sr, Cr	V, Y, Ni, La	Zn, Ba, Mo, B	Pb, Sn, Mn, Zr	Yb	Ti, Ag
53APa27	120,698	Si	Ca	Al, P, K	Mg, Fe	Na, Cr, Ni	Ti, V, Y	Cu, Sr, Zn, B, Ba, La	Mo, Ag	Mn, Ga, Zr, Pb, Yb	----------	Be
53APa37	120,708	Si	------	Ca, P	Al, Fe	Mg	Cr, Cu, Na, V, Ni	B, Mo, Sr, Zn, Ti	Sn	Ba, Mn, Y, Pb, Ag, Zr	----------	Yb
53APa40	120,711	Ca, P	------	----------	----------	Na, Si, Al, Fe, Mg, Y	Sr, Cr	Cu, V, Ni, La, Ba	Zn	Pb, Sn, Mo, Yb, Zr	----------	Ti, Ag
53APa136	120,720	Si	------	Ca, Al, P	Fe, K	Mg, Na	Cr, Cu	Ni, Ti, Y, B, Zn, V, Sr	Mo	La, Ba, Ag, Mn, Pb, Sn, Zr	Yb	Be
53APa147	120,731	P, Ca	Si	----------	Al	Mg, Na	Fe, Sr	V, Y, Ni, La	Cr, Cu, Ba, Pb	Mn, Sc, Yb	Ag, Ti	----------
53APa154	120,738	P, Ca	Si	----------	Al	Mg, Fe, Na	Sr	Cu, Ba, Y, La	Pb, Cr, Ni, V	Mn, Sc, Yb	Ti	Ag

Preliminary investigation of the phosphate rock from northern Alaska shows a probable relationship of the uranium, phosphate, and organic content. Thompson (1953) has demonstrated that the uranium content of the Phosphoria formation of Idaho, Wyoming, and Utah shows a stronger relationship to the product of the phosphate and organic content than to either one separately, but that singly the correlation with phosphate content is better than the correlation with organic content. A similar relationship appears to exist in the phosphate rocks of the Lisburne group.

To determine the distribution of radioactivity in the phosphate rock of the Lisburne group, exposures with nuclear emulsion film were made of the more radioactive samples. The film was exposed for periods as long as 60 days; however, this maximum exposure was evidently insufficient, because no alpha tracks, which indicate the presence of radioactive material, were detected.

LOCAL DETAILS

TIGLUKPUK CREEK AREA

In the Tiglukpuk Creek area the black chert and shale member of the Alapah limestone occurs along a narrow N. 75° E.-striking belt a short distance south of the mountain front (fig. 1). Exposures are found along Tiglukpuk and Skimo Creeks and the small tributaries. Owing to its nonresistant nature, the black chert and shale member does not crop out in the interstream areas. It can be traced, however, by a series of saddles and trenchlike depressions across the mountainous ridges of the more resistant limestone (pl. 6*C*). On Skimo Creek the black chert and shale member is nearly 100 feet thick. It is overlain by massive siliceous limestone and underlain by massive dolomitic limestone. The base of the member is marked by a 6-foot ledge of chert (fig. 3).

The phosphatic zone of the black chert and shale member was logged and sampled in two places (fig. 1). Section 1 (pl. 3) occurs on a small tributary of Skimo Creek where the entire black chert and shale member is exposed along steep canyon walls. Part 1A of the section is on the northeast side of the stream and part 1B lies directly opposite on the southwest side. The phosphatic zone is approximately 36 feet thick. Forty-six beds constituting the phosphatic zone in section 1 were sampled. A 43-inch sequence of beds, 16 feet below the top, averages 21 percent P_2O_5; 6 beds, from 1 to 5.5 inches thick and containing 30 percent P_2O_5, occur in the upper 20 feet.

Section 2 (pl. 3) was measured on the east side of Tiglukpuk Creek, about 1½ miles east of Skimo Creek. The phosphate zone here is poorly exposed; therefore the measured section as shown on plate 3 is not complete. Twenty-five beds were sampled. Four beds, from 2 to 9.5 inches thick and containing 30 percent P_2O_5, occur in the upper 15 feet; 1 bed, 4.5 inches thick and containing 22 percent P_2O_5, occurs 16 feet below the top of the section.

