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Geological Investigations

Naval Petroleum Reserve No. 4

Alaska

Preliminary Report No. 31

PRELIMINARY REPORT ON SELECTED SECTIONS OF LISBURNE LIMESTONE, BROOKS RANGE, ALASKA

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By

William P. Brosgé and Hillard N. Reiser

November 1950

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PRELIMINARY REPORT ON SELECTED SECTIONS OF LISBURNE LIMESTONE, BROOKS RANGE, ALASKA

By

William P. Brosge, Hillard N. Reiser, Vincent E. Shainin,

Arthur L. Bowsher, Sr., and Claire J. Gudim

INTRODUCTION

Location: - This report describes sections of the Lisburne limestone studied in the foothills and northern mountains of the Brooks Range, Alaska. The area covered extends along the front of the range from Sagavanirktok Lake (68°28' N. - 149°25' W.) west to the head of the Kukpowruk River (68°25' N. - 162°40' W.). The southernmost point in the area is at the head of Alapah Creek (68°11' N. - 150°40' W.) and the northernmost point is on Lisburne Ridge just west of the Etivluk River (68°36' N. - 156°40' W.).

Field work was done by the authors at Sagavanirktok Lake, Kanayut Lake, Alapah Creek, the Anaktuvuk and Tiglukpuk Creek, and Chandler Lake. Brief visits were made to the Lisburne Ridge just north and west of the junction of the Nigu and Etivluk Rivers and to outcrops of Lisburne limestone along the Kiligwa River (68°30' N. - 158°35' W.). Data from other areas included in this report were collected by other field parties of the U. S. Geological Survey. A. L. Bowsher, Sr. and J. T. Dutro, Jr. studied the Lisburne limestone at Kanayut Lake, Nanushuk Lake, and Itkillik Lake in 1949 1/. W. W. Patton, Jr. and Irving L. Tailleur described the Lisburne limestone exposed in the northern Brooks Range along the Kiruktagiak River 2/ and the Okokmilaga River 3/ in 1949, and I. L. Tailleur and Bion H. Kent have supplied data on the Etivluk-Kiligwa Rivers area from their field work of 1950 4/. R. M. Chapman, G. D. Eberlein, and C. D. Reynolds measured sections of Lisburne limestone at Kurupa Lake and on the east fork of the Etivluk River in 1950 5/. E. G. Sable and

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1/ Bowsher, A. L., and Dutro, J. T., Preliminary report on the Mississippian rocks of the Kanayut, Namushuk and Itkillik Lake areas, Alaska,; U. S. Geological Survey, Navy Oil Unit Preliminary Report No. 24, 1949.

2/ Patton, W. W. and Tailleur, I. L., Stratigraphy and structure of the Okpikruak and Kiruktagiak Rivers area, Alaska; U. S. Geological Survey, Navy Oil Unit Report No. 34, 1950.

3/ Tailleur, I. L., personal communication.

4/ Tailleur, I. L. and Kent, B. H., Preliminary report on the stratigraphy and structure of the Upper Etivluk-Kuna Rivers area; U. S. Geological Survey, Navy Oil Unit Preliminary Report No. 34, 1950.

5/ Chapman, R. M., Eberlein, G. D., and Reynolds, C. D., Preliminary report on the stratigraphy and structure of the Upper Oolamnagavik, Kurupa, and Etivluk Rivers area; U. S. Geological Survey, Navy Oil Unit Preliminary Report No. 32, 1950.

M. D. Mangus measured the section on Iliglaruk Creek near the head of the Kokolik River in 1950 6/, and Chapman and Sable measured the section at the head of the Kukpowrok River in 1949 7/.

Purpose of the work.--Bowsher and Dutro in 1949 8/ divided the Lisburne limestone of the Kanayut Lake-Itkillik Lake area into two members and 14 lithologic zones. The rocks of two of these zones are dolomites that are porous enough to be reservoirs for accumulations of oil. The purpose of the 1950 work was to determine the lateral extent of the members and zones set up in 1949, and the lateral changes in lithologic facies within the members, with the hope of defining porous zones and their northward extent under Naval Petroleum Reserve No. 4.

Field Work.--U. S. G. S. Party No. 3 consisted of William P. Brosge, Chief; Vincent E. Shainin and Hillard N. Reiser, geologists; C. J. Gudim, Stephen E. Dwornik, and John H. Downs, field assistants; Bernard F. Armknst, camp hand; and William L. Nystrom, cook. A. L. Bowsher was with the party for the first month. It was planned that the party be based in field camps at five large lakes accessible to a DC-3 on skis and to a Norseman on floats. Travel to and from the field sites was to be by U. S. Navy helicopters based at the field camps. The Navy crew consisted of Lt. Richard Carleton, the officer in charge, Chief Aviation Pilots Jenks and Braunfield, and a five-man ground crew. Caches of food and aviation gasoline were set down at Kanayut Lake, Sagavanirktok Lake, Chandler Lake, and Nigu Lake; a gas cache at Sholton's Lake and a food cache at Xenoxpeduitl Lake.

On May 24 Dwornik and Brosge were landed on the Kanayut Lake ice by the Norseman. The rest of the party and equipment arrived by C-46 on skis on May 28. The next day the helicopters, UP-20 and UP-34, landed at the Kanayut camp.

The party was at Kanayut Lake until June 28. Under the guidance of Bowsher the men first familiarized themselves with the stratigraphy at Kanayut Lake. June 8 to 16 were spent in measuring the section on the west side of the Anaktuvuk River to which the helicopters carried the field men on daily flights. June 17 to 23 the field party stayed in a spike camp near the head of Alapah Creek and was supplied with food by helicopter. It was planned next, with W. W. Patton, to make a brief inspection of the Lisburne limestone on the Kiruktagiak River. On the morning of June 25 helicopter UP-20, Braunfield, pilot, took off to carry Patton to a rendezvous point on the Anaktuvuk River.

