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GEOLOGICAL SURVEY
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PRELIMINARY REPORT ON THE GEOLOGY AND OIL POSSIBILITIES OF THE YAKATAGA DISTRICT, ALASKA

By

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Errata

(PRELIMINARY REPORT ON THE GEOLOGY AND OIL POSSIBILITIES OF THE YAKATAGA DISTRICT, ALASKA)

page 1, paragraph 1, line 11--for parrafin-base read paraffin-base

" 3, line 11--for Mount St.Elias (18,000 feet) read Mount St.Elias (18,008 feet)

page 10, paragraph 1, line 16--for in Middleton Island read on Middleton Islar

page 13, paragraph 3, line 6--for contains a high of dark read contains a high percentage of dark--

page 14, paragraph 5, lines 6-7--for is exposed in the area between read is exposed in the mountains east of Steller Glacier, and that it may be exposed in the area between--

page 15, paragraph 4, lines 9-10--for part of the Kushtaka formation. The presence of green sandstone read part of the Kushtaka formation. The presence of plant remains and of numerous coal beds in Unit B, and the apparent absence of marine fossils suggest deposition in a continental environment. The presence of green sandstone--

page 18, paragraph 2, line 5--for lowest occurences read lowest occurence

page 23, paragraph 1, line 17--for the tillte-like rock read the tillite-like rock--

page 28, paragraph 4, line 5--for yield furhter by read yield further by--

page 29, paragraph 4, line 10--for many of the faults read many of the folds--

page 33, paragraph 1, line 11--for Hazardous read hazardous

page 35, paragraph 1, line 12--for open out donward read open out downward--

page 39, paragraph 5, line 5--for Maspina Glacier read Malaspina Glacier

page 41, paragraph 1, line 6--for or shown on read or are shown on--

page 43, paragraph 1, lines 15-16--for to be pre-Poul in the Yakataga read to be pre-Poul Creek in the Yakataga.

page 45, footnote a/, line 1--for St. Yuster read S. T. Yuster

" " , line 3--for etrapolated read extrapolated

page 46, paragraph 1, line 2--for are not are not read are not--

" " 8 - higest → highest

end

Duplicating Section, Department of the Interior, Washington 25, D. C.

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Figure 1. Preliminary geologic map and structure sections of the Yakataga district, Alaska.

Figure 2. Correlated columnar sections of Tertiary rocks exposed in the Yakataga district, Alaska.

INTRODUCTION

The Yakataga district includes the central part of an arcuate lowland and front-range belt that extends about 300 miles along the south coast of Alaska, between the Chugach and St. Elias Mountains and the sea, and is underlain mainly by sedimentary rocks of Tertiary age (index map, fig. 1). Numerous seepages of oil and gas in the Tertiary rocks of the Yakataga district and of the Katalla district to the west were discovered shortly before 1900, immediately attracting attention to the possibilities for commercial production of oil. Exploration was concentrated mainly in the more accessible Katalla district, leading to the discovery in 1902 of the Katalla oil field. In the 32-year period from 1902 to 1933 this field produced about 154,000 barrels of high-gravity, parrafin-base oil from 18 shallow wells. Only one well has been drilled in the Yakataga district. This well, located near one of the largest oil seepages and drilled to a total depth of 2,005 feet, encountered indications of gas, but no oil was reported.

Geologic mapping was undertaken in the Yakataga district during the 1944 field season as part of the U. S. Geological Survey's program of War-Minerals investigations, in response to the then acute situation with regard to oil in the Pacific area. Geologic mapping of the district was resumed in 1946 and continued during the 1947 season and part of the 1948 season under the postwar program of investigation of the petroleum resources of southern Alaska. The purpose of this report is to present, in preliminary form, the principal results of the 1944-1948 investigations, with special emphasis on the geologic features that may aid in the search for accumulations of oil.

The Yakataga district, as defined in this report, includes an area of about 2,500 square miles. It extends about 100 miles along the north shore of the Gulf of Alaska, from Bering and Stellar Glaciers on the west to Malaspina Glacier on the east, and 25 to 35 miles inland to the southern front of the Chugach and St.Elias Mountains. The district is one of strongly contrasting topography, from a coastal plain of low relief to the rugged, youthful Robinson Mountains, which rise abruptly to a general altitude of 2,000 to 5,000 feet and a maximum altitude of 8,800 feet. The southernmost ranges of the Chugach and St. Elias Mountains, forming the northern boundary of the district, culminate in Mount Steller (10,000 feet), Mount Miller (11,000 feet), and Mount St.Elias (18,000 feet).

Although the climate along the coast at low altitude is temperate, more than half of the Yakataga district is covered by glaciers or by permanent snow fields. Malaspina Glacier and the piedmont bulb of Bering Glacier extend nearly to the sea, their margins at places being at an altitude of less than 200 feet, and Guyot Glacier discharges directly into an arm of the sea. A dense growth of vegetation covers most of the ice-free lowland and lower slopes up to an altitude ranging from 2,000 feet near the coast to 1,000 feet or less farther inland. The total precipitation is large, probably averaging 150 inches or more per year. All the larger streams and many of the smaller streams head in glaciers or permanent ice fields. In the summer, consequently, they are muddy and cold and are subject to considerable variation in volume of flow.

Although the Yakataga district borders the sea, it is among the less accessible areas in Alaska and airplanes provide the only scheduled means of transportation. Before the airplane came into general use the district was reached either by traveling along the beach on foot from Controller Bay (west of the Yakataga district), or by landing through the surf in a small boat. The beach route is impractical for transporting supplies in quantity or for moving heavy equipment, and either route of access involves considerable risk--by land the risk of crossing several large glacial streams, by sea the risk of landing through the surf. In 1942 the Civil Aeronautics Administration constructed a 5,000-foot gravel-surfaced landing field near the beach west of Cape Yakataga and in conjunction with the field has since maintained a radio communication and range station and weather observatory. Since 1948 weekly mail and passenger service has been provided to the field from Cordova.

Icy Bay affords the only sheltered anchorage for large boats. The ice front of Guyot Glacier has retreated steadily in recent years, thus increasing the area of the bay, but the glacier still discharges directly into the bay and at times nearly fills it with floating ice. The west shore of the outer part of the bay is somewhat exposed to the ocean surf and to southeast winds. The feasibility of developing a harbor in the bay under present conditions has not been tested, but it seems likely that at least temporary harbor and landing facilities could be maintained. A power barge of the type developed during World War II for beach assaults has been used to land fuel and heavy equipment through the surf near Yakataga Reef. In favorable weather supplies and heavy equipment could probably be landed almost anywhere along the beach by barge, but, because of the frequent storms, this method can not be relied upon for regular transportation.

There are neither roads nor trails within the Yakataga district, except in the immediate vicinity of the airfield and the settlement at Cape Yakataga. Foot travel is made difficult by numerous swift, cold glacial streams that must be crossed, by the dense growth of vegetation that covers much of the lowland and lower slopes, and by the rugged topography of the higher slopes and ridges. During the summer high-water stage the lower parts of the Kulthieth, Kaliakh, and Duktoth Rivers can be ascended with a small boat powered by an outboard motor. A small plane can land at a number of places along the beach, or, if equipped for water landing, on the estuaries at the mouths of some larger rivers, on Hanna Lake, on Icy Bay, and on the small lakes at the southern margin of the Chaix Hills. The natural obstacles to travel on the coastal plain, along the larger river valleys, and on the lower slopes, although serious in the present stage of development of the district, are not insurmountable to modern engineering methods if the resources of the district warrant the expense of building roads and moving heavy equipment inland. The more rugged and icebound parts of the district, however, probably will remain inaccessible to any means of travel except by foot or possibly by air.

The Yakataga district is uninhabited, except for the personnel stationed at the airfield and a few persons living at Cape Yakataga.

Additional information on the general geographic features and early exploration and development of the Yakataga district is given in reports by Russell, Maddren, and Taliaferro, listed in the section following.

PREVIOUS INVESTIGATIONS

Russell 1/ described some of the geologic features in the vicinity

1/ Russell, I. C., Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 24-32, 1893.

of the Chaix Hills in connection with an attempt to climb Mount St. Elias in 1891. The first systematic investigation of the geology of the Yakataga district was made in 1913 by Maddren 2/, who examined the coastal area from Cape Yakataga to Icy Bay in some detail, and made reconnaissance traverses

2/ Maddren, A. G., Mineral deposits of the Yakataga district, Alaska: U. S. Geol. Survey Bull. 592, pp. 119-153, 1914.

inland at several places for a distance of 5 to 25 miles. The part of Maddren's report bearing on the petroleum possibilities, and his previously unpublished topographic map of a part of the Yakataga district, were incorporated in a general report on petroleum in Alaska by Martin 3/. Taliaferro 4/ described some of the physiographic, stratigraphic, and

3/ Martin, G. C., Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, pp. 34-42, pl. 6, 1921.

4/ Taliaferro, N. L., Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., vol. 43, pp. 749-767, 1932.

structural features of the coastal area from Cape Yakataga to Icy Bay based on his examination of the district in 1920. The fossils collected by Taliaferro from the Tertiary rocks were described by Clark 5/.

5/ Clark, B. L., Fauna of the Poul and Yakataga formations (upper Oligocene) of southern Alaska: Geol. Soc. America Bull., vol. 43, pp. 797-846, 1932.

A number of investigations, the results of which were not published, have been made in behalf of companies or individuals interested in the oil possibilities of the Yakataga district. The most recent and probably the most comprehensive was the investigation supported jointly by three oil companies in 1938 6/. Geologists of this party examined the coastal area

6/ Geological party representing the Standard Oil Company of California, the Tide Water Associated Oil Company, and the Union Oil Company of California; G. D. Hanna in charge. Geology by C. E. Leach and J. C. Hazzard, paleontology by G. D. Hanna and L. G. Hertlein. Unpublished report made available to the Geological Survey for confidential review in 1946.

from Cape Yakataga to Icy Bay, part of the Yakataga River-Yakataga Glacier basin, and also traversed the Kaliakh and Kosakuts Rivers.

SCOPE AND METHODS OF RECENT INVESTIGATIONS

This report is based on field investigations made by the U. S. Geological Survey from June to September 1944, from June to September 1946, from June to October 1947, and during May and June 1948. The work was carried out from four main base camps--located at the airfield, on Hanna Lake, near the mouth of the Kaliakh River, and on Crater Lake, and from a large number of supplementary camps. Equipment and supplies were transported to the base camps by plane, and to the supplementary camps by plane, boat, sled, beach cart, or back-packing.

In 1944 E. M. Spieker, M. S. Walton, Jr., and C. E. Kirschner mapped an area of about 240 square miles, including the major part of the Yakataga River-Yakataga Glacier basin, and the coastal area from Cape Yakataga east to Johnston Creek. E. M. Spieker was in charge of the party, which also included Carrol Brower, cook, and Donald Nichols and Norman Handlin, camp assistants. The geologic mapping was carried out by combined use of plane-table traverses, pace traverses, and data derived from aerial photographs. Brief summaries 7/ of the results of this investigation have been published, and a preliminary draft of a more complete report 8/ is in the files of the U. S. Geological Survey.

7/ Spieker, E. M., Walton, M. S. Jr., and Kirschner, C. E., Stratigraphy and structure in the Yakataga area, Alaska (abstract): Geol. Soc. America Bull., vol. 56, p. 1198, 1945. Reed, J. C., Recent investigations by the Geological Survey of petroleum possibilities in Alaska: Am. Assoc. Petroleum Geologists Bull., vol. 30, pp. 1437-1438, 1946.

8/ Spieker, E. M. Walton, M. S., Jr., and Kirschner, C. E., Geology and petroleum possibilities of the Yakataga area, Alaska: Mss., 79 pp., 6 pls., 1 fig., 1947.

The geologic investigations during the field seasons of 1946-1948 were under the direction of the writer, assisted in 1946 by William Back, recorder, and Richard Swanson, cook; in 1947 by R. B. Johnson, geologist, and William Back, Donald Clark, and Richard Swanson, recorders; and in 1948 by J. K. Hartsock, geologist, and Robert Webb, cook. Reconnaissance traverses were made along Bering Glacier to the southern front of the Chugach Mountains, in the area between Bering Glacier and the Duktoth River, and in the vicinity of the Chaix Hills. More detailed mapping was done in the coastal area from Cape Yakataga to Icy Bay, and in the Cotton Creek-Boulder Creek area. Geologic features and field stations were plotted on aerial photographs in the field, and later transferred to sketch planimetric maps compiled from the photographs and other sources. In conjunction with the geologic work in 1946 and 1947, horizontal and vertical control covering approximately the western half of the Yakataga district was obtained by plane-table and theodolite triangulation. Horizontal and vertical control covering the coastal area between the Duktoth River and Icy Bay was obtained during the 1948 field season by a Geological Survey topographic party.

The geology of most of the Yakataga River-Yakataga Glacier basin, as discussed in this report and shown on the accompanying map and sections, is based on the manuscript report by Spieker, Walton and Kirschner 9/.

9/ Spieker, E. M., Walton, M. S., Jr., and Kirschner, C. E., op. cit. (Mss.).

In the main the geologic data shown on their map were transferred without change except for a reduction in the amount of detail as required by the smaller scale of the map accompanying this report. A few changes in the interpretation of the structure and stratigraphy of the Yakataga River-Yakataga Glacier basin have been made as a result of the 1947-1948 work in adjacent areas, and the study of aerial photographs not available in 1944. These changes are discussed in the text. In order to present an integrated discussion of the geology of the entire district it has been necessary to incorporate much material from the report by Spieker, Walton, and Kirschner without specific acknowledgment but they are acknowledged where longer sections of the report are abstracted or quoted directly.

The interpretation of the geology of the part of the Yakataga district not covered on the ground during the recent investigations is based on information obtained during several aerial reconnaissance flights over the district, on ground views from points of vantage, and on study of aerial and ground photographs.

Invertebrate megafossils collected during the 1944-1948 investigations of the Yakataga district were identified by H. E. Vokes of the U. S. Geological Survey and the Johns Hopkins University. The plant fossils were identified by R. W. Brown of the U. S. Geological Survey.

GEOLOGY

General features

The bedded rocks exposed in the Yakataga district and the adjacent part of the Chugach and St. Elias Mountains may be divided conveniently into three groups differing considerably in age, lithology, degree of deformation, and topographic expression. The oldest group is a thick sequence of complexly deformed, somewhat metamorphosed sedimentary and volcanic rocks of pre-Tertiary age, which are restricted in outcrop to the Chugach and St. Elias Mountains. The next younger group, exposed in the lower mountains and hills between the Chugach-St. Elias Mountain Front and the sea, includes an apparently conformable sequence of at least 25,000 feet of indurated marine and continental sediments ranging in age from Paleocene or Eocene to Miocene or Pliocene. This group of Tertiary rocks, in fault contact with the pre-Tertiary rocks along the Chugach-St.Elias Front, is folded and faulted, but is less intensely deformed and less altered than the pre-Tertiary group. The youngest group, consisting of essentially horizontal unconsolidated continental and marine sediments of Quaternary age, forms the lowlands of the coastal plain and the larger river valleys, and overlies the group of Tertiary strata with marked angular unconformity.

Intrusive igneous rocks cut the pre-Tertiary bedded rocks in the vicinity of Mount St. Elias and Mount Steller, but none have been observed to cut the bedded rocks of Tertiary or Quaternary age.

Inasmuch as the indications of oil in the Yakataga district appear to be associated with and restricted to rocks of Tertiary age, the pre-Tertiary and Quaternary groups were given less attention in the recent investigations and are described only briefly in this report.