Suggested correlations between sections 1 and 2 are

shown on plate 3. It is not possible, however, to make a bed-for-bed correlation even though the 2 sections are only 1½ miles apart. This may be due to facies changes and to lensing out of certain beds. Some limestone beds, for example, were observed to pinch out in a few feet. It may also be due in part to discrepancies in measurement and description of section 2 because of the poor exposure.

UPPER KIRUKTAGIAK RIVER AREA

The black chert and shale member of the Alapah limestone in the upper Kiruktagiak River area occurs on both flanks of the Monotis Creek anticline and also 2,000 feet to the south within the belt of Lisburne group that forms the north front of the mountains (fig. 2). Outcrops of the black chert and shale are found on Monotis Creek and along the west bank of the Kiruktagiak River, but the complete sequence is not exposed at any one locality. A composite of several partial sections indicates that the total thickness of the black chert and shale member in this area is about 60 feet. The base of the member is marked by a resistant 8-foot ledge of dark chert that overlies a sequence of massive light-colored fossiliferous clastic limestone. The topmost beds of the member are overlain by a resistant 17-inch bed of light-colored dense limestone.

Two sections of the phosphatic zone of the black chert and shale member were sampled and logged in the upper Kiruktagiak River area. Section 3 shown on plate 4 is located on Monotis Creek on the north flank of the Monotis Creek anticline about 2,000 feet west of the Kiruktagiak River. Part A of section 3 is on the west side of Monotis Creek, and part B is opposite part A on the east side (pl. 6*A*). Fifty-five beds of section 3 were sampled. The upper 19 feet of the section averages 19 percent P_2O_5, including one 27-inch sequence containing 27 percent P_2O_5, 16 feet below the top.

Section 4 shown on plate 4 is on the south flank of the Monotis Creek anticline on the Kiruktagiak River. Twenty-two beds were sampled. The upper 37 inches of the sampled beds averages 25 percent P_2O_5, and the top 13 feet averages 17 percent P_2O_5.

Correlations between sections 3 and 4 are indicated on plate 4. However, the two sections cannot be correlated bed-for-bed in spite of the fact that they are only 2,000 feet apart. As in the Tiglukpuk Creek area, this may be due in part to the lenticular nature of the strata. It may also be due in part to discrepancies in measurement resulting from small faults and folds. Evidence of crumpling and bedding plane movement was found in bed 26 in section 3 and in bed 95 in section 4.

Most beds in sections 3 and 4 were tested in the field for calcium carbonate with dilute HCl. Section 3 on the whole seemed to have a substantially lower calcium carbonate content than section 4. This may be the result of leaching. The rocks in section 3 appear to be slightly weathered. At section 4, however, they are being actively eroded by the river and are fresh.

OTHER AREAS IN BROOKS RANGE-ARCTIC FOOTHILLS BELT

During the petroleum investigations of the Arctic Slope between 1944 and 1953 all the stratigraphic units shown in the correlation chart were examined critically. Hundreds of rock specimens were collected from all parts of the stratigraphic succession across almost the entire length of the Brooks Range-Arctic foothills belt. Thirty-eight of these were selected for chemical and radiometric analyses for phosphate and equivalent uranium. Only 11 proved to be phosphate rock; however, all 38 are described on the following pages and are located on plate 1.

These data, although largely negative, outline in a general way the extent of the phosphate deposits of the Lisburne group. The data also indicate the possibility that significant phosphate deposits occur in the Shublik formation in the eastern Brooks Range.

Eighteen of the samples are from the Lisburne group, 15 are from the Shublik formation, and 1 is from the Kingak shale. The stratigraphic position of 4 samples is uncertain. The samples, together with the field notes of the collectors, are listed on pages 12–14. Six of the samples have been examined in thin section under the petrographic microscope.

ANALYSES OF SAMPLES

The results of the phosphate and radiometric analyses of the 38 selected samples are given in the table below.