6/ Sable, E.G. and Mangus, M. D., Preliminary report on the stratigraphy and structure of the upper Utukok and Kokolik Rivers area; U. S. Geological Survey, Navy Oil Unit Preliminary Report No. 29, 1950.
7/ Chapman, R. M. and Sable, E. G., Stratigraphy and structure of the Kokolik and Kukpowruk Rivers area, Alaska; U. S. Geological Survey, Navy Oil Unit Report No. 33, 1950.
8/ Bowsher, A. L. and Dutro, J. T., op. cit.

Helicopter UP-34, piloted by Lt. Carleton, with Shainin and Downs as passengers, followed a few minutes later. After a normal take-off UP-34 lost power and settled onto the lake. The lake ice was on the verge of spring break-up, and was too weak and honeycombed to support the weight of a man or plane. The helicopter broke through the ice, but floated long enough for all three occupants to get out unhurt. Lt. Carleton, followed by Downs, managed to break a way through the ice to an open lead and both had swum to shallow water by the time help arrived on shore. Shainin did not follow Carleton and Downs but stayed in the pool of open water where the helicopter had broken through the ice. A boat had been brought from camp, and Braunfield, sensing trouble, had returned with the other helicopter, but Shainin drowned just before help got to him.

By mutual decision of the U. S. Geological Survey and the Navy, it was decided to stop helicopter operations, and the remaining helicopter returned to Umiat. Plans for field work were revised, limiting field work to areas accessible by foot from camps at the cache lakes. This eliminated any further work in areas of Lisburne limestone near the Brooks Range Divide. Plans for work from the Sholton Lake-Xenoxpeduitl Lake cache were abandoned because the camp site there was too far from outcrops of Lisburne limestone.

To rebalance the field party, C. J. Gudim was asked to assume the duties of a geologist in place of V. E. Shainin, and B. F. Armbrust was promoted from camp hand to field assistant to replace Gudim.

On June 28 the party began moving to Sagavanirktok Lake by Norseman on floats. Much of the extra equipment that had been needed to maintain the helicopter crews was returned to Umiat. The move was completed on July 1. The party mapped and measured sections within a radius of about 4 miles of the Sagavanirktok Lake camp.

On July 15 the Norseman carried the party and equipment to Little Chandler Lake. The party camped there until August 8, measured sections and mapped the Lisburne limestone belt from about 3 miles west of the lake to about 5 miles east of the lake. While the party was at Chandler Lake, H. N. Reiser and J. H. Downs spent July 26 to August 6 at the camp of Party 2 on Tigluk Creek and measured the two sections of Lisburne limestone there, one in the front of the Brooks Range and the other in the large anticline just north of the Range.

August 8 to 10 the party moved by Norseman to the cache on the Nigu Lake. A search over 60 square miles by foot and over a wider area by plane showed no outcrops of limestone within working distance of this camp, so plans were made to set up a spike camp for two men at each of several exposures of limestone to the west. Lack of plane support delayed these moves almost until the end of the season. On August 29 the Taylorcraft carried Reiser and Downs to a small lake in front of the Lisburne Ridge just west of the Etivluk River. The

same day Gudim and Brosge were flown to the camp of Party 6 on the Kiligwa River. August 30 and 31 the main camp and remainder of the party returned to Umiat, and September 1 Reiser and Downs were flown to Umiat from the Lisburne Ridge. Gudim and Brosge went with Party 6 on a four day spike trip by weasel to the head of the east fork of the Kiligwa River, and returned to Umiat on September 4.

STRATIGRAPHY

The oldest strata seen this year were about 1,300 feet of Devonian limestone that lies in a fault slice at the head of the East fork of the Kiligwa River. The exact stratigraphic relationship between this limestone and the rest of the Paleozoic rocks is not known. It may be equivalent to, or older than, the basal sandstones of the Noatak formation of the eastern part of the area. The Devonian limestone will not be discussed further in this report.

The Noatak formation is the oldest formation seen as part of a sequence continuous with the Lisburne limestone. It is present throughout the length of the Brooks Range covered in this report. In and east of the Kurupa Lake area the Noatak formation consists of a lower sandstone member about 4,000 feet thick and an upper shale member about 900 feet thick. The age of the basal sandstone of the lower member is probably Devonian; the shale member is Mississippian. The Lisburne limestone overlies the shale member of the Noatak formation. The limestone has been divided into three members: a lower member, the Wachsmuth, and two intertonguing upper members, the Alapah and Kiruktagiak. In the eastern third of the area the Lisburne limestone consists largely of cherty hydroclastic limestone and dolomite of the Wachsmuth and Alapah members. Some shale is interbedded in the lower part of the Wachsmuth member, and shale is present in thin tongues of the Kiruktagiak member near the top of the section. In the western part of the area the Kiruktagiak tongues are thicker. Shale beds and coarser detrital grains in the limestone range to the top of the Wachsmuth member in the central part of the area; in the far west this member consists mostly of silty and sandy limestone and some sandstone.

At Sagavanirktok Lake and in the Chandler Lake area rocks of the Siksikpuk group (new name) overlie the Lisburne limestone. The Siksikpuk group consists of shale, siltstone, silicified siltstone, and bedded chert; it is Pennsylvanian to Permian (?) in age. It is probably present above the Lisburne throughout the area but has not yet been differentiated from the Triassic Shublik formation in areas west of the Okpikruak River. The Shublik formatior is mostly shale. It overlies the Siksikpuk group wherever the latter has been mapped. West of the Okpikruak River present maps and sections show the Shublik formation directly above the Lisburne limestone.

At Sagavanirktok Lake the Shublik formation has been thrust upon Cretaceous sandstone and conglomerate that have been assigned to the Torok formation by E. H. Lathram 9/.

9/ Lathram, E. H., personal communication

These are the youngest rocks shown on the geologic map (Plate 1.).