Pre-Tertiary bedded rocks and associated intrusive rocks

During the 1944-1948 investigations of the Yakataga district, the rocks of the Chugach and St. Elias Mountains were examined in outcrop at only two localities--south of Mount Steller and southwest of Mount Miller. Additional information on the general character and structure of the rocks was gained by an aerial reconnaissance flight along the Chugach-St. Elias Mountain Front, by study of oblique aerial photographs, and by examination of the debris on the surface of Bering Glacier and Libbey Glacier. Some observations on the rocks were recorded by the early expeditions to Mount St. Elias.

The southernmost spurs and ridges of the Chugach Mountains near Mount Steller and Mount Miller are made up of a thick, well-stratified sequence of interbedded dark-gray argillite, slate, and graywacke 10/.

10/ The term argillite is used in this report for an argillaceous sediment hardened by recrystallization, but lacking the secondary cleavage of slate. The term graywacke has long been used in Alaska to designate well-indurated dark-colored sandstone, composed dominantly of minerals and fragments derived by rapid disintegration of basic igneous rocks, slates, and other dark-colored rocks; see Mertie, J. B., Jr., in Allen, V. T., Terminology of medium-grained sediments (with notes by P. G. H. Boswell): Nat. Research Council Ann. Rept. 1935-1936, App. I, Rept. Comm. Sedimentation, p. 30, 1936.

Predominantly gray stratified rocks exposed in the south spurs and on the lower part of the south face of Mount St. Elias, which were described as coarse sandstone and dark shale and tentatively correlated with the Yakutat "system" (Yakutat group, see page 13) by Russell 11/, appear from photographs and distant views to be identical with the argillite-slate-graywacke sequence observed on the ground farther west. Aerial photographs show apparently similar rocks in the part of the Chugach and St. Elias Mountains lying between Mount Miller and Tyndall Glacier, but in this area the dark-gray rocks are interbedded with light-colored rocks, probably arkosic sandstone.

11/ Russell, I. C., Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 35, 1893.

In the vicinity of Mount Steller and Mount Miller the argillite-slate-graywacke sequence apparently is overlain to the north by a sequence of more highly colored and more massive-appearing rocks. Judging from the debris carried by Bering Glacier, the more highly colored sequence consists predominantly of bedded volcanic rocks of various shades of green, red, and purple, but includes also some dark-gray argillite, slate, and graywacke. The regional dip of both sequences is to the north, but the nature of their contact has not been determined and it is by no means certain that the predominantly volcanic sequence is the younger.

Several thousand feet of the upper part of the range of mountains in the vicinity of Mount St. Elias consists of bedded schist which has been thrust over the less altered and probably younger rocks of the Yakutat "system," according to Russell 12/. This schist, which he named the St. Elias schist, evidently was not examined in place.

12/ Russell, I. C., An expedition to Mount St. Elias: Nat. Geog. Mag., vol. 3, pp. 168, 173, 1891. Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 35, 1893.

A large body of light-colored intrusive igneous rock, which contrasts strongly with the darker bedded rocks, is exposed well up on the south face of Mount St. Elias. The most abundant type of igneous rock represented in the debris on Libbey Glacier, doubtless derived from the intrusive mass, is light-gray medium-grained hornblende diorite. Specimens of amphibolite and hornblende diorite were collected in place on the northeast side of Mount St. Elias at altitudes of 13,000 feet and 16,500 feet 13/. Southwest of Mount Steller the argillite-slate-graywacke sequence is cut by a large tabular body of light-colored igneous rock that resembles, at a distance, the intrusive rock exposed on Mount St. Elias.

13/ Filippo de Filippi, The ascent of Mount St. Elias by H. R. H. Prince Luigi Amedeo di Savoia, Duke of the Abruzzi, pp. 234-236, 1900. Russell, I. C., op. cit. (1893), p. 49.

No diagnostic fossils have been found in the bedded rocks exposed in the part of the Chugach and St. Elias Mountains adjacent to the Yakataga district, and very few diagnostic fossils have been found in lithologically similar groups of rocks forming the Chugach Mountains farther west and the St. Elias Mountains farther southeast. The available evidence, including degree of deformation and alteration, structural relationship with the Tertiary rocks, and lithologic similarity and continuity with better known and more accurately dated rocks in adjacent districts, indicates that the group is definitely older than Tertiary, probably largely Mesozoic, possibly in part as young as Late Cretaceous.

The bedded rocks of the St. Elias Mountains at Yakutat Bay (index map, fig. 1), 50 miles southeast of Mount St. Elias, were divided by Tarr and Butler 14/ into an older group of metamorphic and crystalline rocks, including

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14/ Tarr, R. S., and Butler, B. S., The Yakutat Bay region, Alaska, pt. 2, Areal Geology: U. S. Geol. Survey Prof. Paper 64, pp. 147-148, 1909.

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gneiss and schist, clay slate and phyllite, and greenstone with associated crystalline limestone, and the younger Yakutat group (Yakutat "system" of Russell), including locally metamorphosed conglomerate, conglomeratic argillite, graywacke, sandstone, black shale, and limestone. The older group was tentatively assigned to the Paleozoic era, the younger Yakutat group to the Mesozoic era. Possibly equivalent bedded rocks exposed in the Fairweather Range of the St. Elias Mountains at Lituya Bay (index map, fig. 1), 170 miles southeast of Mount St. Elias, include an older group of highly metamorphosed sedimentary and volcanic rocks and a younger, less altered group consisting mainly of slate and greenstone. The two groups were first tentatively assigned by Mertie 15/ to the early Paleozoic and to the Carboniferous or Triassic,

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15/ Mertie, J. B., Jr., Notes on the geography and geology of Lituya Bay: U. S. Geol. Survey Bull. 836-B, pp. 125-127, 1933.

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respectively, but are now regarded by Kennedy and Walton 16/ as more probably

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16/ Kennedy, G. C., and Walton, M. S., Jr., Geology and associated mineral deposits of some ultrabasic rock bodies in southeastern Alaska: U. S. Geol. Survey Bull. 947-D, pp. 68-69, 1946.

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of Triassic and Cretaceous age.

In Prince William Sound and the adjacent part of the Chugach Mountains, west of the Yakataga district, a thick sequence of bedded rocks consisting mainly of slate, graywacke, and volcanic rocks, but including also arkosic sandstone, conglomerate and limestone, was assigned by Schrader 17/ to the

17/ Schrader, F. C., A reconnaissance of part of Prince William Sound and the Copper River district, Alaska: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 404, 408-410, 413, 1900.

Valdez and Orca "series" (groups). These groups are now generally considered to be mainly, if not entirely, of Mesozoic age, possibly in part as young as Late Cretaceous 18/.

18/ Smith, P. S., Areal geology of Alaska: U. S. Geol. Survey Prof. Paper 192, pp. 27, 49-50, 1939.

In general the pre-Tertiary bedded rocks bordering the Yakataga district on the north strike N. 70° - 90° W., or nearly parallel to the Chugach-St.Elias front, and dip to the north. In the adjacent districts, where the probably equivalent rocks have been studied in greater detail, they are intricately folded and faulted, and the structure presumably is equally complex north of the Yakataga district. Although the general uniformity of the group and lack of distinctive strata makes difficult the interpretation of the structure from casual observations, several complex folds in the pre-Tertiary group were noted from distant views on the ground and from aerial photographs. Photographs of the spur extending south from Mount St. Elias, just west of Libbey Glacier, show a complex asymmetrical anticline involving beds of the argillite-slate-graywacke sequence through a vertical distance of several thousand feet. On the south flank of the fold the beds are nearly vertical, at places overturned. On the north flank the beds in general dip at a low angle to the north, but show intricate drag-folding and thrust faulting.

Tertiary rocks

During much of the Tertiary period clastic sediments were deposited in a basin along what is now the northern and northeastern shore of the Gulf of Alaska. The sediments deposited in this basin are intermittently exposed in the mountains and hills lying between the sea and the southern front of the Chugach and St. Elias Mountains for a distance of 300 miles, from Ragged Mountain in the Katalla district on the west to Icy Point on the southeast, and probably extend continuously under the intervening low areas covered by glaciers or by Quaternary alluvium. (See index map, fig. 1.) The northern border of the Tertiary basin must have been considerably farther north than the present fault contact of the Tertiary sediments with the pre-Tertiary basement rock along the Chugach-St. Elias front, for the Tertiary sediments adjacent to the Chugach-St.Elias fault in the Yakataga district are no coarser than equivalent sediments 20 miles farther south along the coast. In fact, the sediments of the Poul Creek formation, of middle and upper Oligocene age 19/, show a general decrease in grain size from the coast northward toward the Chugach-St. Elias front.

19/ In this report an attempt is made to classify the Tertiary rocks of the Gulf of Alaska region in terms of the standard time divisions of the Tertiary period. This classification is based mainly on a comparison by H. E. Vokes of the Alaskan marine invertebrate megafaunas with the faunas of the better-known Tertiary sections of Oregon and Washington (Weaver, C. E., Paleontology of the marine Tertiary formations of Oregon and Washington: Washington Univ. Pub. in Geol., vol. 5, correl. chart following p. 627, 1942. Durham, J. W., Megafaunal zones of the Oligocene of northwestern Washington: California Univ. Dept. Geol. Sci. Bull., vol. 27, fig. 7, 1944). It should be noted, however, that considerable difference of opinion exists as to correlation of the marine Tertiary of western North America with the type sections in Europe. This is especially true of the Oligocene epoch.

The Tertiary sediments undoubtedly extend under the Gulf of Alaska, for they are exposed at the coast in the Yakataga district and at Lituya Bay, and on Kayak Island, 20 miles off the coast of the Katalla district. Marine sediments of either late Tertiary or Quaternary age are exposed in Middleton Island 20/, which lies on the edge of the continental shelf, about 70 miles

20/ Miller, D. J., unpublished manuscript based on field examination in 1949.

southwest of the Katalla district (index map, fig. 1).

A depositional contact of the Tertiary rocks with the pre-Tertiary basement may be exposed in the Katalla district, where the pre-Tertiary metamorphic rocks exposed in the up-faulted block forming Ragged Mountain are overlain with apparent angular contact by less altered sediments that resemble some of the known Tertiary sediments. No diagnostic fossils have been found in the less altered sediments of the Ragged Mountain area, and the observed contacts with known Tertiary rocks are fault contacts 21/. The base of the

21/ Miller, D. J., unpublished manuscript based on field examination in 1945.

group of sedimentary rocks of Tertiary age is not exposed in the part of the Yakataga district that has been examined on the ground, and aerial photographs and distant views indicate that it is probably not exposed elsewhere in the district south of the Chugach-St.Elias fault. Remnants of the Tertiary strata in depositional contact with the pre-Tertiary basement rocks may be present north of the Chugach-St.Elias fault. Some of the light-colored beds exposed in the mountains at the northern margin of Guyot Glacier, between Mount Miller and Tyndall Glacier, resemble the arkose beds in the lower part of the exposed Tertiary strata. They appear to be interbedded with dark-colored rocks of pre-Tertiary lithology, however, and more likely are part of the pre-Tertiary group. The contact between the Tertiary and pre-Tertiary groups at Lituya Bay is not described in detail in any of the published descriptions of the area.

The field relations are said to indicate a depositional contact 22/,

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22/ Buddington, A. F., and Chapin, Theodore, Geology and mineral deposits of southeastern Alaska: U. S. Geol. Survey Bull. 800, p. 269, 1929.

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and the contact shown on a geologic map accompanying the most recently published report on the area suggests a depositional rather than a fault contact 23/

23/ Kennedy, G. C., and Walton, M. S., Jr., Geology and associated mineral deposits of some ultrabasic rock bodies in southeastern Alaska: U. S. Geol. Survey Bull. 947-D, pp. 68-69, pl. 19, 1946.

The known part of the group of Tertiary sedimentary rocks totals not less than 14,000 feet in the Katalla district, not less than 25,000 feet in the Yakataga district, and possibly as much as 12,000 feet at Lituya Bay. No evidence of a regional unconformity, either erosional or structural, has been recognized within the group. The oldest diagnostic Tertiary fossils found thus far are marine invertebrates of late Eocene age, according to H. E. Vokes. The beds containing late Eocene fauna in the Yakataga district are underlain with apparent conformity by not less than 7,400 feet of predominantly continental coal-bearing strata, in which only a few poorly preserved plant remains have been found. Probably equivalent upper Eocene strata in the Katalla district (the lower part of the Tokun formation) are underlain by not less than 3,000 feet of continental and marine strata (the Stillwater and Kushtaka formations) containing early Tertiary plant and marine invertebrate fossils. 24/. The coal-bearing sequence in the Katalla district and

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24/ Martin, G. C., Geology and mineral resources of the Controller Bay region, Alaska: U. S. Geol. Survey Bull. 335, pp. 30-41, 1908. Miller, D. J., unpublished manuscript based on field examination in 1945.

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the Yakataga district contains some elements of the so-called Arctic Miocene flora (now generally regarded as of Eocene age) 25/ and probably is equivalent,

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25/ Hollick, Arthur, The Tertiary floras of Alaska, with a chapter on the geology of the Tertiary deposits, by P. S. Smith: U. S. Geol. Survey Prof. Paper 182, pp. 13-29, 1936.

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at least in part, to the Kenai formation. Rocks of Paleocene age have not been recognized in the Tertiary system in Alaska, so far as is known to the writer, although the Paleocene epoch may be represented in the lower part of the group of Tertiary strata of the Yakataga and Katalla districts, or in other rocks heretofore designated as Eocene or early Tertiary. The youngest fauna that has been definitely identified in the Tertiary strata of the Yakataga and Katalla districts is uppermost Oligocene, although the marine invertebrate fossils of the upper part of the Katalla and Yakataga formations, according to H. E. Vokes, have a Miocene or Pliocene aspect.

At Lituya Bay the Tertiary group has yielded a marine invertebrate fauna of late Miocene age 26/. The Pliocene probably is represented at this

26/ Mertie, J. B., Jr., Notes on the geography and geology of Lituya Bay: U. S. Geol. Survey Bull. 836-B, pp. 128-131, 1933.

locality, for the upper Miocene collections were made near the base of the group which may total as much as 12,000 feet. A few marine invertebrates collected by Russell about midway between Icy Bay and Yakutat Bay, from rocks which he designated the Pinnacle "system" and correlated with rocks of similar lithology in the Chaix Hills (upper part of the Yakataga formation), were said by Dall to indicate a Pliocene or Pleistocene age 27/.

27/ Russell, I. C., Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 25, 1893.

In late Tertiary or early Quaternary time the Chugach-St.Elias Mountain mass was uplifted and thrust southward along the Chugach-St. Elias fault and possibly other north-dipping faults, and the bordering belt of Tertiary sediments was uplifted, folded, and faulted. The youngest accurately dated Tertiary beds that were involved in the orogeny are the upper Miocene strata at Lituya Bay, although, as mentioned above, it is possible that beds as young as Pliocene, or even Pleistocene, are represented here or in the Yakataga and Katalla districts. Intensely folded Tertiary strata exposed at the south end of Wingham Island, a small island off the coast of the Katalla district (index map, fig. 1), are overlain unconformably by only slightly warped beds of marine silt, sand, and clay. These unconsolidated beds evidently postdate the major orogeny during which the Tertiary strata were folded and faulted. Foraminifera collected by the writer from the unconsolidated beds at this locality are either Pliocene or Pleistocene forms, according to J. A. Cushman.