Analyses of samples

Sample No.	Rock	Percent			
		P_2O_5 [1 2 3]	V_2O_5 [6 7]	Equivalent U [4]	U [5]
Lisburne group					
45AGr21	Phosphate rock	[2] 25.6	[6] 0.02	0.009	
48ASa35	Limestone	[1] <5		<.001	
48ASa48	Shale	[1] <5		.002	
49ALa8	Limestone and mudstone	[1] <5		<.001	
49ADt134	Phosphatic limestone	[2] 4		.004	
50ATr61	Phosphate rock	[2] 24.8	[7] .17	.008	
50ATr99	Limestone	[1] <5		.001	
50ATr160	Phosphatic mudstone	[3] 13.7			0.004
50AKt89	Shale	[1] <5		<.001	
50ACh53	Limestone	[1] <5		.001	
50ACh55	Siltstone	[2] 1.4		.005	
50AKe279	Phosphate rock	[2] 27.9		.020	
50APa258	Limestone	[1] <5		.008	
50ABo76	Phosphate rock	[1] 15±		.009	
50ABo78	do	[2] 21.4		.014	
51ARr111	Siltsone	[1] <5		<.001	
51ARr126	Shale	[1] <5		.002	
51ARr134	do	[1] <5		<.001	

See footnotes at end of table.

Analyses of samples—Continued

Sample No.	Rock	Percent			
		P_2O_5 [1 2 3]	V_2O_5 [6 7]	Equivalent U [4]	U [5]
Shublik formation					
48ASa98	Limestone	[1] <5		<0.001	
48ASa110	Siltstone	[1] <5		.003	
48ASa222	Phosphate rock	[1] 20±		.004	
48ASa223	Limestone	[1] <5		.002	
48ASa225	do	[1] <5		.002	
48AWh86	Phosphatic siltstone	[1] 10±		.003	
48AWh87	Shale	[1] <5		.001	
48AWh89	Phosphate rock	[1] 15±		.003	
48AWh123	do	[2] 18.4		.003	
48AWh137	Phosphatic limestone	[1] 5±		.002	
50AGr38	Phosphate rock	[3] 14.7			0.001
50AGr44	Limestone	[3] 1.55			.001
50APa245	do	[1] <5		<.001	
51AGr11	Phosphate rock	[3] 35.8			.008
51AKe11	Siltstone	[1] 5±		.001	
Kingak shale					
48ASa217	Sandstone	[1] <5		0.002	
Stratigraphic position uncertain					
48ASa22	Phosphate rock	[2] 22.0		0.007	
49ADt41	Mudstone	[1] 5±		.004	
50ALa257	Siltstone	[1] <5		<.001	
51ASa36	do	[2] 2		.002	

[1] J. J. Matzko, analyst; P_2O_5 determined by rapid field test, U. S. Geological Survey, College, Alaska.
[2] Audrey Smith, analyst; P_2O_5 determined by laboratory analysis, U. S. Geological Survey, Washington, D. C.
[3] J. W. Budinsky, analyst; P_2O_5 determined by laboratory analysis, U. S. Geological Survey, Washington, D. C.
[4] J. J. Matzko, analyst.
[5] J. W. Budinsky, analyst.
[6] Robert Meyrowitz, analyst.
[7] F. S. Grimaldi and J. J. Warr, analysts.

DESCRIPTION OF SAMPLES

LISBURNE GROUP

45AGr21 (*George Gryc, collector*).—Black medium to coarsely oolitic phosphate rock. Float and beds in place(?) on top of flat-topped mountain just east of northernmost lake in the Chandler Lake chain. Stratigraphic position unknown, probably near top of Alapah limestone.

In thin section the phosphatic pellets appear elliptical and show alternating light and dark bands of carbonaceous matter with minor replacement by calcite. The pellets range in diameter from 0.05 mm to 1.4 mm. The matrix consists of large grains of clear strongly twinned calcite. Carbonaceous matter appears along boundaries between adjoining calcite grains. Purple fluorite is found in and around the edges of the phosphatic pellets and in veinlets in the calcite.