NOATAK FORMATION

The name Noatak sandstone was first used in 1913 by P. S. Smith [10] for the rocks exposed along the Noatak River near the mouth of the Nimiuktuk. These rocks were assigned a Mississippian age on the basis of the Mississippian fauna found in shale near the top of the section. In 1930 Smith and Mertie [11] included in the Noatak sandstone the rocks along the Anaktuvuk River that had previously been called Stuver series by Schrader [12]. These rocks consist of several thousand feet of conglomerate, sandstone and shale overlain by about 900 feet of black shale, which is in turn overlain by the Lisburne limestone. They are part of a belt of rocks that can be traced to Kanayut Lake, where the same sequence has been mapped. In 1949 Bowsher and Dutro [13] divided this sequence at Kanayut Lake into two formations, restricting the name Noatak to the black shale unit and naming the underlying rocks Kanayut conglomerate. In 1950 Dutro and Lachenbruch and Lachenbruch [14] have found the probable equivalents of both these new formations in the type area of the Noatak sandstone. It is though best by Bowsher [15] and all others concerned to defer acceptance of the new names, Kanayut conglomerate and Noatak shale (restricted) as proposed in 1949, for the time being and to refer to the units as the shale member and the conglomerate member of the Noatak formation.

Conglomerate member.--The conglomerate member of the Noatak formation is everywhere present at the base of the section from Sagavanirktok Lake to Chandler Lake. Bowsher and Dutro have divided it into three parts; at the Kanayut Lake section the lower unit of brown-weathering sandstone and conglomerate is more than 1,600 feet thick; the middle unit of massive conglomerate is about 1,200 feet thick; and the upper unit that consists of about 30 percent conglomerate, 15 percent sandstone, and 55 percent silt and clay shale is about 1,030 feet thick. The pebbles and cobbles of the conglomerate, as well as the grains of the sandstone and of the conglomerate matrix are mostly gray to green chert and quartzite, with some vein quarts. Little mapping or stratigraphic work was done on these rocks in 1950. At Chandler Lake and Sagavanirktok Lake the lithologic sequence is like that at Kanayut Lake. Only plant fossils were found in the upper 1,000 feet of shale, but brachiopods, assigned a Devonian age by Bowsher, were collected by him in 1950 from the basal part of the conglomerate member east of Kanayut Lake.

10/ Smith, P. S., The Noatak-Kobuk Region, Alaska; U. S. Geological Survey Bull. 536, p. 71, 1913.
11/ Smith, P. S., and Mertie, J. B., Jr., Geology and mineral resources of Northwestern Alaska, U. S. Geological Survey Bull. 815, p. 155, 1930.
12/ Schrader, F. C., A reconnaissance in northern Alaska; U. S. Geological Survey Prof. Paper 20, 1904.
13/ Bowsher, A. L. and Dutro, J. T., op. cit.
14/ Dutro, J. T., Lachenbruch, M. C., and Lachenbruch, A. H., Preliminary report on the stratigraphy and structure of the Nimiuktuk, Kuguroruk, and part of the Noatak Rivers area; U. S. Geological Survey, Navy Oil Unit Preliminary Report No. 35, 1950.
15/ Bowsher, A. L., personal communication.

Sandstones probably equivalent to part of the conglomerate member underlie all of the area traversed around Nigu Lake. A section about 12,000 feet thick was roughly measured on the mountain 3 miles northwest of the lake. The lowest 4,300 feet consists of about 10 percent fine-grained massive sandstone, 50 percent thin-bedded, fine-grained ferruginous sandstone, and 40 percent red and black shale and phyllite. Above this is a unit 3,300 feet thick consisting of 40 percent massive sandstone, 40 percent thin-bedded sandstone, and only 20 percent shale. The top 4,400 feet of section is almost entirely massive sandstone, fine- to medium-grained, with 10 percent thin-bedded sandstone, and 10 percent shale. The sandstone of this section and of all the area traversed have about 90 percent white quartz grains. Clay galls and ironstone concretions are common in the sandstones, but the chert-pebble conglomerates typical of the member at Kanayut Lake are almost absent. Only one such bed, about 30 feet thick, was found in place, and a couple of boulders of chert-granule conglomerate were found in the bed of one mountain stream. No fossils except plants were found. The continuity of this 12,000-foot measured section is uncertain. No physical evidence of faulting was found there, but such evidence is lacking in many places to the east where imbricate bedding-plane thrusts were mapped in the Lisburne on the basis of duplication of section. Here, however, the gradational change in the percentages of shale and massive sandstone in the section make it appear to be continuous. The one cross-bedded sandstone found was right side up. If these rocks are equivalent to the conglomerate member of the Noatak formation mapped at Kanayut Lake, they represent a much finer-grained facies. The lower shaley zone at Nigu Lake may be a finer facies of the lower sandstone and conglomerate zone at Kanayut Lake, and the upper sandstone zone may be a finer facies of the middle conglomerate zone.

Shale member.---The shale member of the Noatak formation has been found just beneath the Lisburne limestone from Sagavanirktok Lake to the East Fork of the Etivluk River and probably continues west of there. It conformably (?) overlies the conglomerate member. At Kanayut Lake the basal part of the shale member is 159 feet of ferruginous sandstone. Above this is 622 feet of black shale, then a zone of 83 feet of limestone, 110 feet of black shale and an uppermost 17 feet of red-weathering limestone. This sequence of sandstone, shale, limestone and shale is typical of the shale member along the front of the Brooks Range. Thickness of the member at Kanayut Lake, Anaktuvuk River, and East Fork Etivluk River is 991 feet, 780+ feet and 840 feet respectively. In the southern belt of shale of the Noatak formation at the head of Alapah Creek, this sequence is only 453 feet thick. The basal sandstone maintains its thickness of about 150 feet, but the shales and limestones are much thinner than in the northern sections. Beneath the basal sandstone and above the top of the conglomerate member is a unit of shale and lenticular sandstone 1,500 to 2,000 feet thick, capped by 50 feet of massive sandstone. There are plant fossils and some bony coal in the upper part of this unit, but no fossils by which it may be correlated. The unit has not been found elsewhere in the area.