In this report three major divisions of the sedimentary rocks of Tertiary age are recognized: an unnamed and undifferentiated lower Tertiary sequence not less than 9,400 feet thick; and the Poul Creek formation of middle and late Oligocene age, ranging from 4,300 feet to more than 5,800 feet in thickness; and the upper Oligocene (?) and younger Yakataga formation, more than 11,600 feet thick (see fig. 2).

Lower Tertiary sequence

In the Yakataga River-Yakataga Glacier basin Spieker, Walton, and Kirschner recognized and mapped two stratigraphic units older than the Poul Creek formation, which they designated the lower sandstone sequence and the upper sandstone sequence. The two sequences were assumed to be conformable, although the contact was not observed in the field. The following description of these sandstone sequences is abstracted from the manuscript report by Spieker, Walton, and Kirschner.

> The lower sandstone sequence is exposed in the thrust fault block near the head of Yakataga Glacier. Neither the top nor the bottom of the sequence was recognized in the field. The exposed thickness is estimated to be between 3,000 feet and 4,000 feet. About 1,000 feet of the sequence was examined in detail and considerable information on the rest was obtained from moraines restricted in source area to the sequence.
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> The lower sandstone sequence consists largely of sandstone and shale. Most of the sandstone is massive, and much of the sandstone is gray on fresh surfaces, buff on weathered surfaces, and consists chiefly of quartz grains of medium size. Gray coarse-grained arkosic sandstone that contains a high percentage of feldspar, and greenish-gray sandstone that contains a high of dark minerals also are common. The shale is dark, fissile, and thick-bedded. The morainal debris from the lower sequence also contains some limy concretions and large fragments of coarsely crystalline, thick-bedded, greenish-gray limestone, but the relative amount of limestone and limy sediments is not known. Crossbedding is common in the sandstone.
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> The upper sandstone sequence forms much of the mountainous area between Boulder Creek and the Yakataga Glacier. The total thickness of the sequence is not known because the base was not recognized in the area mapped. The top of the upper sandstone sequence is fairly well marked by the transition from predominantly sandy rocks to predominantly silty rocks of the overlying Poul Creek formation. The exposed thickness is about 6,400 feet on Boulder Creek. At least 4,500 feet of strata belonging to the upper sandstone sequence were observed on Porcupine Creek and in the mountains north of Yakataga Glacier. About 1,000 feet of sandstone exposed north of the thrust fault on Poul Creek is tentatively identified as belonging to the upper sandstone sequence.
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> The upper sandstone sequence consists largely of sandstone, but locally includes considerable shale, and other rocks. From a distance the upper sandstone sequence has a pinkish cast compared to the dominantly gray Yakataga formation...On Boulder Creek the upper sandstone sequence consists mainly of massive medium-grained sandstone, gray on fresh surfaces and buff to brown on weathered surfaces, interbedded with some gray or dark-brown to black shale, thin-bedded sandstone, and ferruginous claystone. Outcrops of a coal bed, 12 to 15 inches thick, were observed at two localities on Boulder Creek. The character of the strata that are tentatively assigned to the upper sandstone sequence on Porcupine Creek is shown in this report (fig. 2, section 5). The lower part of this section may belong in the lower sandstone sequence.

Investigation of the area north and west of the Duktoth River during the 1946 and 1947 field seasons has resulted in a better understanding of the section underlying the Poul Creek formation and indicates that it is divisible into four lithologic units that probably warrant designation as formations. Assignment of formal stratigraphic names is not warranted at present, because the writer did not attempt to differentiate the four units everywhere in the parts of the district mapped during the 1946-1948 field seasons, and without further field work, cannot determine their relation to the lower and upper sandstone sequences in the area mapped in 1944 by Spieker, Walton, and Kirschner. The exposed sequence of pre-Poul Creek Tertiary rocks, including the lower and upper sandstone sequences of Spieker, Walton and Kirschner, is designated as the lower Tertiary sequence on the map accompanying this report.

The best locality known to the writer for studying the lower Tertiary sequence is near the head of the Kulthieth River between Bering Glacier and Duktoth River. At this locality the Poul Creek formation is underlain by a continuous and well-exposed section of at least 9,400 feet of strata, apparently without significant duplication or cutting out of beds by faults or folds. As shown in columnar section 2 (fig.2), the lower Tertiary sequence at this locality is divisible into four lithologic units, designated, for convenience, as units A, B, C, and D. The thickness of the units was determined approximately from measurements made on the map and from aerial photographs, supplemented by horizontal and vertical control obtained in the field. The lithology is generalized from field traverses and from data obtained from ground and aerial photographs.

Unit A.--The oldest unit of the lower Tertiary sequence, unit A, consists predominantly of massive fine-to medium-grained yellowish-brown to gray sandstone interbedded with dark-gray to black micaceous siltstone and thin-bedded fine-grained sandstone. The sandstone is typically poorly sorted, well indurated, and consists principally of angular to subrounded rock fragments, quartz grains, and feldspar grains, in approximately equal amounts. Some of the more feldspathic sandstone is calcareous. The unit contains many thin beds of coal that range in rank from bituminous to anthracite and commonly are much shattered and sheared. The highest rank coal occurs adjacent to the Chugach-St.Elias fault. The striped appearance resulting from regular alternation of thin beds of light-colored sandstone with contrasting dark-colored siltstone, sandstone, and coal, as well as the yellow to yellowish-orange color of weathered concretions and of calcareous arkose beds, are distinctive features of unit A.

Unit A is at least 5,000 feet thick. The base of the unit has not been observed in the field, and judging from the aerial photographs, is not exposed anywhere in the Yakataga district. The exposed contacts with the pre-Tertiary rocks near Mount Steller and Mount Miller are fault contacts.

Unit A is exposed in a continuous band extending from the head of Kulthieth River northeastward through the area lying between Chugach Mountains and the head of Duktoth River. In the field it was recognized also in the low hills adjacent to the Chugach-St. Elias fault near Mount Steller and Mount. Miller. Study of aerial photographs, supplemented by ground and aerial views, indicates that the unit almost certainly is exposed in the area between Duktoth River and Mount Leeper.

No diagnostic fossils have been found in unit A, but the fact that it is conformable with and lithologically similar to the overlying beds of Paleocene or Eocene age permits its assignment to the early Tertiary with considerable confidence. Unit A is correlated on lithology with the lower, anthracite-bearing part of the Kushtaka formation in the Katalla district 28/.

28/ Martin, G. C., Geology and mineral resources of the Controller Bay region, Alaska: U. S. Geol. Survey Bull. 335, pp. 31-35, pl. 9, A, 1908.

The presence of plant remains and numerous beds of coal, and the lack of marine fossils indicate deposition at least in part in a continental environment.

Unit B.--This unit consists of thin-bedded to massive, gray, dark-green and yellowish-brown to brown sandstone; gray to black siltstone; and thin beds of bituminous coal. The predominant rock type is massive, hard, medium- to coarse-grained gray to yellowish-brown arkose, consisting principally of poorly sorted, angular grains of feldspar and quartz, and fragments of rocks. The sandstone beds in unit B are generally much thicker and more massive than those in unit A, and the siltstone beds correspondingly thinner. Unit B contains some beds of dark-green sandstone not found in unit A, and lacks the yellow- or yellowish-orange-weathering beds and concretions that are so characteristic of unit A. The contact of unit B with the underlying unit A is gradational, but the contact with the overlying unit C, which is marked by a change from predominantly sandy, massive strata to predominantly silty, thin-bedded strata, is sharp.

At the head of Kulthieth River (columnar section 2, fig. 2) unit B is approximately 2,400 feet thick. The unit is extensively exposed in the area drained by the Kulthieth River, in the ridge north of Hope Creek, and along the Duktoth River. The upper part of the unit forms the southern end of the ridge between Hanna Lake and Kosakuts River. Correlation with the lower part of the upper sandstone sequence and part or all of the lower sandstone sequence in the Yakataga River-Yakataga Glacier basin is suggested by the lithologic descriptions given by Spieker, Walton, and Kirschner, and by the general appearance of the rocks they assigned to the sandstone sequences, as seen from a distance and as shown on aerial photographs. Study of aerial photographs indicates that unit B probably is exposed in the vicinity of Steller Glacier, in the area between Duktoth River and Mount Leeper, and north and northwest of the Chaix Hills.

Plant remains are common in unit B, particularly in some of the sandstone beds, but are poorly preserved. A leaf specimen collected near the head of the Kosakuts River was identified by R. W. Brown as Daphnogene kanii Heer. According to Hollick 29/ this species has been found in the Eocene

29/ Hollick, Arthur, The Tertiary floras of Alaska, with a chapter on the geology of the Tertiary deposits, by P. S. Smith: U. S. Geol. Survey Prof. Paper 182, pp. 121-122, 1936.

of Greenland and in the Kushtaka formation in the Katalla district. Unit B is believed to be equivalent, at least in part, to the upper part of the Kushtaka formation. The presence of green sandstone beds, on the other hand, suggests that part of the unit may have been deposited in a marine environment.

Unit C.--In the area between Bering Glacier and Duktoth River the predominantly sandy upper and lower parts of the lower Tertiary sequence are separated by a more silty and more conspicuously bedded unit, designated unit C in this report. At the head of the Kulthieth River (columnar section 2, fig. 2) unit C includes about 1,000 feet of gray to brown siltstone with many thin interbeds of fine-grained banded sandstone and a few thicker beds of massive sandstone. Near Hanna Lake (columnar section 1, fig. 2) the unit apparently is about 2,500 feet thick. At this locality the upper 560 feet of the unit, which is well exposed and was examined and measured in detail, consists of massive sandstone alternating with interbedded siltstone and thin-bedded sandstone. The lower part of the unit is poorly exposed, but the outcrops observed are all of siltstone or interbedded siltstone and thin-bedded sandstone. The sandstone in unit C is similar in mineral composition, degree of induration, and color to the sandstone in the underlying and overlying units, but in general is finer grained and better sorted. Biotite and muscovite mica are prominent constitutents of many sandstone and siltstone beds, the banded appearance of these beds being due to the concentration of mica along bedding planes.

The writer is not able to determine conclusively from the columnar section and descriptions in the report by Spieker, Walton, and Kirschner whether or not unit C is represented in the area just north of Yakataga River and Yakataga Glacier. Aerial photographs of this area show at least one interval of silty rocks in the unit mapped as the lower sandstone sequence, which may represent unit C. More detailed study may show that unit C is developed only locally and should be regarded as a member of a formation including the entire interval between the Poul Creek formation and the top of unit B.

Unit C probably represents a marine facies in an otherwise predominantly continental or brackish marine sequence. Marine invertebrate fossils were found in the unit at several localities in the area between Bering Glacier and Duktoth River. According to H. E. Vokes, the fossils indicate clearly the unit is of late Eocene age. They also indicate a somewhat warmer environment than the fauna of the Poul Creek and Yakataga formations. Unit C probably is equivalent, at least in part, to the Tokun formation in the Katalla district. 30/.

30/ Martin, G. C., op. cit. (1908), pp. 35-36.

Unit D.--As exposed in the area between Bering Glacier and Duktoth River, unit D consists of well-indurated massive fine- to medium-grained gray to brown sandstone, with minor interbeds of gray siltstone and gray to brown thin-bedded fine-grained sandstone. One thin bed of bituminous coal was observed in the unit on the east shore of Hanna Lake, and several outcrops of coal, possibly from the same bed, were observed within unit D in the Kulthieth River valley. The unit contains some poorly sorted brown and yellow arkose of the type found in unit B, but consists predominantly of better-sorted, less-feldspathic gray to greenish-gray sandstone.

Unit D is extensively exposed in the area between Bering Glacier and Duktoth River. It is about 1,200 feet thick in the vicinity of Hanna Lake, where it was measured and described in detail (columnar section 1, fig. 2), and about 1,000 feet thick near the head of Kulthieth River (columnar section 2, fig. 2). Equivalent strata undoubtedly are represented in the lower Tertiary sequence in the part of the Yakataga district lying east of Duktoth River and north of Yakataga River and Yakataga Glacier, but it is not known whether unit D can be differentiated from the rest of the lower Tertiary sequence in this area. The possibility that the upper part of the lower Tertiary sequence is exposed in the coastal area between Poul Creek and Johnston Creek is discussed in the section describing the Poul Creek formation.

The only fossils observed in unit D are fragments of plant stems and leaves, and a few poorly preserved marine pelecypods. Inasmuch as the unit lies with apparent conformity between strata containing upper Eocene and middle Oligocene fossils, it may be assumed to represent all early Oligocene time, and possibly part of late Eocene and part of middle Oligocene time. The presence of coal, plant remains, and marine invertebrates suggests deposition in an environment alternating between continental and shallow marine or brackish water conditions.

Poul Creek formation

The Poul Creek formation was named by Taliaferro 31/ and defined, in part,

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31/ Taliaferro, N. L., Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., vol. 43, pp. 754-756, 1932.

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as follows:

> This formation, named from its exposures along Poul Creek, is made up of fully 3,000 feet of dark hard platy shales, in part calcareous and in part sandy, thin-bedded sandstones, conglomerates, occasional thin limestones, and a few beds of glauconitic sandstone.

Taliaferro's description of the Poul Creek formation was based on his examination of the coastal area between Cape Yakataga and Icy Bay. He stated that the base of the formation is not exposed in this area. Spieker, Walton, and Kirschner tentatively recognized a full section of the Poul Creek formation at the type locality on Poul Creek, assigning approximately 1,000 feet of sandstone north of the fault to the upper sandstone sequence. They also recognized the Poul Creek formation in the Yakataga River-Yakataga Glacier basin, assigning to it more than 3,000 feet of siltstone with thin sandstone beds lying above the upper sandstone sequence north of Yakataga River and Yakataga Glacier, and about 2,200 feet of similar beds underlying the Yakataga formation in Yakataga Ridge and north of Yaga Glacier.

During the 1946-1948 investigations the Poul Creek formation was studied and mapped in the coastal belt from Cape Yakataga east to Icy Bay, in the Boulder Creek-Cotton Creek area adjoining the area mapped by Spieker, Walton, and Kirschner, and in the area between Bering Glacier and Duktoth River. In the coastal area between Cape Yakataga and Icy Bay, the Poul Creek formation, as recognized in this report, differs from the formation as recognized by Taliaferro and by Spieker, Walton, and Kirschner in the following respects: (1) Much, if not all, of the sequence of predominantly sandy rocks exposed north of the thrust fault on Poul Creek is considered to be part of the Poul Creek formation rather than part of the lower Tertiary sequence (upper sandstone sequence of Spieker, Walton, and Kirschner); (2) Careful tracing of the Poul Creek-Yakataga contact westward along the coast indicates that the lower 1,350 feet of the section exposed on Yakataga Reef, placed in the Yakataga formation by Taliaferro and by Spieker, Walton, and Kirschner, actually belongs in the Poul Creek formation; (3) The glauconitic sandstone beds are restricted to the Poul Creek formation, and do not occur in the Yakataga formation as stated by Taliaferro; (4) The sandy mudstone beds containing scattered rock fragments of gravel size are restricted to the Yakataga formation, and do not occur in the Poul Creek formation as stated by Taliaferro.

The Poul Creek formation, as defined in this report, comprises the fossiliferous, reddish-brown-weathering, predominantly silty sequence lying conformably between the lower Tertiary sequence and the Yakataga formation. Sandstone is fairly abundant locally in the lower part of the formation. The base of the formation is drawn at the stratigraphically lowest occurences of the reddish-brown-weathering, concretion-bearing, fossiliferous siltstone. The top of the formation is drawn at the highest occurrence of the predominantly reddish-brown-weathering siltstone, in contact with gray-weathering siltstone or, where it is present, with the basal sandstone of the Yakataga formation.