48ASa35 (*E. G. Sable, collector*).—Dark-gray fine-grained limestone. Cutbank on west side of Hulahula River. Stratigraphic position probably upper part of Lisburne group.

48ASa48 (*E. G. Sable, collector*).—Black shale. Hill on east side and near headwaters of small tributary west of Hulahula River. Near contact of intrusive rocks and Lisburne group. Stratigraphic position uncertain but thought to be from Lisburne group.

49ALa8 (*A. H. Lachenbruch, collector*).—Fractured dark-gray fine-grained limestone, calcareous silty shale, and black sooty siliceous siltstone. Probably upper shale unit of Alapah limestone. From bluff about 250 yards long on north bank of Fay Creek, 3 miles above junction with Etivluk River.

49ADt134 (*R. L. Detterman, collector*).—Black phosphatic limestone. From a chert, shale, and limestone sequence, probably the black chert and shale member of the Alapah limestone. On north side at base of the northernmost Lisburne group ridge. West side of Killik River.

50ATr61 (*I. L. Tailleur, collector*).—Phosphate rock. From 8-foot zone of rubble of black chert; black paper shale; black shaly dolomite; and oolitic phosphate rock. This zone underlies an outcrop and float of interbedded black chert and dark-gray dolomite. Probably two horizons of phosphate rock, each about 6 inches thick. Between Etivluk and Ipnavik Rivers on westernmost segment of high ridge of Lisburne group.

Thin-section examinations shows large dolomite rhombs replacing the phosphatic pellets. The presence of dolomite was also confirmed by X-ray examination. Many of the dolomite rhombs have ragged edges due to solution. Fine-grained quartz is present. The average diameter of the pellets is 1.5 mm, the dolomite rhombs 1.0 mm, and the quartz grains 0.2 mm.

50ATr99 (*I. L. Tailleur, collector*).—Black limestone. From rubble traces of black shaly limestone that weathers medium gray and black and from cindery limestone that appears to be brecciated and cemented with bitumen and weathers medium gray. Probably near top of Lisburne group. Between Etivluk and Ipnavik Rivers on headwaters of Hard Way Creek.

50ATr160 (*I. L. Tailleur, collector*).—Phosphatic calcareous mudstone. Badly slumped cutbank exposure of black very bituminous shale, sooty chert, and fine-grained dark limestone with a strong fetid odor. Sequence underlies Siksikpuk formation. Probably equivalent to the Alapah limestone formation. On north limb of overturned anticline that forms Mount Bupto.

50AKt89 (*B. H. Kent, collector*).—Shale. Fifty feet of black cherty shale with 18-inch flatiron concretions with pyritized cephalopods. Bands of chert. Probably from approximately same horizon as 50ATr99. Craggy ridge at west end of southern ridge of Lisburne group. Between Etivluk and Ipnavik Rivers.

50ACh53 (*R. M. Chapman, collector*).—Dark-gray to black limestone. About 10 feet of limestone, dark gray to black with strong petroliferous odor, highly fractured, irregularly bedded in beds ½ to 10 inches thick, tan to

white weathered. Limestone locally weathers bluish white. Lisburne group. Near head of Oolamnagavik River.

50ACh55 (R. M. Chapman, collector).—Black siltstone. About 30 feet of interbedded grayish-black petroliferous limestone and black shaly siltstone. Some 1- to 3-foot oval concretions of limy siltstone.

Thin-section examination indicates that the black siltstone contains subangular quartz grains cemented by abundant carbonaceous matter and only a few phosphatic nodules. Also shows one large rounded grain of chert with a clear center and edges stained by carbonaceous material.

50AKe279 (A. S. Keller, collector).—Phosphate rock. Sequence of black chert, lenticular dark siltstone, dark brittle shale, and oolitic phosphate rock. Probably black chert and shale member of the Alapah limestone. On thrust plate overlying Siksikpuk formation shale and chert. Between Tiglukpuk Creek and Anaktuvuk River, 3 miles south of Natvakruak Lake.