In the typical shale member of the area, Lower Mississippian (Kinderhookian) fossils were found in the upper limestones at Kanayut Lake 16/ in 1949, and at Anaktuvuk River and the head of Alapah Creek in 1950. None but plant fossils have been found in the lower part of the member, but it is all considered to be of Kinderhookian age.

LISBURNE LIMESTONE

In 1904 Schrader 17/ called the limestones on the Anaktuvuk River the Lisburne formation after limestones exposed at Cape Lisburne. In 1949 Bowsher and Dutro measured sections of Lisburne limestone at Kanayut Lake, Nanushuk Lake, and Itkillik Lake, and divided the formation into two members, the Wachsmuth and the Alapah, in ascending order. The type localities of these members are at Mt. Wachsmuth on the east side of Kanayut Lake. The division between members is based upon faunal as well as lithologic differences. The Wachsmuth fauna is Lower Mississippian; the Alapah fauna, Upper Mississippian. The Alapah member is characterized by lithostrotionoid corals, which, at Kanayut Lake, range from the base to near the top of the member, but do not occur in the Wachsmuth member. At Kanayut Lake the contact between members is a disconformity of low relief upon which fish teeth are concentrated.

Bowsher and Dutro subidivided each member into lithologic zones, most of which were traced east from the Kanayut section to the Nanushuk Lake and Itkillik Lake sections.

The lithologic zones of the Wachsmuth member at Kanayut Lake are:

Zone 4 - Mostly fine-grained limestone interbedded with nodular limestone and some coarse-grained limestone.

Zone 3 - Mostly fine to coarsely crystalline dolomite and some fine-grained limestone.

Zone 2 - Coarsely crystalline dolomite.

Zone 1 - Coarse-grained limestone, argillaceous and shaly limestone.

The lithologic zones of the Alapah member are:

Zone 9 - Fine-grained limestone containing large nodules of silicified limestone.

Zones 8, 7 and 6 - Mostly coarse-grained limestone. Zone 7 is characterized by unusually small lithostrotionoid corals.

16/ Bowsher, A. L. and Dutro, J. T., op. cit. p. 10.
17/ Schrader, F. C., A reconnaissance in northern Alaska; U. S. Geological Survey Prof. Paper 20, 1904.

Zone 5 - Shale, chert, and siliceous limestone.

Zone 4 - Interbedded coarse-grained and nodular fine-grained limestone.

Zone 3 - Coarse-grained limestone.

Zone 2 - Fine-grained limestone.

Zone 1 - Shaly limestone containing botryoidal chert nodules and abundant large black silicified gastropods.

Graphic sections of these zones are shown in plate 1 of this report. They are described here in different terms than those used by Bowsher and Dutro. According to Krynine 18/, almost all the Lisburne limestone is composed of clastic grains of organically-produced calcite. Therefore for this report the limestones have been described as fine-, medium-, or coarse-grained in terms of sand grain sizes. The 1949 notes and sections have been translated into these terms.

A third member, the Kiruktagiak, was described by W. W. Patton, Jr., from exposures on the Kiruktagiak River 19/. The member there consists of chert, shale, shaly limestone, and phosphatic limestone; it has an Upper Mississippian fauna. It is overlain by post-Lisburne rocks formerly called Triassic, and lies upon coarse-grained limestone of the Alapah member. It was therefore described as the uppermost member of the Lisburne limestone. The Kiruktagiak River section is also shown on plate 1.

Bowsher and Dutro and Miss Helen Duncan have compiled a handbook of fossils showing ranges in the sections studied in 1949 20/. Some fossils have been shown to be characteristic of certain zones in those sections. No time significance has been attributed to these fossils; the presence of some of them is certainly controlled by the lithologic facies.

One aim of the 1950 work was to trace the members and lithologic zones from the type locality to new sections of Lisburne limestone. Many of the zones have been traced by correlation of like sequences of lithology with those at the type locality. Some of the characteristic fossils have been found in these zones. In places the typical lithology of a zone is absent at the proper level of the zone in the sequence. In these places the lithologic zone, as defined, does not exist, but the zonal boundaries have been traced through on the basis of fossils.

18/ Krynine, P. D. and Folk, R. L., Petrology of the Lisburne Limestone; U. S. Geological Survey, Navy Oil Unit Special Report No. 22, 1950.
19/ Patton, W. W., Jr. and Tailleur, I. L., op. cit. p. 3.
20/ Bowsher, A. L. and Dutro, J. T., A handbook of some Mississippian fossils from the central part of the Brooks Range, and Duncan, H., A preliminary report on the Mississippian Corals and Bryozoans from the Brooks Range, Alaska, U. S. Geological Survey, Navy Oil Unit, (not for distribution) 1950.

Bowsher has examined some of these critical fossils collected in 1950 at the U. S. National Museum, but most of the rest of the paleontological work on which this preliminary report is necessarily based has been confined to field identification. It may be that laboratory study of all the fossil collections will show some conflicts between the faunal evidence and the lithologic correlations given in this report. No faunal lists have been prepared, but the fossils that are important zone markers will be mentioned in the description of the zones.

SUMMARY OF RESULTS OF FIELD WORK

This report not only deals with the results of field work by Party 3, but also attempts a correlation of almost all sections of Lisburne limestone measured north of the Brooks Range divide. The conclusions and most of the field data of the party's own work are on the geologic map (plate 1) and the fence diagram (plate 2).