The siltstone, fine-grained sandstone, and sandy mudstone that make up the major part of the Poul Creek formation are typically massive, hard, and poorly sorted, consisting of angular grains of sand-, silt-, and clay-size. Quartz, feldspar, and rock fragments are the most abundant constitutents. Glauconite is abundant to predominant locally. Brown or green biotite mica, brown organic material, muscovite mica, and pyrite are common constitutents. Gray limestone in the form of concretions or, less commonly, in thin discontinuous beds, occurs mainly in the siltstone and sandy mudstone beds. The smaller concretions range in shape from nearly spherical masses (the so-called cannon-ball concretions) to flat lenses. The larger concretions (2 to 5 feet or more in largest diameter) are lenticular and are restricted to the upper part of the formation. The siltstone, sandy mudstone, and sandstone are not noticeably calcareous except in the vicinity of limestone beds or concretions.

Most of the coarser-grained sandstone in the Poul Creek formation is similar to the siltstone and fine-grained sandstone in texture, degree of induration, and composition. A few of the coarser-grained sandstone beds exposed in the coastal area between Cape Yakataga and Johnston Creek are conspicuously better sorted and less indurated.

The entire Poul Creek formation is exposed in continuous sequence with the underlying and overlying formations in the Cotton Creek-Boulder Creek area (columnar section 4, fig. 2). In this area the formation is about 4,300 feet thick. The section was traversed from the top of the lower Tertiary sequence on Boulder Creek to the base of the Yakataga formation on the east side of Duktoth Mountain, and the approximate thickness was determined from measurements made on aerial photographs, supplemented by horizontal and vertical control obtained in the field. The lower contact, on a tributary of Boulder Creek, is marked by abrupt change from massive gray sandstone to fossiliferous, concretion-bearing, reddish-brown-weathering siltstone and fine-grained sandstone. The upper contact, as exposed on the southeast side of Duktoth Mountain, is gradational over an interval of 100 to 200 feet in which reddish-brown-weathering siltstone is interbedded with the gray-weathering siltstone of the Yakataga type. A few thin beds of glauconitic sandstone were noted about 700 feet below the top of the formation. The lower part of the Poul Creek formation contains less sandstone at this locality than in the coastal area or west of the Duktoth River.

In the Poul Creek-Johnston Creek area the Poul Creek formation is at least 3,730 feet thick, possibly more than 4,000 feet thick. The general character of the formation in this area is shown in the section measured on the upper part of Poul Creek (columnar section 8, fig. 2). The lower 140 feet of sandstone beds in this section, and a possibly thicker section of similar sandstone beds exposed farther east in the Munday Creek-Johnston Creek area, may represent the upper part of the lower Tertiary sequence, or they may be underlain by fossiliferous siltstone that is not exposed and thus represent a sandy facies in the lower part of the Poul Creek formation. These sandstone beds were mapped as part of the Poul Creek formation in the field and are so shown on figure 1.

The Poul Creek formation crops out in a continuous belt extending from the vicinity of Yakataga Reef eastward to or nearly to the mouth of Carson Creek. Throughout this belt the upper 700 to 900 feet of the formation, consisting of siltstone that is less sandy and less resistant to erosion than the adjacent parts of the Yakataga and Poul Creek formations, is marked by conspicuous strike valleys and by topographic sags in the ridge crests. Beds of dark-green, olive-green, or greenish-black glauconitic sandstone are common in the Poul Creek formation in the coastal area, being especially well developed in the lower part of the section exposed on Yakataga Reef (columnar section 6, fig. 2). From Yakataga Reef eastward to the vicinity of White River, the lower part of the exposed section of the Poul Creek formation--the interval about 800 to 1,200 feet below the top of the formation--includes several thick beds of medium-grained sandstone. In the vicinity of Poul Creek the equivalent interval is mainly siltstone and fine-grained sandstone, but thick beds of medium-grained sandstone are present in the lower part of the formation (columnar section 8, fig. 2).

A narrow belt of predominantly silty beds of the upper part of the Poul Creek formation is exposed south of the Sullivan fault between Poul Creek and Little River.

The belt of Poul Creek strata extending from the central part of the Kulthieth River valley westward to the nunataks in Bering Glacier (west of Hanna Lake) was traversed at several localities. The lower part of the Poul Creek formation was measured and described in the vicinity of Hanna Lake (columnar section 1, fig. 2). Near Hanna Lake the lower 870 feet of the Poul Creek formation includes, in addition to the typical siltstone, two thick sandstone units, some units of rhythmically interbedded sandstone and siltstone, and two thin beds of dark-green tuff and volcanic breccia. Similar volcanic material was observed at about the same horizon on Kulthieth River but was not seen in the Poul Creek formation elsewhere in the Yakataga district. The strata above the lower, sandy part of the Poul Creek formation near Hanna Lake are mostly massive concretion-bearing siltstone and sandy mudstone. The upper part of the Poul Creek formation has been removed by erosion in the Hanna Lake-Kulthieth River belt.

The character of the Poul Creek formation as exposed in the narrow belt at the margin of Bering Glacier and the head of Kulthieth River is shown in columnar section 2 (fig. 2). The lithology of the lowest 500 feet and the thickness of the lowest 900 feet of the Poul Creek formation in this section is based on data derived from aerial and ground photographs, supplemented by field observations and measurements. The upper part of the section was measured by plane table-stadia traverse. The upper 4,000 feet of the Kulthieth River section, representing the highest strata exposed in the vicinity, consists of a monotonous sequence of massive to platy, concretion-bearing siltstone. The section was measured on a continuous exposure of bare rock. No reversal of dip or other evidence of duplication of strata was noted, although the dip steepens progressively toward the top of the sequence. Unless the siltstone sequence is repeated by folds or faults not detected in the field, the upper fine-grained part of the Poul Creek formation is considerably thicker here than farther south and southeast, and the total thickness of the formation is more than 5,800 feet.

The fossils collected by Taliaferro from the Poul Creek and Yakataga formations in the coastal part of the Yakataga district were stated by Clark 32/

32/ Clark, B. L., Fauna of the Poul and Yakataga formations (upper Oligocene) of southern Alaska: Geol. Soc. America Bull., vol. 43, pp. 799-800, 1932. The San Ramon and Blakeley formations, with which Clark correlated the Poul Creek and Yakataga formations, still are considered to be more likely Miocene than Oligocene by Ralph Stewart and W. P. Woodring (personal communication).

to represent a single fauna of late Oligocene age, indicating a cool temperature, relatively shallow, marine environment. Collections made from the Poul Creek formation during the 1944 and 1946-1948 investigations, according to H. E. Vokes, confirm the late Oligocene age of the upper part of the formation, but indicate that approximately the lower one-third of the formation is uppermost middle Oligocene (fig. 2). The fossils indicate correlation with the Blakeley and Lincoln formations of Washington, and with the middle part of the Katalla formation in the Katalla district 33/. The known range of some of the more common and diagnostic forms in the Poul Creek formation is shown at the left side of the columnar sections (fig. 2).

33/ Miller, D. J., Rossman, D. L., and Hickcox, C. A., Preliminary report on petroleum possibilities in the Katalla area, Alaska, pp. 6-13, 1945. (Mimeographed. Accompanies geologic and topographic map and sections of the Katalla area, Alaska: U. S. Geol. Survey war minerals investigations, 1945.) Miller, D. J., unpublished manuscript based on field investigations in 1945.

Yakataga formation

Taliaferro 34/ assigned the name Yakataga formation to more than 5,000

34/ Taliaferro, N. L., Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., vol. 43, pp. 756-759, 1932.

feet of sandstone, dark shale, and conglomerate conformably overlying the Poul Creek formation in the coastal area between Cape Yakataga and Icy Bay. In this area, according to Taliaferro, the base of the Yakataga formation is marked by the first thick sandstone occurring above the shales of the Poul Creek formation. The top of the Yakataga formation was not defined.

The writer's study of the Yakataga-Poul Creek contact in the coastal area and in the vicinity of Duktoth Mountain indicates that the occurrence of sandstone is not everywhere a reliable criterion for determining the location of the base of the Yakataga formation. Although a conspicuous sandstone bed is present at some places between the reddish-brown-weathering strata of the Poul Creek formation and the gray-weathering siltstone beds of the Yakataga formation, it does not persist laterally. The change from the reddish-brown-weathering strata characteristic of the Poul Creek formation to the gray-weathering strata characteristic of the Yakataga formation, however, does persist laterally, and occurs everywhere at about the same horizon. The horizon of the Yakataga-Poul Creek contact at the head of Poul Creek, when traced westward, was found to lie several hundred feet stratigraphically above the sandstone cited by Taliaferro 35/ and accepted by

35/ Taliaferro, N. L., op. cit., p. 757.

Spieker, Walton, and Kirschner as marking the base of the Yakataga formation between Twomile Creek and the White River. The horizon was traced along the coast on the ground and with the aid of aerial photographs, using the color change and the topographic break at the top of the Poul Creek formation as checks. This sandstone and several hundred feet of higher beds, including the glauconitic sandstone exposed in Yakataga Reef, are here assigned to the Poul Creek formation. In Yakataga Ridge the reddish-brown-weathering siltstone of the Poul Creek formation is overlain by a conspicuous sandstone marking the base of the Yakataga formation (columnar section 7, fig. 2), according to Spieker, Walton, and Kirschner.

The Yakataga formation, as described in this report, includes the entire sequence of Tertiary strata overlying the Poul Creek formation in the Yakataga district. The strata forming the Chaix Hills, correlated by Russell 36/

36/ Russell, I. C., Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, pp. 24-27, 1893.

with the Pinnacle "system", are indistinguishable lithologically and faunally from the upper part of the Yakataga formation as exposed in the Robinson Mountains, and are therefore included in the Yakataga formation.

The Yakataga formation is either exposed or forms the bedrock beneath a cover of ice or alluvium in three belts, each of which is bounded on the north by a major thrust fault. These include the narrow belt extending along the coast from Twomile Creek east to the vicinity of Johnston Creek, the broad belt extending from the Yakataga River-Yakataga Glacier basin eastward to the Chaix Hills, and the belt extending from Duktoth Mountain westward to the isolated hill near the head of Tsivat River. The maximum thickness of exposed strata assigned to the Yakataga formation is about 12,000 feet in the vicinity of the Chaix Hills, at least 8,000 feet between Icy Bay and the Duktoth River, and at least 10,000 feet, possibly as much as 15,000 feet, in the vicinity of Kulthieth Mountain. This information is based in part on fairly detailed ground examination and in part on information from ground and aerial photographs. The base of the formation is not known to be exposed in the Chaix Hills and is only tentatively identified in the Kulthieth Mountain area. The top of the Yakataga formation has not been recognized anywhere in the district.

The Yakataga formation includes a large variety of sedimentary rock types. The most abundant and characteristic types are listed below:

Gray to dark-gray, partly calcareous, massive to platy siltstone containing lenses and thin discontinuous beds of dark-gray limestone. The siltstone remains gray on weathering.

Gray to brown fine- to coarse-grained sandstone, mostly massive to slabby, and well indurated, but locally thin-bedded or poorly indurated.

Gray to greenish-gray moderately indurated sandy mudstone containing scattered round to angular rock fragments of gravel size ("conglomeratic" sandy mudstone).

Pebble or cobble conglomerate with a matrix of sandstone or sandy mudstone.

Claystone, siltstone, and fine-grained sandstone in rhythmically alternating thin beds.

The most characteristic lithologic type in the Yakataga formation, the "conglomeratic" sandy mudstone, resembles typical tillite in that it consists of fresh rock and mineral fragments ranging in size from clay to huge boulders, thrown together without sorting, but differs in that it contains marine fossils and is associated with normal marine sediments. The clay- to sand-size grains are angular, but the rock and mineral fragments of gravel size show a complete range in degree of roundness from wholly angular to well rounded. Glacial striae are preserved on many of the larger rock fragments.

The difficulty of selecting an appropriate name for the tillite-like rock called "conglomeratic" sandy mudstone in this report is illustrated by the variety of names or phrases that have been used to describe it in earlier reports 37/: stratified morainal material, and sandy clay containing

37/ Russell, I. C., Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth Ann. Rept., pt. 2, p. 25, 1893. Maddren, A. G., Mineral deposits of the Yakataga district, Alaska: U. S. Geol. Survey Bull. 592, p. 132, 1914. Taliaferro, N. L., Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., vol. 43, pp. 758-762, 1932. Spieker, E. M., Walton, M. S., Jr., and Kirschner, C. E., op. cit. (Mss., 1947)

***both angular and rounded bowlders *** up to 6 or 8 feet in diameter (Russell); Massively bedded marine silty sandstones and shales containing *** large and moderately-sized bowlders (Maddren); shale-matrix conglomerate, shale-matrix breccia-conglomerate, marine breccia conglomerate, and "conglomerate" (Taliaferro--in a single report); and cobble-bearing mudstone (Spieker, Walton, and Kirschner). None of these names or phrases is wholly suitable for describing the tillite-like rock in the Yakataga formation, according to the definitions recommended by the Committee on Sedimentation of the National Research Council 38/

38/ Wentworth, C. K., The terminology of coarse sediments, with notes by P. G. H. Boswell: Nat. Research Council Bull. 98, pp. 225-246, 1935. Allen, V. T., Terminology of medium-grained sediments (with notes by P. G. H. Boswell): Nat. Research Council Ann. Rept., 1935-1936, App. I, Rept. Comm. Sedimentation, pp. 18-47 (mimeographed), 1936. Twenhofel, W. H., Terminology of the fine-grained mechanical sediments: Nat. Research Council Ann. Rept., 1936-1937, App. I, Rept. Comm. Sedimentation, pp. 81-104 (mimeographed), 1937. For definitions of the sedimentary rock terms used in this paragraph, and a detailed discussion of the problems of sedimentary rock classification, see Pettijohn, F. J., Sedimentary rocks, pp. 8-80, 177-194, 1949.

Among the sedimentary terms in common use, the term sandy mudstone accurately describes the part of the tillite-like rock composed of particles 2mm or less in diameter. The term conglomeratic seems to be the most appropriate for the part composed of fragments larger than 2 mm in diameter, although it is generally applied to fragments showing some rounding and therefore does not accurately describe the significant portion of the fragments in the tillite-like rock that are angular. The provisional term "conglomeratic" sandy mudstone is used for the tillite-like rock in this report, as any term within the framework of the commonly accepted sedimentary nomenclature that can be applied to it is either inaccurate or is too long to be useful. Pettijohn 39/ called

39/ Pettijohn, F. J., op. cit., p. 179.

attention to the possibility of using a single term, derived from the geographic or stratigraphic type locality, for commonly recurring rock types. The name yakatagite would be appropriate for the tillite-like rock that is characteristic of the Yakataga formation in the Yakataga district.