50APa258 (W. W. Patton, Jr., collector).—Black shaly limestone. From base of 100-foot sequence of dark calcareous shale at the top of the Alapah limestone. At mountain front three-fourths mile east of Tiglukpuk Creek.

50AB076 (A. L. Bowsher, collector).—Phosphate rock. From same stratigraphic level of black chert and shale member of the Alapah limestone as 50ABo78. From weathered dip slope. West side of Anaktuvuk valley opposite locality of sample 50ABo78.

50ABo78 (A. L. Bowsher, collector).—Phosphate rock. From thin stringers of phosphatic limestone which occur in calcareous shale along with chert and limestone nodules, 45 feet above base of the black chert and shale member of the Alapah limestone. Base of the black chert and shale member is about 2,630 feet above base of the Lisburne group. From measured section of the Alapah limestone formation on east side of Anaktuvuk valley near mountain front.

Thin-section examination of 50ABo76 and 50ABo78 shows phosphatic pellets in a calcite matrix. The pellets have concentric growth rings and show a lack of orientation that is thought to be caused primarily by minor cataclastic deformation. The calcite is mostly fine grained and exhibits minor twinning. Quartz is abundant and occurs mainly in the phosphatic pellets. The fluorite is purple and commonly has centers of carbonaceous matter.

51ARr111 (H. N. Reiser, collector).—Black to gray siltstone. From 3-foot bed of black to gray siltstone at top of 96-foot section of platy black shale. Lisburne group. Precise stratigraphic position unknown.

51ARr126 (H. N. Reiser, collector).—Shale. From cutbank exposure of faulted section of black shale at least 27 feet thick. Occurrence of *Pericyclus* suggests that the beds are equivalent to the lower part of the Wachsmuth limestone. However, rubble of Siksikpuk formation above the cutbank suggests that the beds may be equivalent to the Alapah limestone. Headwaters of Kiligwa River.

51ARr134 (H. N. Reiser, collector).—Shale. Same locality as 50ARr126.

SHUBLIK FORMATION

48ASa98 (E. G. Sable, collector).—Dark-gray to black limestone. Shale and limestone sequence of Shublik formation. Precise stratigraphic position unknown. Tributary east of Sadlerochit River.

48ASa110 (E. G. Sable, collector).—Dark-gray to black siltstone. Sample probably from within 50 feet of the base of the Shublik formation. Bedding traces on hillside east of Sadlerochit River.

48ASa222 (E. G. Sable, collector).—Phosphate rock. From 10-foot bed within 25 feet of base of Shublik formation. Large eastward-facing cliff on west side of Sadlerochit River.

48ASa223 (E. G. Sable, collector).—Black, very fine grained limestone. From 90 to 108 feet above base of Shublik formation. Same locality as 48ASa222.

48ASa225 (E. G. Sable, collector).—Dark-gray to black sandy limestone. From 140 to 165 feet above base of Shublik formation. Same locality as 48ASa222.

48AWh86, 87, and 89 (C. L. Whittington, collector).

Exposed section.

	Feet
Shublik formation:	
Black fossilferous limestone containing numerous phosphatic nodules. 48AWh89	20
Covered interval	180
Dark-gray to black siltstone with about 10 percent interbedded black earthy shale. Upper half black weathering, lower half dull-brown weathering. Phosphatic nodules throughout siltstone, from very sparse to a 1-foot bed composed almost entirely of nodules. Nodular phosphatic siltstone 48AWh86. Earthy shale 48AWh87	120
Sadlerochit formation:	
Dark-gray siltstone similar to above but lacks nodules. Brown weathering	30
Covered interval, below which are several exposures of Sadlerochit formation	500

East bank Hulahula River at north edge of mountains. Steeply northward-dipping rocks forming north flank of an anticline.

48AWh123 (C. L. Whittington, collector).—Black siltstone, weathers black and contains black phosphatic nodules. From the basal few feet of Shubik formation. The underlying siltstone of the Sadlerochit formation differs in weathering brown and in having no nodules. West bank of Sadlerochit River. North edge of the southern of two belts of Shublik formation in the Ikiakpauruk synclinorium.