The fence diagram shows all Lisburne limestone sections measured by Party 3, and also shows the sections of Bowsher and Patton at the type localities of the members. The detail of description and of division into lithologic units has been reduced by about one half from that of the field work. Boundaries of zones have been drawn by the methods just described. In order to make a continuous restored section between the correlated measured sections the boundaries of lithologic units smaller than zones have been extended from section to section. Although these correlations within the zones are true in general, they may be inaccurate in any detail.

The interpretations of data gathered from other field parties is shown on the restored sections (pl. 3). This work consisted largely in recasting all the lithologic descriptions into the stereotyped categories used in plate 2 and then making correlations based on lithology and faunal control. In many of the areas diagnostic fossils are rare. Sections are lacking to show details of the abrupt change east of Iligluruk Creek. Detailed descriptions of the individual sections are given in reports of the other U. S. Geological Survey field parties and will not be repeated. Unless specifically stated, the discussion of Lisburne limestone will deal only with the Sagavanirktok Lake to Chandler Lake area.

The season's field work by Party 3 showed that: (1) The Wachsmuth, Alapah and Kiruktagiak members are mappable lithologic units along the north front of the Brooks Range. Within the range, at the head of Alapah Creek, these members were distinguishable only with the aid of fossils, (2) The Kiruktagiak member in its type locality is equivalent to the fifth lithologic zone of the Alapah member at Kanayut Lake. It is one tongue of a shaly facies, of which another tongue lies above the ninth zone in some sections. Both tongues are here designated Kiruktagiak member, (3) Most, but not all, the lithologic zones

can be distinguished outside the type area. The following groups of zones are distinct, and in some places may be subdivided. In the Wachsmuth member: zones 1 and 2; and zones 3 and 4. In the Alapah member: zones 1 and 2; zones 3 and 4; zone 5, the lower tongue of the Kiruktagiak member; zones 6, 7 and 8; zone 9; the upper tongue of the Kiruktagiak member.

WACHSMUTH MEMBER

The Wachsmuth member everywhere lies upon the Noatak shale and beneath the Alapah member of the Lisburne limestone. Bowsher and Dutro [21] suggest that both contacts are at disconformities. The base of the member is drawn at the faunal break just above the red-weathering ferruginous limestone of the Noatak. Limestones at the base of the member are like the Noatak limestone in grain size. At Chandler Lake and at the head of Alapah Creek the lowest 50 feet of the Wachsmuth member is mostly shale, and in other sections this interval includes shaly limestone, suggesting that the environment of deposition of the lowest Wachsmuth was similar to that of the upper Noatak.

In the Kanayut Lake to Itkillik Lake area, the disconformity at the top of the Wachsmuth member is marked by local concentration of fish teeth, phosphatic concretions, and chert pebbles along a surface of low relief, as well as by a change from Lower to Upper Mississippian faunas. This disconformity was not found in the other areas. At the Anaktuvuk River fish teeth and fragments of lithostrotionoid corals were concentrated at the base of a bed of very coarse grained, irregularly bedded limestone. This was tentatively chosen as the disconformable contact, but abandoned in order to include in the Alapah member another zone lithostrotionoid corals found a short distance below.

The thickness of the Wachsmuth member is shown on the isopachous map (fig. 1). It decreases consistently to the north. Most of the decrease represents northward thinning in the third and fourth lithologic zones shown in figure 2. Zones 1 and 2 form a unit of fairly constant thickness. West of Chandler Lake the Wachsmuth member thickens from about 900 feet in the Chandler-Okokmilaga area to 1,340 feet at Kurupa Lake and to about 6,500 feet at Iligluruk Creek near the head of the Kokolik River (see pl. 3).

Lithologic zones 1 and 2.—These zones together form one of the most consistent lithologic units in the section, although they can be differentiated in most sections. Lithologic zone 2 is distinguished as a thin unit of coarse-grained limestone or dolomite from Sagavanirktok Lake to the Anaktuvuk River. Lithologic zone 1 is largely coarse-grained limestone with interbedded shaly and nodular limestone and some clay shale near the base. East of Kanayut Lake the zone thins, and the shale and shaly limestone thicken at the expense of the coarse-grained rocks.

21/ Bowsher, A. L. and Dutro, J. T., op. cit. p. 16.

At Chandler Lake zones 1 and 2 are indistinguishable. Both include abundant fine-grained nodular cherty limestone. At Kurupa Lake the coarse-grained limestones are interbedded with clay shale throughout. Here a new lithologic unit of fine-grained massive limestone appears above the rocks that can be correlated with zones 1 and 2 and below those that can be correlated with zones 3 and 4. This new unit may represent increase of thickness of zones 1 and 2 from an average of about 350 feet to 800 feet. In the next section to the west, at Iligluruk Creek, zone 1 is at least 5,000 feet thick. It consists mostly of limestone with quartz sand and silt. Near the base are interbedded quartzites. The silty limestones of the zone grade upward into about 600 feet of cherty limestone. This cherty limestone has a fauna like that of the first lithologic zone in the type section. The fauna of the silty limestones is not found in the type section but has been tentatively assigned a Lower Mississippian (Osagian) age like that of the type section, by Bowsher, who believes that the thick silty limestones are probably equivalent to the very lowest part of the first zone of the type section. In the restored section the silty rocks have been interpreted as part of a detrital facies that climbs upward and eastward with time and interfingers with the non-detrital section at Kurupa Lake.

Lithologic zones 3 and 4.--These zones consist mostly of fine-grained massive limestone, and fine-grained shaly and nodular limestone. Chert is common in the massive rocks and abundant in the thinner bedded rocks. In the type area zone 4 consists mostly of coarse-grained limestone, but this facies thins to the east, south, and west, and the zone cannot be distinguished from zone 3.

In the Kanayut Lake-Itkillik Lake area, much of zone 3 is coarsely crystalline dolomite. Similar dolomite is present only in the southern section on Tiglukpuk Creek and in the northern section at Chandler Lake.