The siltstone and some of the fine-grained sandstone of the Yakataga formation closely resembles, both macroscopically and microscopically, the unweathered siltstone, sandy mudstone, and fine-grained sandstone of the Poul Creek formation. Limestone occurs more commonly in thin, discontinuous beds, and less commonly as concretions, in the siltstone of the Yakataga formation. Spherical "cannon-ball" concretions and large lenticular concretions occur sparsely in the siltstone of the Yakataga. Because of the characteristic reddish-brown color assumed by the siltstone and sandstone of the Poul Creek on exposure to chemical weathering, the two formations are readily differentiated in large outcrops. The siltstone and fine-grained sandstone of the Yakataga formation typically is hard, massive to somewhat platy, and consists of poorly sorted angular grains. Quartz, feldspar, rock fragments, mica, and organic material are common to abundant constituents, occuring in approximately the same proportions as in the Poul Creek formation. Glauconite occurs in small amount, if at all, in the siltstone and sandstone of the Yakataga formation, and pyrite is notably less abundant in the Yakataga formation than in the Poul Creek formation.

The medium- and coarse-grained sandstone in the lower part of the Yakataga formation is similar in texture, degree of induration, and composition to the coarser-grained non-glauconitic sandstone of the Poul Creek formation. Most of the sandstone in the upper part of the Yakataga formation appears to be better sorted and less indurated.

Spieker, Walton, and Kirschner noted the presence in the Yakataga formation of units made up of rhythmically alternating thin beds of light-colored siltstone and dark-colored claystone (columnar section 7, fig. 2). The individual layers of claystone and siltstone range in thickness from a fraction of an inch to several inches, and the units showing rhythmic interbedding range in thickness from a few feet to several hundred feet. The writer observed similar units of interbedded siltstone and claystone, and also of rhythmically interbedded siltstone and fine-grained sandstone, in other parts of the Yakataga district (columnar sections 3, 6, 9, and 10, fig. 2). The units showing rhythmic interbedding generally are found in association with the "conglomeratic" sandy mudstone.

Fairly typical sections of a substantial part of the Yakataga formation are shown in columnar sections 3, 7, 9, and 10 (fig. 2). A well-developed basal sandstone is shown in columnar section 7, and the more typical gradational contact with the underlying Poul Creek formation is illustrated by columnar sections 4, 6, and 8. West of Icy Bay two fairly distinct lithologic facies of the Yakataga formation can be recognized. The lower part of the formation consists predominantly of interbedded siltstone and sandstone, whereas the upper part consists predominantly of massive "conglomeratic" sandy mudstone. Relatively thin beds of the "conglomeratic" sandy mudstone occur, but not abundantly, in the sandstone-siltstone facies, and beds of sandstone and siltstone occur in the "conglomeratic" sandy mudstone facies but tend to be lenticular and do not persist laterally. Viewed from a distance, the sandstone-siltstone facies is more strikingly banded and shows more regular bedding than the "conglomeratic" sandy mudstone facies.

The sandstone-siltstone facies forming the lower part of the Yakataga formation is about 5,500 feet thick in the vicinity of Kulthieth Mountain and in the vicinity of Yakataga Ridge. South and southeast of Yakataga Ridge the sandstone-siltstone facies decreases in thickness and the "conglomeratic" sandy mudstone facies increases correspondingly in thickness, due to lateral gradation of the higher sandstone and siltstone beds into "conglomeratic" sandy mudstone. The sandstone-siltstone facies is about 2,000 feet thick in Brower Ridge at the head of Oil Creek, and 2,000 to 3,000 feet thick along the coastal ridge between Oil Creek and Icy Bay. Only the "conglomeratic" sandy mudstone facies of the Yakataga formation is exposed northeast of Icy Bay in the vicinity of the Chaix Hills.

Between Kulthieth River and Hope Creek, in the footwall block of the Hope Creek fault, "conglomeratic" sandy mudstone and sandstone beds similar to those of the Yakataga formation appear to be overlain by a siltstone sequence that contains large lenticular limestone concretions and tends to weather reddish brown. Both of these features are more characteristic of the upper part of the Poul Creek formation than of the Yakataga formation, but neither a fault nor fold that would account for the presence of beds of Poul Creek age at this locality was detected in the field. A similar sequence of siltstone is exposed in the footwall of the Hope Creek fault just west of Duktoth River. The siltstone may represent an unusual lithologic phase of the Yakataga formation, or it may represent a part of the Poul Creek formation brought to the surface by an undetected fault or fold.

Many fossils were collected from the Yakataga formation during the 1944 and 1946-48 field investigations. Concerning the collections from the upper part of the Yakataga formation (about 2,000 feet to 10,000 feet above the base) H. E. Vokes 40/ commented as follows:

40/ Vokes, H. E., written communication, 1948.

> This upper Yakataga fauna is close to that described by Clark, but the presence of several large gastropods not heretofore reported from this area gives it a somewhat more modern aspect. The Priene and the Neptuneids are mainly Miocene and later types--I believe that this is probably a Miocene fauna, possibly lower Miocene.

The gastropod *Echinophoria apta*, considered to be a guide to the uppermost Oligocene in Washington 41/, occurs in the upper part of the Poul Creek

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41/ Durham, J. W., Megafaunal zones of the Oligocene of northwestern Washington: California Univ., Dept. Geol. Sci. Bull., vol. 27, no. 5, pp. 113-114, fig. 7, 1944.

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formation but, so far as is known to the writer, has not been found in the Yakataga formation as defined in this report.

Although three of the collections made by Taliaferro are listed as having come from the Yakataga formation, most, if not all of the diagnostic forms on which Clark 42/ based the late Oligocene age of the beds containing them

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42/ Clark, B. L., Fauna of the Poul and Yakataga formations (upper Oligocene) of southern Alaska: Geol. Soc. America Bull., vol. 43, pp. 798-801, 845-846, fig. 1, 1932.

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actually came from the Poul Creek formation.

The fauna of the Yakataga formation, as well as that of the Poul Creek formation, indicates a comparatively shallow, cool temperate marine environment, similar to that of the adjacent coast at the present time, according to Clark 43/. Deposition in a cool marine environment is confirmed by the

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43/ Clark, B. L., op. cit., p. 800.

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presence of the marine glacial deposits in the Yakataga formation. The glacial origin of the tillite-like "conglomeratic" sandy mudstone has been recognized and discussed by Russell 44/, Maddren 45/, Taliaferro 46/, and

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44/ Russell, I. C., Second expedition to Mount St. Elias: U. S. Geol. Survey Thirteenth. Ann. Rept., pt. 2, pp. 24-25, 1893.
45/ Maddren, A. G., Mineral deposits of the Yakataga district, Alaska: U. S. Geol. Survey Bull. 592, p. 127, 1914.
46/ Taliaferro, N. L., Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., vol. 43, pp. 759-762, 1932.

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by Spieker, Walton, and Kirschner. The "conglomeratic" sandy mudstone probably was deposited in relatively shallow water adjacent to a land mass that was undergoing erosion by glaciers discharging directly into the sea. Detrital fragments ranging in size from clay to boulders were released by melting of ice floating over the site of sedimentation, and were deposited without sorting on a bottom that was, for the most part, subjected to little wave or current action. The floating ice may have been in the form of discrete bergs, or continuous shelf ice. The presence in the "conglomeratic" sandy mudstone of locally developed stratified and better sorted beds or lenses of siltstone, sandstone, and conglomerate may be explained by assuming (1) the surface of deposition was below the effective limit of ordinary wave or current action, but part of the bottom deposits were subjected to sorting at times by uplift of the bottom, lowering of sea level, or by waves or currents of abnormal intensity, as during storms; (2) the surface of deposition, although relatively shallow, was protected most of the time from wave or current action by the presence of unstable land areas or by floating shelf ice or bergs; (3) streams or other transporting agents contributed sorted sediment sporadically to an environment of type 1 or 2, above, in which "conglomeratic" sandy mudstone was the normal deposit.

The units of rhythmically interbedded sediments are interpreted by Spieker, Walton and Kirschner as representing seasonal cyclic deposition, that is, each claystone-siltstone or siltstone-sandstone pair represents a year. From field study of the rhythmically interbedded sediments and observation of the present environment of Icy Bay, the writer concludes that (1) although some of the rhythmic changes in lithology may represent seasonal cyclic deposition, others represent periods of variable length, some longer and some shorter than a year; (2) it is not possible to determine which, if any, of the rhythmically interbedded pairs are true varves.

Quaternary unconsolidated deposits

The Tertiary rocks of the Yakataga district are overlain with marked angular unconformity by essentially horizontal, unconsolidated deposits of Quaternary age. These are both marine and terrestrial in origin, including alluvial deposits along the streams; morainic, fluvioglacial, and lacustrine deposits near the margins of the glaciers; marine beach and lagoon deposits; and marine glacial moraines.

The marine glacial deposits resemble the "conglomeratic" sandy mudstone units in the Yakataga formation and give a clue to their origin. They are exposed at a number of localities on both the east and west sides of Icy Bay, being especially well developed in a group of low ridges on the coastal plain between Big River and Icy Bay. These ridges are terminal and recessional moraines deposited at the margin of Guyot Glacier, at least partly in the sea, marking the maximum extent of its last advance, and pauses in the retreat which apparently began about the year 1900.

The various types of Quaternary deposits are not differentiated on the map. They are of interest with respect to the petroleum possibilities of the Yakataga district only in that they conceal the potentially petroliferous Tertiary rocks over a considerable area.

Structure of the Tertiary rocks

The Tertiary rocks in the Yakataga district are slightly to intensely folded and are displaced southward along several major northward-dipping high-angle thrust faults. The folds and major thrust faults are the result of uplift combined with compressive forces acting, in general, from the north. Thus, in the central part of the Yakataga district the intensity of folding increases from south to north and the magnitude of displacement along successive thrust faults likewise increases in the same direction, culminating in the Chugach-St. Elias fault which bounds the belt of Tertiary rocks. The regional trend of both the fold axes and the major thrust faults in the Tertiary belt is N. 85°-90° W., at a slight angle to the more northwesterly trend of the Chugach-St. Elias front, but there are many local variations from the regional trend. The most extensive and significant variations are in a zone extending from north to south through the central part of the Yakataga district, between the meridians 142° and 142°40'. At some place within this zone the trend of each of the major thrust faults, as well as the strike of the Tertiary strata in the overthrust fault block, swings in a broad arc to an extreme of N. 10° E., or nearly at a right angle to the regional trend.

The Chugach-St. Elias fault is one of the major structural features of southern Alaska. The arcuate block of pre-Tertiary rocks which form the Chugach and St. Elias Mountains was uplifted and thrust southward against the bordering belt of Tertiary strata along this fault. It has been traced with some certainty for a distance of 170 miles, by ground and aerial reconnaisance and study of aerial photographs, from the Katalla district on the west to Yakutat Bay on the east (index map, fig. 1). The regional geologic and topographic trends suggest that the same fault may continue southwestward beyond the Katalla district, under the delta of the Copper River and the Gulf of Alaska, perhaps as far as Kodiak Island, and southeastward beyond Yakutat Bay under the alluvial plain at the front of the St. Elias Mountains. The trace of the fault at the bedrock surface evidently a zone of weakness due to shattering of the rocks, is largely concealed beneath glaciers from the Katalla district to Yakutat Bay, the fault plane being exposed only where it crosses some of the more rugged spurs.

During the recent investigation, the Chugach-St. Elias fault was examined on the ground at two localities--south of Mount Steller and southwest of Mount Miller. At the latter locality the fault plane is well exposed through a vertical distance of several hundred feet; it dips about 60° N. Aerial photographs of the spurs south of Mount. St. Elias indicate that the dip of the fault plane is much lower there, probably not more than 30°. In the stretch between Mount Miller and Tyndall Glacier the trace of the fault at the bedrock surface may lie farther north than the location shown on the may accompanying this report. Aerial photographs of the spurs and nunatak mountains at the northern margin of Guyot Glacier between Tyndall Glacier and meridian 141°50' show a sequence of dark rocks resembling those of the pre-Tertiary argillite-slate-graywacke sequence, interbedded with light-colored rocks--probably arkosic sandstone--resembling the strata in the lower Tertiary sequence. The location of the Chugach-St. Elias fault in this stretch cannot be determined with certainty from the aerial photographs.

The amount of displacement along the Chugach-St. Elias fault in the Yakataga district cannot be determined because the stratigraphic interval separating the strata that are placed in contact by the fault--the pre-Tertiary argillite-slate-graywacke sequence and the lower Tertiary sequence--is not known. The net displacement is presumed to be at least 10,000 feet, and may be much larger.

Most, if not all, of the major faults within the belt of Tertiary rocks are high-angle thrust faults like the Chugach-St. Elias fault, but are of smaller magnitude in both longitudinal extent and total displacement. They are believed to have formed at a late stage in the orogeny, when blocks of the relatively rigid basement rocks, unable to yield furhter by folding, broke along lines of weakness and, together with the overlying Tertiary sediments, were displaced upward and southward. Seven major thrust faults are recognized in the Tertiary belt south of the Chugach-St. Elias fault in the central part of the Yakataga district. (See structure sections C-C' and E-E', fig. 1.)

The faults in the Tertiary rocks for the most part trend parallel to the strike of the rocks on each side and characteristically are sharp breaks, with little disturbance of the adjacent beds. Consequently, the faults are difficult to recognize unless they place in contact rocks of contrasting lithology. Furthermore, little of the belt of exposed Tertiary rocks was mapped in detail, and much of it has not been covered on the ground at all. It is possible, therefore, that some major faults have been overlooked. Numerous minor faults, both thrust faults and normal faults, were noted during the field work or are visible on aerial photographs, but are not shown on the map.

In the part of the Yakataga district mapped in 1944, Spieker, Walton and Kirschner recognized two rather distinct structural belts separated by the Yakataga fault-- a southern belt characterized by narrow, tightly pinched anticlines and broad synclines, and a northern belt characterized by smaller, more closely spaced folds. The more recent work has indicated that the two-fold division may appropriately be extended to the parts of the Yakataga district adjacent to the area mapped by Spieker, Walton and Kirschner. The two structural belts are separated by the Hope Creek fault west of the area mapped in 1944, and by a fault tentatively identified with the Yakataga fault east of the area. The surface rocks in the southern structural belt are mainly of the Yakataga formation. Outcrops of the Poul Creek formation are restricted to narrow belts along the axes of the anticlines, and beds of pre-Poul Creek age, if exposed at all in the southern structural belt, are extremely limited in outcrop. In the northern structural belt, on the other hand, the surface rocks are mainly of the lower Tertiary sequence. Outcrops of the Poul Creek formation are limited to narrow belts in synclinal areas, and the Yakataga formation is not known to be represented at all in the northern belt.

The two-fold division has an economic as well as a geologic significance with respect to oil possibilities in the Yakataga district. The likelihood of finding significant accumulations of oil are believed to be much more promising in the southern structural belt, not only for fundamental geologic reasons, but also because this belt, as a whole, is much more easily accessible than the northern belt. In the description following, therefore, more attention is given to the southern belt, particularly to the folded structure therein.

Northern structural belt

The unnamed glacier north of the head of Kulthieth River evidently conceals a major fault, as shown in structure section C-C' (fig. 1). The presence of a fault is indicated by the divergent trend and difference in age of the rocks exposed north and south of the glacier. The stratigraphic displacement is probably not less than 10,000 feet. The exposed part of the overthrust block was examined briefly in the area adjacent to the Chugach-St. Elias fault southwest of Mount Miller, where the exposed rocks are mainly anthracite-bearing beds of unit A of the lower Tertiary sequence. The lower part of unit B may also be represented here. The strata are tightly and complexly folded; many of the faults are overturned.