48AWh137 (C. L. Whittington, collector).

Exposed section.

Shublik formation:

	Feet
Black fossiliferous limestone containing black phosphatic nodules. 48AWh137	50
Black earthy calcareous shale with some layers of phosphatic nodules	20
Covered interval	20
Black thin-bedded fine-grained sandstone with only scattered layers of sparse nodules	6
Dark-gray siltstone with many layers of phosphatic nodules	35
Covered interval below. Contact with Sadlerochit formation probably within a few feet of base of siltstone.	

West bank of Sadlerochit River. Northward-dipping beds on south flank of Ignek Valley synclinorium.

50AGr38 (George Gryc, collector).—Phosphate rock. From about 165 feet above base of well-exposed 265-foot section of Shublik formation. Bluish-black shale and bluish-black limestone, believed to be phosphatic, are common throughout section. Upper and lower contacts of Shublik formation are not exposed. Exposure at base of conspicuous isolated low peak just in front of ridge which extends west from Mount Weller in the Shublik Mountains.

50AGr44 (George Gryc, collector).—Black limestone. From a 20-foot black limestone that contains abundant brachiopod shells and "nodules" which appear to be shell fillings. Limestone, fossils, and "nodules" commonly have pronounced bluish cast suggestive of the presence of phosphate. The limestone is overlain by 1,000 feet of predominantly shale with lenses and nodules of black limestone. Shublik formation at type locality, Shublik Island, Canning River.

50APa245 (W. W. Patton, Jr., collector).—Dark limestone. From thin-bedded fossiliferous dark limestone 73 to 100 feet below top of Shublik formation. Uppermost 214 feet of Shublik formation is exposed in a cutbank on east side of a small tributary near the head of Kanayut River.

51AGr11 (George Gryc, collector).—Phosphate rock. From basal 20 feet of 100-foot sequence of black oolitic limestone. Bluish bloom, indicative of phosphate, noted in at least the basal 20 feet. Base of sequence within 20 feet of contact with Sadlerochit formation. Total thickness of Shublik formation at this locality is about 475 feet. South side of Sadlerochit Mountains; between the two major forks of the Katakturuk River which join at south edge of mountains.

Petrographic examination indicates a fine-grained phosphate rock containing equigranular phosphatic pellets; only a very few show concentric structure. The pellets are closely packed and distorted, are stained a light brown, and are generally isotropic. The average size of the pellets is 0.2 mm along the long axis and 0.1 mm along the short axis.

Quartz grains make up 3 percent of the constituents and are generally angular. The quartz is chiefly interstitial but also occurs in the pellets; a few grains exhibit strain figures. The average size of the quartz is 0.03 mm.

Only trace amounts of carbonate, sericite, and hematite are found. The carbonate (calcite?) generally consists of anhedral grains in phosphatic pellets; the grains average about 0.004 mm in size. The sericite and hematite occur very sparsely and are interstitial between the quartz and phosphate.

51AKe11 (A. S. Keller, collector).—Dark-gray siltstone. Sample is associated with fossils *Germanonautilus brooksi* Smith and *Monotis* sp. and probably is from uppermost beds of Shublik formation. East side of tributary of Shaviovik River, on rubble trace one-fourth mile east of river channel. In this general area between the Ivishak and Canning Rivers, phosphatic beds have been noted at several localities in the uppermost beds of the Shublik formation and also near the base.

KINGAK SHALE

48ASa217 (E. G. Sable, collector).—Dark-gray to black sandstone. Fossils indicate an Early Jurassic age. Isolated cutbank exposure on east side of Sadlerochit River.

STRATIGRAPHIC POSITION UNCERTAIN

48ASa22 (E. G. Sable, collector).—Phosphate rock. Stratigraphic position unknown. Appears to be associated with black shale and Sadlerochit formation quartzites. Possibly from Shublik formation. High ridge west of Okpilak River.