In the southern section at Chandler Lake, and on the Okokmilaga River, the lower part of the two zones undifferentiated is mostly shaly limestone, and the uppwer part is fine-grained cherty limestone. At Kurupa Lake the lower part is true clay shale and coarse-grained limestone; the upper part is coarse-grained limestone interbedded with sandy limestones in which the sand grains are limestone detritus. The detrital clay and sand and the coarse-grained limestones are shown on plate 3 as part of a western detrital facies in the Wachsmuth member.

ALAPAH AND KIRUKTAGIAK MEMBERS

At the type locality at Kanayut Lake, the Alapah member lies disconformably (?) on the Wachsmuth member and includes the youngest beds of Lisburne limestone exposed. The rocks between the Triassic shale and the tenth lithologic zone of the Alapah member are covered. The Kiruktagiak member was supposed to be younger than the tenth lithologic zone of the Alapah member and probably to lie in the covered interval above the tenth zone at Kanayut Lake.

The Kiruktagiak member differs from the Alapah in lithology and in fauna. The rocks are black bedded chert, black fine-grained shaly limestone, black shale, and phosphatic limestone. Goniatitic cephalopods are common in the Kiruktagiak member, but are absent from the coral-brachiopod fauna of the Alapah member.

This season's work shows the type Kiruktagiak member to be equivalent to the fifth lithologic zone of the Alapah member, for in the Anaktuvuk River and southern Tiglukpuk Creek sections the younger zones of the Alapah have been identified above rocks typical of the Kiruktagiak member. Rocks similar to Kiruktagiak in lithology and fauna are also found at the top of these sections, above zone 9. To the west, the two zones of Kiruktagiak type rocks thicken. They probably merge as indicated on plate 3 and the chert and shale and goniatite facies of the Kiruktagiak may replace the hydroclastic shell facies of the Alapah. Although the two members are at least in part equivalent in time, they are distinct mappable units and the name member will be used for each.

Evidence for drawing the Alapah-Wachsmuth contact has been of three kinds: (1) Recognition of the general sequence of Alapah zones above those of the Wachsmuth member, (2) Restriction of the lithostrotioncid corals to the Alapah member, and (3) Recognition of lithologic zone 1 of the Alapah member, by the typical abundant chert nodules and chert replacements of bellerophontid gastropods.

Rocks immediately overlying the Lisburne limestone were seen only at three places. At each place these rocks were shales of the Siksikpuk group. At Sagavanirktok Lake the shales lie upon a zone of dense, dark, fine-grained limestone and siltstone that contains abundant nodules and disseminated grains of fresh pyrite. These rocks are of the ninth or a younger zone. There was no evidence for a break in sedimentation at the contact. At Tiglukpuk Creek the uppermost zone of Lisburne limestone is a tongue of the Kiruktagiak member younger than zone 9. The lower part of the tongue is shaly limestone; the upper part is black calcareous shale like that at the base of the Siksikpuk group. The contact is drawn in the shale at an oxidized zone that separates rocks bearing Mississippian fossils from those bearing Pennsylvanian fossils.

At Chandler Lake red and green shale of the Siksikpuk group lie without apparent disconformity upon shaly limestone of the zone 5 tongue of the Kiruktagiak member. This tongue also underlies the Siksikpuk group at the Kiruktagiak River and at the Lisburne Ridge west of the Etivluk River. Just south of the ridge, and at Mt. Bupto farther southwest, the upper tongue of the Kiruktagiak is again present at the top of the Lisburne.

Thickness of the Alapah member and of some of the zones is shown on isopachous maps. Figure 3 shows the total thickness to the base of lithologic zone 9, the highest zone that could be traced across the

area. Zones younger than zone 5 are absent at Chandler Lake. Figure 4 shows the total thickness of zones 1 and 2, and figure 5, the total thickness of zones 1 through 4. The thickness of the zone 5 tongue of the Kiruktagiak member is shown by isopachous lines on the map of plate 3. The thickness of the whole member below zone 9 decreases very rapidly northward in the Sagavanirktok Lake to Chandler Lake area from 2,490 feet at the head of Alapah Creek to 540 feet at Sagavanirktok Lake. No complete sections of the Alapah member have been measured west of Chandler Lake, but the positions of the top of the almost complete sections at the Okokmilaga River and Kurupa Lake can be estimated.

On the restored section the Alapah-Wachsmuth contact has been arbitrarily drawn as a horizontal line west of Kurupa Lake, but should slope down to the west to show an increase in thickness of the member from about 1,500 feet at Kurupa Lake to more than 2,600 feet at Mt. Bupto.

Lithologic zones 1 and 2.--The lowest zone, where distinguished, is less than 100 feet thick and consists of cherty shaly limestone. Zone 2 is an almost equal thickness of shaly limestone east of Kanayut Lake. At Kanayut Lake zone 2 is about 200 feet thick and consists largely of fine-grained limestone. Rocks at the same horizon at Alapah Creek are fine-grained dolomites. The two zones are not differentiated westoof Kanayut Lake, but the lower parts contain abundant chert in all sections. Figure 4 shows an abrupt thickening of the zones at the southern Tiglukpuk Creek section where they consist of shaly limestone with very cherty limestone interbedded at the base. The shaly limestone gives way to fine-grained massive limestone, which persists from Chandler to Kurupa Lake.

Lithologic zones 3 and 4.--These zones have been differentiated only in the Kanayut Lake-Itkillik Lake area, where zone 3 is mostly coarse-grained limestone and zone 4 is fine-grained limestone interbedded with coarse-grained limestone at Itkillik Lake and with fine-grained nodular limestone at Kanayut Lake. East of Itkillik Lake the coarse-grained limestones make up most of both zones. West of Kanayut Lake the coarse-grained rocks in the lower parts of the zones are thin, but a tongue of coarse grained limestone appears in the upper part of the zones at Anaktuvuk River and thickens westward. Both zones are mostly coarse-grained at Chandler Lake. Southward from Kanayut Lake the total thickness of both zones increases from 410 feet at Kanayut Lake to 1,910 feet at the head of Alapah Creek. The thickness of the coarse-grained rocks in the lower part increases correspondingly, but both the fine- and coarse-grained rocks of the lower part are dolomite in the south. In the southern section the massive fine-grained rocks of the upper part are interbedded with nodular chert rather than with nodular limestones as at Kanayut Lake.