The fault at the head of Kulthieth River near the southern margin of Bering Glacier is a strike fault, paralleling the trend of the strata in both the hanging-wall and foot-wall blocks. It trends nearly east along the base of a south-facing scarp from the southeastern margin of Bering Glacier to a point near the head of one of the forks of Kulthieth River, where it turns northeastward under the glacier, probably intersecting the fault described above. The fault plane dips about 70°. N. and the fault has a stratigraphic displacement of about 1,500 feet near its northeast end. The displacement increases to the west, being not less than 2,500 feet at the southeastern margin of Bering Glacier. The hanging-wall block exposes a section ranging from unit B of the lower Tertiary sequence well up into the Poul Creek formation. As shown in structure section C-C' (fig. 1), the exposed part of the hanging-wall block is essentially a northward-dipping homocline with minor anticlinal folds.

The Kosakuts fault, so named because it is well exposed in the headwaters of the Kosakuts River, has been traced on the ground with some certainty from a nunatak near the margin of Bering Glacier eastward to the Kosakuts River-Kulthieth River divide, and what is probably the same fault was recognized on three tributaries of Kulthieth River and near the head of Duktoth River. The belief that the fault extends up the eastward-trending part of the Duktoth River valley is based on the discordant trend and stratigraphy on opposite sides of the valley. It may also extend northwestward under Bering Glacier to the spur between Bering and Steller Glaciers, where aerial photographs and distant views indicate that predominantly sandy beds of the lower Tertiary sequence are in fault contact with a predominantly silty sequence tentatively identified as the Poul Creek formation. The fault plane was observed at three localities. At the margin of Bering Glacier northwest of the Kosakuts River the dip is about 40° N., but 2 miles farther east it is 80° N. On one of the northeast tributaries of Kulthieth River the fault plane dips about 70° N. Because of the variable dip of the fault plane and the complex folding of the adjacent strata, the stratigraphic displacement is not an accurate measure of the movement along the fault plane, but the net slip is probably several thousand feet.

The rocks exposed in the hanging-wall block of the Kosakuts fault between Bering Glacier and Duktoth River are almost entirely of the lower Tertiary sequence, including the lowest Tertiary beds known to be exposed in the Yakataga district. (See columnar section 2, fig. 2.) The lower part of the Poul Creek formation is preserved in a few small areas in synclinal structures or high on ridges or peaks. Judging from the aerial photographs, only rocks of the lower sandstone sequence are exposed in the parts of the hanging-wall block lying east of Duktoth River and adjacent to Steller Glacier. The folds in the overthrust block are extremely variable in both trend of fold axes and degree of compression, but in general are of moderate amplitude, rather tightly compressed, and are either asymmetrical, with the steeper limb of the anticlines on the south, or are overturned to the south.

The Hope Creek fault was first tentatively recognized and named in the area at the head of Hope Creek by oil company geologists 47/.

47/ Unpublished report by a geological party representing the Standard Oil Company of California, the Tidewater Associated Oil Company, and the Union Oil Company of California, 1938.

It separates the northern and southern structural belts between Duktoth River and the eastern margin of Bering Glacier. Between Kulthieth River and Duktoth River the stratigraphic and topographic evidence for the fault is prominent. The trace of the fault lies near the base of a southward-facing scarp formed by beds of the lower part of the lower Tertiary sequence, in contact on the south with beds of the upper part of the Yakataga formation. Fairly accurate locations of the fault trace on the ridge northwest of Hope Creek and in adjacent valleys on either side indicate that the fault plane there dips about 80° N. The stratigraphic displacement is approximately 21,000 feet, and the net slip is probably still larger. West of Kulthieth River, the fault passes through a topographic sag that separates a low hill on the south, consisting of beds of the Yakataga formation, from the steep ridge on the north formed of sandstone beds of the lower Tertiary sequence. Still farther west the trace of the fault is concealed beneath the alluvium of the upper Kaliakh River valley, but its presence is indicated by the fact that northward-dipping sandstone beds well down in the lower Tertiary sequence are exposed in the spurs just north of the Kaliakh River, whereas northward-dipping beds of the Yakataga formation are exposed in the isolated hill south of the Kaliakh River. In the vicinity of Duktoth River, the fault may extend up the valley of Duktoth River, or northeastward into the ridge between Duktoth River and the tributary heading near Mount Leeper, or up the tributary valley toward Mount Leeper as suggested on figure 1. The interpretation shown on figure 1 is favored by the apparent discordance in trend of strata exposed in the ridge between Duktoth River and tributary valley and in the isolated hill in the valley floor. In any case, there is a gap of several miles between the Hope Creek fault and the Yakataga fault, in which the boundary between the northern and southern structural belts must be drawn more or less arbitrarily.

The section exposed in the hanging-wall block of the Hope Creek fault extends from the upper part of unit A or the lower part of unit B of the lower Tertiary sequence well up into the Poul Creek formation. The character of the folding in the western part of the block is well illustrated in the structure sections A-A' and B-B' (fig. 1). The folds were studied and mapped in greater detail here than elsewhere in the northern structural belt west of Duktoth River, because the area is adjacent to a base camp from which investigations were carried out during one season and because the folds expose a distinctive contact--that between the lower Tertiary sequence and the Poul Creek formation--which is easily recognized and traced. In this area the folds are typically of moderate amplitude, moderately compressed, and slightly asymmetrical, the steeper limb of the anticlines being on the south. Farther east, in the vicinity of Duktoth River, the folds are more tightly compressed and some probably are overturned. Aerial photographs and distant views indicate that the Poul Creek formation is exposed in the southern part of the ridge between Steller Glacier and Bering Glacier, but give no clue as to the structure of the beds.

In the area between Watson Glacier and the head of Yakataga Glacier, Spieker, Walton, and Kirschner recognized a major thrust fault that places complexly folded strata assigned to the lower sandstone sequence (part of the lower Tertiary sequence of this report) on the north in contact with the upper sandstone sequence (upper part of the lower Tertiary sequence of this report) and the Poul Creek formation on the south. The fault plane and the zone of complexly disturbed beds adjacent to it are well exposed in the west valley wall near the head of Yakataga Glacier. At this locality the fault plane dips about 40° N. Study of aerial photographs by the writer indicates that the fault dies out a few miles west of Watson Glacier, and intersects the Yakataga fault to the east under Yakataga Glacier or one of its eastern tributaries. The hanging-wall block of the fault described above has been examined on the ground only near the head of Yakataga Glacier and near the head of Watson Glacier, by Spieker, Walton, and Kirschner. At both localities the strata exposed are predominantly sandstone, representing some part of the lower Tertiary sequence. Aerial photographs indicate that the beds farther north are mainly of the lower Tertiary sequence, but suggest that the lower part of the Poul Creek formation also is present. According to Spieker, Walton, and Kirschner, five small tight folds were noted in the hanging-wall block between the fault and the headwall of Yakataga Glacier. Aerial photographs show a tight anticline and syncline between Mount Leeper and the headwall of Yakataga Glacier, and also suggest the probable presence of a fault passing through the saddle south of Mount Leeper.

The Yakataga fault was named by Spieker, Walton, and Kirschner and was mapped by them in the area between Boulder Creek and the foot of Yakataga Glacier. One minor change in the location of the fault has been made, and other changes in the interpretation of the structure in this area are suggested as a result of the writer's field examination near the mouth of Boulder Creek and also along the north channel of the Yakataga River between Porcupine Creek and the foot of Yakataga Glacier. As the strata on the west side of Boulder Creek are entirely of the Poul Creek formation, the fault is shown as swinging sharply southward along Boulder Creek. In 1948 the writer examined the fault exposed at the source of the north channel of the Yakataga River and collected some fossils in the hanging-wall block of the fault, from beds assigned to the upper sandstone sequence by Spieker, Walton and Kirschner. The collection includes some species that are common in the Yakataga formation and the upper part of the Poul Creek formation, but that have not been found in the lower part of the Poul Creek formation or older beds. This suggests either that the hanging-wall block of the Yakataga fault includes beds of Poul Creek age (a possibility recognized by Spieker, Walton, and Kirschner), or that the fault exposed at the head of the north channel of the Yakataga River is a separate fault of lesser magnitude or a branch of the Yakataga fault, which lies farther north. The topography of the ridge between Porcupine Creek and the foot of Yakataga Glacier suggests the presence of a major fault north of the Yakataga fault as mapped by Spieker, Walton, and Kirschner. Additional field work in this area is needed to settle the question.

In their discussion of the probable location of the Yakataga fault east of the foot of Yakataga Glacier, Spieker, Walton, and Kirschner noted the lack of evidence of major faulting in the eastern wall of Yakataga Glacier near Eberly and Yaga Glaciers, and suggested that the fault either dies out in a northward-swinging arc under Yakataga Glacier, or is concealed underneath the thrust-fault block at the head of Yakataga Glacier. On figure 1 the writer shows the fault extending up the Yakataga Glacier, swinging eastward in a broad arc under Guyot Glacier, and appearing again from beneath the ice in the ridges on either side of Tyndall Glacier. Projecting the fault under ice for such a long distance and identifying it with the fault observed east of Tyndall Glacier is Hazardous, but, as thus interpreted, the Yakataga fault throughout its length separates belts of contrasting stratigraphy and structural pattern.

The sinuous trace of the Yakataga fault is paralleled to some extent by a similar swing in the strike of fold axes or of homoclinal structures in the hanging-wall block of the fault. This may be due in part to changes in the dip of the fault plane, the southward-extending salients occurring where the dip of the fault plane is lowest and the horizontal component of the total displacement is correspondingly greatest. The close relationship between the strike of the fault plane and the strike of the beds in the adjacent part of the hanging-wall block is well illustrated in the vicinity of Boulder Creek. The available observations on the dip of the Yakataga fault, although not adequate to prove the relationship suggested above, apparently do support it. The dip is 40° N. at the foot of Yakataga Glacier (assuming the fault exposed here is the Yakataga fault) and about 35° N. on the ridge east of Tyndall Glacier. The fault plane was observed from a distance at the head of Miller Creek, and, although the dip could not be determined accurately, it appeared to be steeper there than farther east at Yakataga Glacier, according to Spieker, Walton, and Kirschner.

The strata exposed in the hanging-wall block of the Yakataga fault between Boulder Creek and Yakataga Glacier consist mainly of the upper part of the lower Tertiary sequence, with small areas of the lower part of the Poul Creek formation. As shown in the structure sections E-E' and F-F' (fig. 1), the folds are closely spaced, fairly open, and have the total effect of an asymmetrical anticlinorium. West of Boulder Creek the folds die out and the structure becomes a simple northwest-dipping homocline which exposes the entire thickness of the Poul Creek formation and the lower part of the Yakataga formation. The hanging-wall block of the Yakataga fault east of Guyot Glacier was examined on the ground only where the fault crosses the ridge east of Tyndall Glacier. From the ground observations and study of aerial photographs the structure appears to be a northward-dipping homocline which exposes beds of the lower Tertiary sequence.

Southern structural belt

The southern structural belt, including the part of the Yakataga district lying south of the Hope Creek fault and the Yakataga fault, ranges in width from a minimum of about 5 miles near longitude 142°15' to a maximum of about 20 miles near longitude 141°40'. The northern boundary of the belt is sharply defined except in the vicinity of Duktoth River, where the Hope Creek and Yakataga faults overlap but do not intersect. The strata exposed in the southern structural belt are mainly of the Yakataga formation. The Poul Creek formation is exposed in narrow belts along the axes of the larger upfolds, and the lower Tertiary sequence may be exposed at one locality near the coast. The southern structural belt presumably continues eastward under Malaspina Glacier and westward under Bering Glacier and the adjacent coastal plain, beyond the area in which bedrock is exposed.

The exposed part of the southern structural belt west of the Duktoth River is essentially a northward-dipping homocline in which the dip of the beds increases gradually northward toward the Hope Creek fault. Near the Duktoth River the generally simple character of the structure is complicated by a high-angle thrust fault that is estimated to have a total displacement of several hundred feet, and by small folds. Aerial photographs suggest the presence of a flat syncline adjacent to the Hope Creek fault in the vicinity of the structure section C-C' (fig. 1), but no reversal of dip was noted on the ground a short distance to the west. In the upper part of the first valley west of the Hope Creek basin a zone of sheared and steeply dipping beds, possibly locally overturned, may indicate more complex folding or faulting. The possibility that beds of Poul Creek age are exposed here and farther east near the Duktoth River is discussed on page 25.

The homoclinal structure west of the Duktoth River may represent the south limb of a broad syncline (and north limb of an anticline) of the type illustrated by the White River syncline farther east. Comparison of the profile of the homocline, as shown in structure section C-C' (fig. 1), with the profile of the synclines of the southern structural belt shown in structure sections E-E', F-F', and G-G' brings out one difference that may be significant: The beds in the homocline in the vicinity of Kulthieth Mountain are convex upward whereas the beds in the typical synclines of the southern structural belt farther east are convex downward. This may indicate that a broader and less tightly compressed anticline is present under the coastal plain sediments south of Kulthieth Mountain and the isolated hill near the head of Tsivat River. Because of the interruption of the regional structural trend by the southerly swing of the Yakataga fault at Boulder Creek, the structures exposed in the coastal mountains east of Duktoth River are of little help in predicting the structure under the coastal plain farther west.

The principal structures in the part of the southern structural belt bounded by Duktoth River on the west and by Guyot Glacier and Icy Bay on the east are the coastal upfold and associated Sullivan fault, the White River-Clear Creek syncline, the Yakataga anticline, and the Inner Yakataga syncline (fig. 1). The regional strike of the structures is N. 70°-90° W. except in the vicinity of Yakataga Reef, where the strata swing southward in a sharp arc. The structural pattern in this part of the southern structural belt has been compared by Spieker, Walton, and Kirschner to that of the Jura Mountains, where an upper sheet of sedimentary rocks was sheared from a more rigid basement and folded independently of it. They concluded, from this comparison, that sharply compressed anticlines like the Yakataga anticline would open out donward, and at levels 5,000 to 10,000 feet beneath the surface should have flank dips of considerably less than 45°.

Interest in the petroleum possibilities in the Yakataga district has centered mainly in the coastal belt between Cape Yakataga and Icy Bay since initial discovery of oil seepages. This is because pradtically all of the known seepages are in this belt, the structure of the belt appears to be anticlinal and therefore is presumably favorable for trapping oil, and the belt is the most accessible part of the Yakataga district.

The structure of the coastal belt between Cape Yakataga and Icy Bay has been interpreted by most geologists as a single, tightly compressed, faulted anticline 48/, called the Sullivan anticline in recent years.

48/ Maddren, A. G., Mineral deposits of the Yakataga district, Alaska: U. S. Geol. Survey Bull. 592, p. 132, 1914. Taliaferro, N. L., Geology of the Yakataga, Katalla, and Nichawak districts, Alaska: Geol. Soc. America Bull., vol. 43, p. 762, 1932. Spieker, E. M., Walton, M. S., Jr., and Kirschner, C. E., op. cit. (Mss.).

Interpretations of the structure have differed considerably in details, for example: the location of the axis of the anticline, the significance of the divergent trend of the strata exposed in Yakataga Reef, the identity of the beds in the zone of steep or vertical dips adjacent to the coast, and the magnitude of faulting. At least one group of geologists, although recognizing minor anticlinal folding in the vicinity of Johnston Creek, considered the major structure from the axis of the White River syncline southward to the coast to be a homocline.

The 1947-1948 field work indicates that the structure of the coastal belt is a longitudinally faulted asymmetrical complex upfold. The divergent trend of the strata exposed in the vicinity of Yakataga Reef is interpreted as reflecting a similar change in the trend of a major fault, called the Sullivan fault in this report. Many details of the structure have not been solved, and much information can be obtained by more detailed mapping, especially in the zone of vertical or nearly vertical beds.