49ADt41 (R. L. Detterman, collector).—Calcareous mudstone. From bluff about one-fourth mile long, exposing red and green shale at north end, chert of the Siksikpuk formation in middle, and igneous and associated contact rock at south end. Sample from contact rock between igneous rock and chert in the Siksikpuk, about 300 feet above red and green shale. First bluff on east side of Nigu River, 5 miles upstream from junction with Etivluk River.

50ALa257 (A. H. Lachenbruch, collector).—Black siltstone. From near contact of mafic igneous mass. Precise stratigraphic position unknown. Shublik formation(?).

51ASa36 (E. G. Sable, collector).—Black siltstone. Stratigraphic position unknown. May be Lisburne group, Shublik formation or Tiglukpuk formation.

SUMMARY

Phosphate rock samples 45AGr21, 50AKe279, 50ABo76, and 50ABo78 were collected from the black chert and shale members of the Alapah limestone. Their distribution indicates that phosphate deposits of the black chert and shale member of the Alapah limestone, which have been described on the upper Kiruktagiak River and on Tiglukpuk Creek, extend eastward at least to the Anaktuvuk River. At Shainin Lake, 10 miles east of the Anaktuvuk River, thin beds of "phosphorite(?)" are reported in the type section of the black chert and shale member (Bowsher and Dutro, 1957), but no samples are available. East of Shainin Lake the Lisburne group has been examined in detail at many localities, but no phosphate rock has been found (W. P. Brosgé, oral communication, 1953).

West of the Kiruktagiak River only two samples from the Lisburne group proved to be significantly phosphatic, 50ATr61 and 50ATr160. They were collected in the foothills between the Etivluk and Kuna Rivers, 100 miles west of the Kiruktagiak River. The stratigraphic position within the Lisburne group of 50ATr61 is uncertain. Sample 50ATr160 is from a sequence of dark shale and chert that underlies the Siksikpuk formation and overlies fossiliferous clastic limestone containing a crinoid-brachiopod fauna similar to that of the Alapah limestone. This suggests that the sample is probably from a stratigraphic level correlative with the black chert and shale member in the Tiglukpuk Creek and upper Kiruktagiak River areas.

No deposits of phosphate rock have been found in the Lisburne group along the Brooks Range-Arctic foothills belt between the Kiruktagiak River and the Etivluk River (R. M. Chapman, oral communication, 1952) or west of the Kuna River (I. L. Tailleur, E. G. Sable and J. T. Dutro, Jr., oral communications, 1952).

Five specimens from the Shublik formation proved to be phosphate rock: 48ASa222, 48AWh89, 48AWh123, 50AGr38, and 51AGr11. All five were collected along the north flank of the Brooks Range between the Canning and Okpilak Rivers. Three are from the basal 25 feet of the Shublik formation. Sample 48AWh89 occurs 300 feet above the base and 51AGr11 is 165+ feet above the base. Keller noted the occurrence of phosphatic rocks near the base and near the top of the Shublik formation in the area between the Canning and Ivishak Rivers. Unfortunately, none of the phosphate-bearing rocks in the Shublik have been systematically sampled; therefore nothing is known about their thickness and quality.

CONCLUSIONS

The phosphate deposits in the black chert and shale member of the Alapah limestone (Mississippian) have been measured and sampled at two localities in the central Brooks Range and Arctic foothills provinces. Nearly all the phosphate rock is low or medium grade. Furnace-grade phosphate rock (25 percent or more P_2O_5) was found in thicknesses of as much as 37 inches, but no thicknesses of acid-grade phosphate rock (31 percent or more P_2O_5) exceed 16 inches. A comparison of measured sections of the black chert and shale member in the upper Kiruktagiak River, Tiglukpuk Creek, and Shainin Lake areas indicates that there are marked lateral variations in lithologic character as well as phosphate content. Because of these facies changes and because of the complex structure of the rocks along the mountain front, further work will be necessary before the black chert and shale phosphate deposits can be fully evaluated.

Samples of phosphate rock containing as much as 35.8 percent P_2O_5 have been found in the Shublik formation (Triassic) in the eastern Brooks Range. Nothing is known about the thickness and extent of the deposits, but, because of the grade and widespread distribution of the samples, further investigation would seem warranted.

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