Lithologic zone 5, Kiruktagiak member.--This zone was not found east of Kanayut Lake, and is very thin (25 to 30 feet) at Kanayut Lake and at the northern Tiglukpuk Creek section. Isopachs on the map (plate 3) show the thickness of the zone.

At the type locality the Kiruktagiak member consists in ascending order of 40 feet of black phosphatic and shaly limestone; 175 feet of dark cherty limestone, shaly limestone, and shale; and 5 to 6 feet of black pyritic shale. An 8-foot bed of black chert just below this sequence has been assigned to the Alapah member by Patton 22/. It is here included in the Kiruktagiak member because bedded chert is rare in the Alapah member but common throughout the Kiruktagiak member to the west.

The phosphatic limestone and also shaly limestone are present in the zone 5 at Chandler Lake, both Tiglukpuk Creek sections, and at the Anaktuvuk River. The basal black chert bed is 30 feet thick at Chandler Lake, but absent in the other sections. A zone of finely laminated limestone containing abundant large nodules of botryoidal chert is at the top of the Anaktuvuk section. Goniatites were found at the Kiruktagiak River, at the Anaktuvuk River and in the thick section on southern Tiglukpuk Creek. Brachiopods like those of zone 5 at Kanayut were found in the northern Tiglukpuk Creek section in the 25 feet of shaly limestone that has been correlated with the Kiruktagiak. In the Alapah Creek section 190 feet of dark fine-grained limestone and black banded chert has been shown as zone 5 because of the abundance of bedded chert and because corals typical of the zone 7 at Kanayut Lake occur just above it and brachiopods indicative of zones 3 or 4 occur 250 feet below it.

Upper lithologic zones of the Alapah member.--Zones in this group are not easily distinguished. Zone 6 has never been found outside the type section. Zone 7 was distinguished in the type section by the presence of very small lithostrotionoid corals. Small corals have been used as guides to zone 7 in the Sagavanirktok Lake, Alapah Creek, and Anaktuvuk River sections where their position in the sequence is proper for that of zone 7. However, in the Chandler Lake and northern Tiglukpuk Creek sections small lithostrotionoid corals range to 475 feet and 850 feet below zone 5. No laboratory work has been done on these corals from the lower zones to help explain their long range in these sections. Their presence does not seem to be controlled by any particular lithology.

The boundaries of zone 9 have been drawn to include the very light colored, very fine grained massive limestones (calcilutites) near the top of the Sagavanirktok, Alapah Creek and Anaktuvuk sections, and the limestones containing abundant large silicified and unsilicified nodules of light, fine-grained limestones in the Sagavanirktok section, northern Tiglukpuk Creek section, and in the type section. Brachiopods of the genus Gigantella are common in these rocks, so the boundaries

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22/ Patton, W. W. and Tailleur, I. L., op. cit. p. 3.

have also been drawn to include the range of Gigantella where other control is lacking. However, the destinations between the typical faunas of zone 8 and zone 9 are not sharp enough for definition of a boundary between them. Probably part of zone 8 has been included with zone 9 and part with zone 7.

At Alapah Creek, and in the northern section at Sagavanirktok a zone of crinoid conglomerate lies above zone 9 calcilutites. This conglomerate is composed of granule- and pebble-size fragments of crinoid stems as much as 2 inches long and 1 inch in diameter in a matrix of finer broken shell material. At Alapah Creek this conglomerate is unstratified. At Sagavanirktok Lake it is massively bedded.

In the foothills of the Brooks Range from Castle Mountain to the Kiligwa River are isolated outcrops of quartz sandstone and granule and pebble conglomerate associated with Lisburne limestone. Not all are fossiliferous, but all the fossils are those of zone 8 or 9, including Gigantella. Some of the conglomerates near the Kiligwa River contain abundant fragments of very large crinoid stems like those in the crinoid conglomerate at Alapah Creek. Detrital grains are absent in these zones in the Brooks Range, so a northerly source of the detritus is indicated.

The outcrops of these detrital rocks are marked on the map on plate 3. Close to the outcrops are areas in which zones younger than zone 5 are absent, (or probably absent) in the Lisburne limestone, either because of unconformity or nondeposition. Two restored sections (P-D-Q and R-S of plate 3) through the outcrops of sandstones and the areas of missing section show zone 5 and younger zones with the present top contact of the Lisburne limestone restored to the horizontal.

The local presence of detrital sand and pebbles in zones 8 or 9 seems to be related to the local hiatus of those zones nearby. The northerly source rock of the grains is unknown, but it could not have been older Lisburne rocks of the kinds seen so far. Except in the basal quartz sandstone in the shale member, chert is abundant in the Noatak formation nearby, but only a small percentage of the detrital grains in the Lisburne are chert. The quartz grains may have come from exposed basement rocks to the north.

SIKSIKPUK GROUP

The Siksikpuk group is named and the type section near the Siksikpuk River described by Patton and Keller 23/. At the type section the group consists of black, red, and green shale and siltstone, and bedded chert. The lower part has a Pennsylvanian macrofauna, the upper part a Pennsylvanian or Permian (?) microfauna. The group lies upon the Lisburne limestone and beneath Triassic shale.

23/ Patton, W. W. and Keller, A. S., Preliminary report on the stratigraphy and structure of the upper Nanushuk-Siksikpuk Rivers area; U. S. Geological Survey, Navy Oil Unit Preliminary Report No. 30, 1950.