The Sullivan fault has been traced with fair assurance from Acme Creek east to Poul Creek. Evidence for the fault is largely stratigraphic and topographic in this interval. The beds along the fault are much shattered, the zone of weakness being marked by the development of subsequent streams and by topographic saddles where the zone crosses ridges between the subsequent streams. Good exposures of the fault are scarce. From Acme Creek east to the vicinity of Poul Creek the fault places generally northward-dipping beds of the Poul Creek formation on the north in contact with vertical or nearly vertical beds of the Yakataga formation on the south. On Poul Creek and farther east a thin sliver of the upper part of the Poul Creek formation is exposed south of the fault. Approximate locations of the trace of the fault on Poul Creek, on Lawrence Creek, and on the intervening ridge, as well as on Oil Creek, on Hamilton Creek, and on the intervening ridge, indicate the fault plane dips about 80° N. in the Poul Creek-Lawrence Creek area and about 60° N. in the Oil Creek-Hamilton Creek area.

The location of the Sullivan fault west of Acme Creek and east of Poul Creek is less certain. The southerly swing of the trace of the fault plane near the mouth of Twomile Greek, and the flattening of the dip of the fault plane, as shown on the map and structure section D-D' (fig.1), is suggested by the swing of the strata exposed in the western end of Brower Ridge and on Yakataga Reef. The situation here may be comparable to the arcuate swing of the Yakataga fault and the strata in the hanging-wall block in the vicinity of Boulder Creek (see page 33).

Several alternate interpretations of the location of the Sullivan fault east of Poul Creek are possible with the data at hand. Each interpretation is supported or suggested by one or more features of the topography, the structural trends, or the stratigraphy. The interpretation shown on the map (fig. 1) is believed to fit best the data at hand, but it is by no means certain that it is the correct one. More field work is needed in the area of complex structure between Poul Creek and Little River. In this area two faults, either of which might be interpreted as the eastward continuation of the Sullivan fault, have been observed. Near the head of Johnston Creek, in the west wall of the valley, sandstone and siltstone beds dipping gently northward are thrust over similar strata dipping steeply southward. The fault plane dips 25° N. The displacement along the fault is probably small, for the beds on both sides of the fault belong either in the lower part of the Poul Creek formation or the upper part of the lower Tertiary sequence. Furthermore, no evidence of displacement was found a few hundred feet to the east, on the opposite side of the valley of Johnston Creek. On the Little River, about half a mile south of the main forks, sandstone and siltstone beds of the Poul Creek formation, dipping southward at a low angle, are thrust over complexly folded and sheared dark siltstone and sandstone. The fault plane dips 20° N. The beds beneath the fault resemble parts of both the Poul Creek and Yakataga formations, but have no diagnostic features that permit definite correlation with either formation. Regional geologic and topographic trends suggest that the fault exposed here is the Sullivan fault, and that the disturbed strata to the south belong in the upper part of the Poul Creek formation.

The uniform northward dip of the beds that are so strikingly exposed in the southward-facing scarp from Cape Yakataga to Icy Bay, coupled with the presence of a zone of vertical or nearly vertical beds along the coast, gives the impression of a single large asymmetrical anticline. The complex character of the upfold is evident on more detailed study, however. In the stretch between Poul Creek and Icy Bay at least three anticlines which have the total effect of an anticlinorium have been recognized. Each of the anticlines is cut off by the Sullivan fault to the west and either dies out or passes into a fault to the east.

The northenmost anticline in this group is well exposed in the west valley wall of Johnston Creek, near the foot of the glacier, and on the divide between Johnston and Munday Creeks. Opposing dips on Munday Creek indicate the fold is present there, although the axial area is not exposed. The zone of vertical or southward-dipping beds just north of the Sullivan fault on Poul Creek may indicate the approximate location of the intersection of the fault and fold axis at the surface there. The anticline dies out abruptly, or else passes into a fault, east of Johnston Creek. The fold is asymmetrical, like most of the other anticlinal folds of the southern belt, but is not so tightly compressed.

The presence of an anticline that crosses Johnston Creek just north of the trace of the Sullivan fault is indicated by the zone of steeply-dipping sandstone beds (representing either the lower part of the Poul Creek formation or the upper part of the lower Tertiary sequence,) on Johnston Creek and farther west, and more clearly, by reversal of dip along the same trend on the ridge east of Johnston Creek. The fold axis evidently intersects the Sullivan fault somewhere between Johnston and Munday Creeks. It may either die out or pass into a fault to the east between Johnston Creek and the west fork of the Little River, or it may cross the west fork in an interval where no outcrops were observed (structure section H-H', fig. 1). The anticline is not present on the east fork of the Little River.

The southernmost anticline is clearly shown by reversal of dip near the mouth of the Little River and on a small stream $1\frac{1}{2}$ miles farther east. This anticline probably is cut off by the Sullivan fault a short distance west of the Little River. A zone of disturbed beds and discordant attitudes near the mouth of the canyon of Crystal Creek, and a reversal of dip at the mouth of the canyon of the Priest River may indicate the eastward continuation of the same anticline. If so, the anticline plunges to the east at a low angle east of the Little River. Inasmuch as only a short stretch of the south flank of the southernmost anticline is exposed, it is not possible to determine whether it represents only a minor reversal or the south flank of the anticlinorium.

From Poul Creek westward only northward-dipping strata, none of which are overturned, are exposed north of the Sullivan fault, indicating that the axis of the upfold lies beneath the plane of the Sullivan fault (structure sections D-D' and E-E', fig. 1). It is difficult to reconcile the apparently nearly vertical dip of the Sullivan fault in the vicinity of Lawrence Creek and Poul Creek with the considerable stratigraphic displacement that has taken place along it. Either the net slip along the fault is considerably larger than the stratigraphic displacement, amounting to at least several thousand feet, or the fold axis, or the fault plane, or both, flatten at depth.

The complexity of the coastal upfold is also indicated by the numerous reversals of dip in the zone of steeply-dipping strata south of the Sullivan fault. These may indicate the presence of tightly compressed, nearly isoclinal folds, which have not been recognized because of the lack of distinctive key beds and of mapping sufficiently detailed to permit recognition of duplication of beds by other means.

The White River-Clear Creek syncline, one of the largest and most persistent folds in the Yakataga district, was named by Spieker, Walton, and Kirschner from excellent exposures of the structure in the vicinity of White River Glacier and Clear Creek. The fold probably extends westward under the alluvial fill of the Yakataga River valley. Aerial photographs show southward-dipping or horizontal beds in the nunataks in Guyot Glacier as far east as the Karr Hills, indicating that the fold extends eastward under the Guyot Glacier, merging gradually into the northward-dipping homocline of the Chaix Hills. The syncline is broad and flat-bottomed. Its width (distance between the crests of the adjacent anticlines) ranges from about 4 miles near the foot of Yakataga Glacier (structure section E-E', fig. 1) to more than 10 miles near Icy Bay (structure section I-I', fig. 1). The syncline is slightly asymmetrical, the north flank being the steeper.

The upfold lying between Yakataga Ridge and the Yakataga and Eberly Glaciers was named the Yakataga anticline by Spieker, Walton, and Kirschner. The following description, applying particularly to the stretch between Yakataga Glacier and meridian 142°05', is abstracted from their manuscript report:

> The Yakataga anticline is a closely folded, asymmetrical structure, the south flank being the steeper. The axial plane undoubtedly dips steeply northward but its position cannot be accurately determined because of a thrust fault parallel to the axis. This fault is in some respects a puzzling feature. In the mouth of the gorge at the west end of Yakataga Ridge, where north-dipping siltstone and shale of the Poul Creek formation is directly juxtaposed to south-dipping sandstone of the Yakataga formation, the fault plane either is not exposed or was not recognized in the disturbed beds near the axis of the fold. About 3½ miles farther east, however, the fault is exposed, and here it dips 50° to 60° southward. If this condition holds farther west the minimum dip-slip possible on this fault at the western exposure is about 6,000 feet, and structural projection of stratigraphic horizons from the south suggests a dip-slip of 7,000 feet or more. At the eastern exposure the dip-slip apparently is 1,000 feet or more.

The fault described above, if it is correctly interpreted, presents the reverse of the usual situation found in the Yakataga district, where the major faults dip northward and the north side (hanging-wall side) has moved up relative to the south side. The writer suggests that the southward-dipping fault observed at one locality by Spieker, Walton, and Kirschner may be a minor fault, or a small segment of a curved but generally northward-dipping major fault. The situation described at the west end of Yakataga Ridge, where northward-dipping Poul Creek beds are faulted against southward-dipping beds of the Yakataga formation, is similar to that found at many places along the Sullivan fault, which is known to be a northward-dipping thrust fault.

Excellent aerial photographs giving a relatively close but comprehensive view of the Yakataga anticline just east of the stretch described above seem to show beds arching over the crest of the anticline with little or no faulting.

The Yakataga anticline may die out eastward under Guyot Glacier, or it may be represented by the sharp upfold near the southern end of the Guyot Hills (fig. 1). It was assumed by Spieker, Walton, and Kirschner to continue westward under the alluvium of Yakataga Valley, the axis curving slightly southward beyond the last exposures near the west end of Yakataga Ridge. On figure 1 the writer suggests an alternate interpretation, that is, that the anticlines near the mouth of Porcupine Creek and near the head of Miller Creek, mapped as separate folds by Spieker, Walton, and Kirschner, actually represent the northwestward continuation of the Yakataga anticline. This interpretation is supported by the predominantly northwest regional strike of the beds in the west end of Yakataga Ridge and in the lower Porcupine Creek-Miller Creek area, by the general similarity of the outline of anticlines on Miller and Porcupine Creeks and the Yakataga anticline farther east, and by the presence of reddish-brown-weathering beds of the Poul Creek type at the point where the axis of the anticline is assumed to cross the north channel of the Yakataga River. The anticline at the head of Miller Creek, here tentatively identified with the Yakataga anticline, was described by Spieker, Walton, and Kirschner as a relatively large, asymmetrical anticline with much minor disturbance along its crest, comparable in outline to the Yakataga anticline farther southeast.

In the headland between Yaga and Eberly Glaciers Spieker, Walton, and Kirschner mapped a broad, eastward-plunging syncline which they named the Inner Yakataga syncline. At the eastern margin of Yakataga Glacier the width of the syncline, measured between the crests of the Yakataga anticline and a minor anticline not shown on the map, is about 6 miles. The axis plunges to the east at an angle of 10° to 15°. To the west the syncline is concealed underneath the Yakataga Glacier and the overthrust block of the Yakataga fault. Its easterly extent under Guyot Glacier is not known.

Aerial photographs show a series of anticlines and synclines in the Guyot Hills. Two of the anticlines and the intervening syncline appear to continue eastward into the Karr Hills. As shown in structure section I-I' (fig. 1), the folds are of moderate amplitude and are asymmetrical, the south flank of the anticlines being the steeper. The southernmost anticline exposed in the Guyot Hills is tightly compressed and is similar in outline to the Yakataga anticline. The photographs show what appears to be a silty sequence in the core of this fold, suggesting that it may bring to the surface the upper part of the Poul Creek formation.

The beds of the Yakataga formation exposed in the Chaix Hills form a northward-dipping homocline. The similarity in the profile of the exposed part of this homocline (structure section J-J', fig. 1) to the south flank of the White River-Clear Creek syncline farther west suggests the presence of a sharp upfold to the south, underneath Maspina Glacier.

OIL POSSIBILITIES

History of exploration

Some of the oil seepages along the coast in the Yakataga district are reported to have been discovered in 1896. By 1897 a continuous tract extending about 20 miles along the coast and including all the known seepages was located and surveyed 49/. Since 1897 there have been sporadic bursts of

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49/ Martin, G. C., Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, pp. 34,39-40, 1921.

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interest during which land rights have been acquired for the purpose of prospecting for oil, at first under the placer law and later under the oil and gas leasing law. In July 1950, applications were on file for oil and gas leases covering a tract that extends along the coast for about 55 miles from the vicinity of Cape Yakataga east to the boundary of the district, and from 6 to 12 miles inland.

Up to July 1950 only one well had been drilled in search for oil in the Yakataga district. During the years 1926-1927 the General Petroleum Corporation of California drilled the Sullivan No. 1 well, located near the large oil seepage on Johnston Creek (fig. 1), to a total depth of 2,005 feet 50/. Small showings of gas were encountered between the surface and a

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50/ Smith, P. S., Mineral industry of Alaska in 1927: U. S. Geol. Survey Bull. 810, pp. 59-60, 1929.

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depth of 232 feet, and also at a depth of 1,643 feet, but no oil was reported. Although a geologist was employed by the company to select a location for drilling, it is reported that the well was not drilled at the site he selected on geologic grounds. As the structure and stratigraphy are interpreted in this report, the Sullivan well was started in steeply dipping beds of the upper part of Poul Creek formation, on the south limb of the coastal upfold and not far south of the trace of the Sullivan fault. The beds penetrated by the well were reported to be dominantly hard sandstone and sandy shale. In 1947 the open casing of the well was flowing salt water and enough gas to maintain a steady flame above an opening 2 inches in diameter.

Presence, source, and character of the oil

Nearly all the known oil seepages in the Yakataga district are in a belt extending 18 miles along the coast and as much as 2 miles inland, between Cape Yakataga and Johnston Creek (fig. 1). About 25 separate oil seepages were noted in this belt during the 1947-1948 field investigations. More careful search probably would disclose still others. Many of the oil seepages in the coastal belt were described by Maddren 51/ or shown on Maddren's map of the Yakataga district 52/. It is likely that most, if not all, of the seepages shown on figure 1 have been observed at one time or another by prospectors or geologists.

51/ Maddren, A. G., Mineral deposits of the Yakataga district, Alaska: U. S. Geol. Survey Bull. 592, pp. 143-145, 1914.

52/ Martin, G. C., op. cit. (1921), pl. 6.

More than half of the known oil seepages in the coastal belt are located on or very near the trace of the Sullivan fault. The seepages south of the Sullivan fault on lower Poul Creek and on the ridge between Poul Creek and Lawrence Creek are located on or near minor faults or shear zones in the rocks of the Yakataga formation. The seepages north of the Sullivan fault between the White River and the western end of Brower Ridge are located on outcrops of apparently unfaulted but permeable sandstone beds in the upper part of the Poul Creek formation and at the base of the Yakataga formation. A group of small seepages on Munday Creek and one small seepage on Johnston Creek, all north of the Sullivan fault as shown on figure 1, are on outcrops of sandstone beds that may be at or near the top of the lower Tertiary sequence, but more likely are in the basal part of the Poul Creek formation. (See pages 18-19.) At the large seepage near the well on Johnston Creek oil accumulates on small pools of water on an alluvial terrace that forms the west bank of the creek, some distance south of the probable location of the Sullivan fault and in an area underlain by the Poul Creek formation. The oil may issue from the bedrock some distance north of the place where it accumulates, for it is being carried to the pools by small streams that drain from the ridge to the north and northwest. The oil may issue along the Sullivan fault or a minor fault that branches from it.

Indications of oil either were observed during the recent investigations, or have been reliably reported at several localities in the Yakataga district outside of the coastal belt. Spieker, Walton, and Kirschner noted a small seepage in fault gouge on the westernmost tributary of Clear Creek draining from the north side of Brower Ridge (fig. 1), and also noted a strong odor of oil on the next stream west of the above locality, and on Miller Creek. The bedrock at each locality is the Yakataga formation. R. B. Johnson and the writer noted a strong odor of oil at several localities near the head of the unnamed stream entering the Kaliakh River from the north near Sunshine Point. The odor seemed to be associated with one or more beds of gray siltstone and fine-grained sandstone in the Yakataga formation, although the beds in the general vicinity are also much faulted and sheared.