Rocks of similar lithology and age overlie the Lisburne limestone at Sagavanirktok Lake. The contact of the Siksikpuk group with the Lisburne seems to be conformable. A large covered interval lies between the highest exposures of the Siksikpuk group and the lowest exposures of Triassic shale. The entire section of Lisburne, Siksikpuk and Triassic is upside down and has been thrust northward onto Cretaceous rocks. Many small folds and erratic dips were found in the Triassic shales, but the exposed shales of the Siksikpuk group seems to be in sequence. The measured section is given below:

50 feet	Triassic black paper shale. Abundant Monotis sp.
approx. 2,000 feet	covered
17 feet	Red shale.
0.8 feet	Calcareous siltstone. Spirifer sp. and Phricodothyris ? sp.
23 feet	Red shale.
1.2 feet	Shaly siltstone. Spirifer sp., "Spirifer" of Spiriferella texanus type, "Spirifer" of Neospirifer type. Chonetes sp., Phricodothyris ? sp. indet., Straparollus sp. indet.
192 feet	Red and black shale.
0.8 feet	Siltstone. "Spirifer" of the Neospirifer type, Phrycodothyris (?) sp. indet., Chonetes sp., productid (? young of Gigantella latissimus (Sowerby))
42 feet	Red and black shale.
1.0 feet	Lenticular red siltstone.
60 feet	Black shale
0.7 feet	Silt-ironstone.
186 feet	Black paper shale.
36 feet	Red paper shale.
15 feet	Covered interval.
21½ feet	Lisburne limestone, fine-grained, silicified, pyritic, nodular to shaly.

At Chandler Lake the zone 5 Kiruktagiak member is overlain by about 350 feet of red and black shales and partly silicified siltstone which is overlain by a fault slice of older Lisburne limestone. No fossils were found in the shale and siltstone, but because of its lithologic similarity to the Siksikpuk group in the nearby type section, this unit has been mapped as Siksikpuk group.

SUMMARY OF LISBURNE LIMESTONE TRENDS

In the eastern area, isopachous lines have a general east trend. All members thin to the north, the Wachsmuth at the rate of about 50 feet per mile, the Alapah at about 75 to 125 feet per mile. In the Wachsmuth member most of the change in thickness is in zones 3 and 4. In the Alapah member most of the change in thickness is in zones 3 and 4. The zone 5 Kiruktagiak member is a tongue that thins to extinction northward and eastward. Data on the upper tongue of the Kiruktagiak member are incomplete, but it is known to be absent by change of facies in the extreme east, and by unconformity or nondeposition around Chandler Lake. All zones above the fifth are locally absent along a line from Chandler Lake to the Lisburne Ridge on the Etivluk River.

In the western areas, information is based on sections along an east-west line. All members thicken westward from Chandler Lake, but the Wachsmuth thickens by 5,000 feet. In the west the Wachsmuth member includes a detrital facies that thins and contains finer-grained detrital material to the east. This facies is represented by 4,300 feet of sandy to silty limestone and sandstone at Iligluruk Creek and by clay shales and some sandy limestones at Kurupa Lake. The facies of the Kiruktagiak member may replace most of the Alapah facies in the west.

Dolomites in the east are restricted geographically rather than stratigraphically. They may be found in almost any zone, but are not laterally persistent in any zone. In general, the Wachsmuth member contains more dolomite in the northern sections, the Alapah member more dolomite in the southern sections. Coarse-grained carbonate rocks are most persistent in zones 1 and 2 of the Wachsmuth member and zones 3 and 4 of the Alapah member.

Quartz sandstones and conglomerates occur in zones 8 and 9 north of the Brooks Range but not in those zones within the Range. The quartz comes from an unknown northerly source.

SUMMARY OF POROSITY DATA

Results of Krynine's 24/ studies of the 1949 Lisburne samples were used by the field men in the 1950 season. Krynine speaks of a potentially adequate limestone reservoir as one having a minimum

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24/ Krynine, P. D. and Folk, R. L., Petrology of the Lisburne limestone; U. S. Geological Survey, Navy Oil Unit Special Report No. 22, 1950.

absolute porosity of 5 percent. Using this as a basis for judgment, the good porosity zones of the Lisburne limestone are restricted to the coarse-grained dolomites. These dolomites are a syngenetic replacement of the hydroclastic limestones. Krynine also believes that the more porous, coarser-grained dolomites are lighter-colored; that the coarser, lighter dolomites are a replacement of well-sorted limestones from which fine-grained impurities have been winnowed. Krynine pointed out then that a good criterion for a good porous zone in the field would be a light-colored dolomite.

The results of the field work of Party 3 are in accord with all Krynine's conclusions. Only one sample of limestone had a porosity that would put it in a "potential reservoir" class. In all places the light-colored dolomites were coarser-grained.

It was thought that the porous dolomites of zones 2 and 3 of the Wachsmuth member might persist laterally. Because of this, and to obtain good control, a more complete and objective sampling of these dolomitic zones was made at the Kanayut Lake. Samples were taken at 10-foot intervals, and where a higher porosity was indicated, at 5-foot intervals. Results of porosity determinations made in the Fairbanks laboratory have been plotted in graph form on plate 4. Approximately 50 percent of the samples from these zones fall into the "adequate" or "good reservoir" class. This is in agreement with the results obtained by the "representative" sampling of the same zones taken by Bowsher in 1949 and bears out the validity of his method of sampling the Lisburne limestone.

As the field work progressed it was found that the dolomites are not persistent. The dolomites are sporadic in the sections and amount to only 15 percent of the total Lisburne limestone measured by Parties 3 of 1949 and 1950. Dolomitization apparently was controlled more by local conditions than by any widespread or general environment. Some of the dolomite facies persist vertically through a change in grain size.

In the areas newly worked the 1950 Lisburne party took representative samples of the light-colored dolomites and the coarser-grained limestones (plate 4). Of the dolomite samples tested, approximately 20 percent had porosities equal to or higher than that of an adequate reservoir.