Some fresh specimens of the sandstone and siltstone, when crushed and thrown in a still pool of water, left an oily film on the surface. However, a specimen of the siltstone analyzed in the laboratory of the U. S. Geological Survey was found to contain appreciable organic material but no petroleum or kerogen 53/. According to R. B. Watson 54/, who has long been

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53/ Analysis by W. W. Brannock. Kerogen is the solid bituminous material found in oil shales, 1949.

54/ Watson, R. B., personal communication, Aug. 17, 1947.

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a resident of the Yakataga district and is familiar with the characteristics of oil seepages in the district, an oil seepage could be seen at one time north of the north channel of the Yakataga River, between Porcupine Creek and the foot of Yakataga Glacier. Mr. Watson reported that he could not find the seepage at the time of his last visit to the locality, and the writer was not able to find it in 1948. The location reported for the seepage is at or near the crest of an anticline, tentatively identified as the Yakataga anticline in this report, at the outcrop of beds that are believed by the writer to be either the upper part of the Poul Creek formation or the lower part of the Yakataga formation.

Oil seepages have been reported in at least three other localities in the Yakataga district, but none of the occurrences has been confirmed. A sketch map in the files of the Geological Survey, made by prospectors, shows a seepage on the unnamed stream that enters Duktoth River from the east about 3 miles northwest of Duktoth Mountain. Seepages have also been reported near the mouth of Yahtse River 55/, and on several streams that drain into

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55/ Maddren, A. G., Mineral deposits of the Yakataga district, Alaska: U.S. Geol. Survey Bull. 592, p. 114, 1914.

Icy Bay from the margin of Tyndall Glacier 56/. The writer visited the Duktoth

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56/ Miller, M. M., personal communication, 1947.

River locality and one of the streams in the Icy Bay locality during the 1947 season. At both localities a black scum was observed floating on the surface of the muddy glacial streams, especially in eddies or quiet pools. The scum resembles oil in the way it clings together on the surface of the water, but it lacks the green color and odor that are characteristic of the oil in typical seepages in the Yakataga district. A black scum of similar appearance was observed by the writer on streams draining from Bering Glacier and in pools on the surface of the glacier. It is believed to be finely divided organic material, possibly derived by glacial erosion of coal beds or of fine-grained sediments that contain considerable organic material, such as the siltstone of the Poul Creek formation.

The distribution of the known seepages in the Yakataga district, with respect to stratigraphic and structural features, suggests that the petroliferous rocks giving rise to the oil are located in the Poul Creek formation and possibly in the lower part of the Yakataga formation. The evidence for this conclusion may be summarized as follows: (1) About 70 percent of the known seepages in the Yakataga district are located either on outcrops of the Poul Creek formation or on faults along which the Poul Creek formation forms either the hanging-wall or footwall. (2) Most, if not all, of the remaining known seepages in the Yakataga district are located on outcrops of the lower part of the Yakataga formation--some on apparently unfaulted but permeable beds at or near the base of the formation, and others on faults or fracture zones along which the oil could have risen from a source in the lower part of the Yakataga formation, in the Poul Creek formation, or even in pre-Poul Creek beds. (3) No seepages or other indications of oil have been observed in the Yakataga district on outcrops of beds known definitely to be pre-Poul in age, nor on outcrops of beds more than 5,000 or 6,000 feet above the base of the Yakataga formation.

Descriptions of typical oil seepages in the Yakataga district and some information on the character of the oil are given by Maddren 57/. The oil is

57/ Maddren, A. G., op. cit., pp. 143-147.

light green in color, and is similar in appearance to the oil from seepages in the Katalla district. The volume of oil issuing at most of the seepages in the Yakataga district is small, but the flow at the large seepage on Johnston Creek, according to Maddren 58/, may be at the rate of as much as

58/ Idem, p. 144.

a barrel a day. An analysis of a sample of oil collected from the large seepage on Johnston Creek by Spieker, Walton, and Kirschner follows:

Oil sample from seepage on Johnston Creek, Yakataga district, Alaska a/.

Specific gravity at $\frac{60^\circ F}{60^\circ F}$	0.987 (A. P. I. gravity 11.8°)
Color	browñish black
Type of base	naphthene

Distillations at atmospheric pressure:

	Percent by volume	Specific gravity $\frac{60^\circ F}{60^\circ F}$	A. P. I. gravity
Fraction up to $200^\circ C$	Trace	-------	-----
Fraction between 200°-$225^\circ C$ more than	1	-------	------
" " 225°-$250^\circ C$	6	0.887	28.1
" " 250°-$275^\circ C$	10	0.899	25.9

a/ Analysis by W. W. Brannock, U. S. Geological Survey.

The fresh oil in the Yakataga district probably is similar in character to the oil produced from the approximately equivalent Tertiary rocks in the Katalla field. The oil from the wells of the Katalla field was described as follows by A. M. Bateman 59/:

> The gravity of the oil is from 41½° to 45° Baumé. The oil is high in gasoline and naptha and has a paraffin base. Sulphur is absent. The recoverable content of gasoline and distillate is about 63 percent.

59/ Martin, G. C., Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, p. 30, 1921. The gravity expressed in degrees A. P. I. would be the same as, or within a fraction of , a degree of the gravity cited above.

Accumulations of oil

Much of the sandstone in the exposed Tertiary strata in the Yakataga district is poorly sorted, containing a large proportion of silt- and clay-size grains that fill the interstices between the sand grains, and therefore is low in porosity and permeability. The sandstone in the lower Tertiary sequence appears to be uniformly hard and tight, but some of the sandstone in the Yakataga formation and in the Poul Creek formation near the coast seems to be fairly porous and permeable, and may provide suitable reservoirs for the accumulation of oil.

The result of porosity and permeability tests on outcrop samples of Tertiary sandstones in the Yakataga district are given in the table on page 45. The samples selected for testing represent some of the most favorable sandstone beds, with respect to reservoir characteristics, that were seen in the lower Tertiary sequence, the Poul Creek formation, and the lower part of the Yakataga formation. Some sandstone in the upper part of the Yakataga formation, especially in the vicinity of the Chaix Hills, appears to be better sorted, less indurated, and more porous and permeable than any of the sandstone seen in the lower Yakataga or pre-Yakataga part of the Tertiary strata, but no samples suitable for porosity and permeability tests were collected.

Porosity and permeability of samples of Tertiary sandstone exposed in the Yakataga district, Alaska

Sample number, description and locality	Percent effective porosity	Air permeability (millidarcies)
Lower Tertiary sequence, unit B:		
46AMr 49 a/----100-foot unit of coarse-grained sandstone; 5 miles north of Hanna Lake	8.4	less than 0.01
Poul Creek formation:		
47AMr 123 a/---100-foot unit of medium-grained sandstone about 2,600 feet below top of formation; Poul Creek	6.8	less than 0.001
47AMr 127B a/--20-foot unit of fine-grained sandstone about 900 feet below top of formation; Poul Creek	15.9	less than 0.001
48AMr 6 b/ ----Fine-grained sandstone about 600 feet below top of formation; at oil seepage on Twomile Creek	11.7	less than 5.0
48AMr 19A b/---Medium-grained sandstone, 50 feet exposed, about 1,000 feet below top of formation; at oil seepage 1 mile east of Hamilton Creek	18.3	28
48AMr 19B b/---Same as above; core cut perpendicular to bedding..........................	17.1	23
Yakataga formation:		
47AMr 81 a/----Fine-to medium-grained sandstone at base of formation; at oil seepage near head of Oil Creek................	10.9	less than 0.001
47AMr 77 a/----Medium-grained sandstone about 5,000 feet above base of formation; reef near mouth of Mink Creek	5.7	less than 0.001
47AMr 113 a/---60-foot unit of medium-grained sandstone, position in formation not known; Poul Creek..................	20.0	12.4
47AJn 45 a/----Medium-grained sandstone about 6,000 feet above base of formation; Hope Creek........................	12.8	1.4

a/ Tested by St. Yuster, The Pennsylvania State College, Division of Petroleum and Natural Gas Engineering. Permeability tests were performed using air at several mean pressures, the final result being etrapolated to infinite mean pressure (Klinkenberg permeability, initial).

b/ Tested by the Fairbanks Laboratory of the Navy Oil Unit, U. S. Geological Survey. Permeability tests were performed using air at standard pressure.

The largest well-defined upfolds in the southern structural belt, the coastal upfold, and the Yakataga anticline are not are not the type of structures generally regarded as being favorable for trapping significant accumulations of oil. The Yakataga anticline and the western part of the coastal upfold are tightly compressed near the present level of erosion, and thus afford a rather restricted area along the crest for the accumulation of oil. Both the Yakataga anticline and the western part of the coastal upfold are faulted along or near the crest. The structurally higest part of the coastal upfold, in the Poul Creek-Johnston Creek area, exposes all or nearly all of the Poul Creek formation. Most of the Poul Creek formation is below the surface in the crest of the Yakataga anticline, but the Poul Creek formation at approximately the same latitude farther west, in the vicinity of Boulder Creek and Cotton Creek, is for the most part fine-grained and seemingly lacking in sandstone beds with favorable reservoir characteristics. Spieker, Walton, and Kirschner pointed out that tightly pinched folds like the Yakataga anticline may be expected to open out at depths of 5,000 to 10,000 feet. The rocks of the lower Tertiary sequence, which would be present at such depth in both the Yakataga anticline and the coastal upfold, are not known to be petroliferous in outcrop elsewhere in the Yakataga district.

Some of the anticlines exposed in the Guyot and Karr Hills are fairly open at the present erosion level, and probably bring the Poul Creek formation to within reasonable drilling depth (structure section I-I', fig. 1). It would be extremely difficult to get drilling equipment into this area however.

On the basis of the information now available, considering both the known geologic factors and the accessibility of prospective drilling sites, locations on the Yakataga anticline in the vicinity of Porcupine Creek and on the minor anticlines of the coastal upfold between Munday Creek and the Priest River are suggested as the most favorable places to test for possible anticlinal accumulations of oil.

The sandstone beds in the exposed part of the Tertiary strata in the Yakataga district, especially in the Poul Creek and Yakataga formations, show lateral variations in grain size, sorting, and thickness that may offer possibilities for trapping oil.

Most of the sandstone beds in the Poul Creek formation and the lower part of the Yakataga formation are in the form of fairly extensive sheets that grade into siltstone or other fine-grained sediments around the margins. The sandstone beds in the Poul Creek formation appear to thin or thicken in an irregular manner in an east-west direction, but show a regional tendency to become finer grained and to wedge out from south to north. The northward thinning and decrease in grain size of sandstone beds in the Poul Creek formation is illustrated by comparing the sections measured on Poul Creek and on Yakataga Reef with the sections measured in the Cotton Creek-Boulder Creek area, on Porcupine Creek, and Yakataga Ridge (fig. 2). No regional trend in the variation in thickness, grain size, and sorting of the sandstone beds in the lower part of the Yakataga formation has been detected.

The sandstone beds in the upper part of the Yakataga formation are notably lenticular, but no regional trend in the variation in thickness of the sandstone units is apparent. Some of the units appear to represent submarine channel deposits.

Significant accumulations of oil may be present in sealed-off reservoir beds along the major faults of the southern structural belt, especially along the Sullivan fault. Possibilities for accumulations against the Sullivan fault, in gently dipping reservoir beds in the lower part of the Poul Creek formation on the hanging-wall side, and in more steeply dipping reservoir beds in both the Poul Creek formation and Yakataga formation on the footwall side, are suggested in structure sections D-D', E-E', F-F', and G-G' (fig. 1). The presence of oil seepages along the Sullivan fault indicates that it does intersect one or more reservoir beds, but the seepages may also indicate that the fault seal is too imperfect to permit accumulation of large amounts of oil.

Zones of shattered rock affording openings for the accumulation of oil may be present along the major faults and along the tightly compressed upfolds in the Yakataga district. The wells in the Katalla field are believed to have produced from fractured but otherwise relatively impermeable siltstone and sandstone of middle or late Oligocene age, in a complexly folded and faulted zone 60/. More substantial production has been obtained from

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60/ Miller, D. J., Rossman, D. L., and Hickcox, C. A., Preliminary report on petroleum possibilities in the Katalla area, Alaska, p. 16, 1945. (Mimeographed. Accompanies geologic and topographic map and sections of the Katalla area, Alaska: U. S. Geol. Survey war minerals investigations, 1945.)

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fracture zones in fine-grained relatively impervious rocks in several of the major oil fields in the United States 61/.

61/ Lalicker, C. G., Principles of petroleum geology, p. 103, 1949.

Summary of oil possibilities

The distribution of oil seepages in relation to structural and stratigraphic features in the Yakataga district points to the presence of petroliferous rocks in the Poul Creek formation and possibly in the lower part of the Yakataga formation. Beds of pre-Poul Creek age are not known to be petroliferous anywhere in the district. Much of the sandstone in the Poul Creek and Yakataga formations is poorly sorted and is low in porosity and permeability, but some beds of suitable though not exceptionally favorable reservoir characteristics probably are present. Possibilities for accumulations of oil in permeable sandstone beds are offered by anticlinal traps, fault traps, and permeability wedge-outs. Accumulations of oil may also occur in fracture zones along the major faults and along tightly compressed upfolds. The area including the coastal upfold between Cape Yakataga and Icy Bay probably is the most promising part of the Yakataga district for initial exploration by drilling, because it is the most readily accessible part of the district and because it includes most of the known oil seepages as well as what appear to be some of the most favorable reservoir beds in association with potential anticlinal and fault traps.

Selection of drilling sites in the Yakataga district should be preceded by detailed geologic mapping of the general vicinity of the proposed sites, supplemented by core drilling if necessary, in order to determine as accurately as possible the character of the structure, and the location and character of potential oil traps at depth. Because of the general scarcity of diagnostic fossils, either macroscopic or microscopic, and general lack of key beds of distinctive lithology, careful study of well cuttings and cores and comparison with exposed sections will be necessary in order to accurately correlate subsurface sections. Location of oil accumulations at depth in the Yakataga district is likely to be difficult, at least in the initial stage of exploration, because of the complexity of the structure and the lack of information on the local factors affecting oil accumulation. Any plan for testing the oil possibilities of the Yakataga district should take into account the possibility that many test wells may be required to prove the presence or absence of significant accumulations.

Attention is called to the possibility of obtaining at least a small amount of oil, in addition to stratigraphic and structural information, by drilling essentially horizontal holes 62/ across the structural trend in areas of high relief, as in the coastal belt between Cape Yakataga and Johnston Creek. Some of the oil seepages in this belt are high up on the narrow divides between the major transverse streams.

62/ Ranney, Leo, Horizontal drilling through outcrop brings results: Oil and Gas Jour., vol. 37, no. 49, pp. 68-69, 82, 1939.

Much or all of the broad coastal plain lying east of Icy Bay and west of Cape Yakataga, part of Bering Glacier, and part of Malaspina Glacier probably are underlain by rocks of the Poul Creek and Yakataga formations. The structure in these areas may be expected to be comparable to the exposed part of the southern structural belt, and possibly is less complex. The oil possibilities in this large part of the Yakataga district can be evaluated only by geophysical prospecting, or by drilling through the cover of ice and unconsolidated Quaternary sediments to the underlying bedrock.

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