Bulletin No. 335

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

GEOLOGY AND MINERAL RESOURCES

OF THE

CONTROLLER BAY REGION, ALASKA

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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PREFACE.

By Alfred H. Brooks.

This volume presents the results, both geologic and topographic, of the first detailed survey made of any of the Alaska coal fields. Most of the other important coal fields have been covered by surveys of a reconnaissance character (see p. 130, this report), and it is purposed to carry detailed surveys over them as fast as they are likely to be rendered accessible by transportation facilities, provided the means permit.

It is an established policy in the investigation of the mineral resources of Alaska to precede detailed work by that of a reconnaissance character. This makes it possible to determine not only the areas of probably greatest commercial importance, which should be surveyed in detail, but also to obtain an insight into the larger geologic problems and thus pave the way for the more detailed investigations. The following report is the result of such a policy, a general investigation of the fuel resources and of the geologic problems connected therewith of the Pacific coastal belt of Alaska,[a] made in 1903–4, having indicated the Controller Bay region as the part of this province which gave promise of being of greatest immediate commercial importance.

It is considered desirable that areas selected for survey, especially those for mapping in detail, should be of quadrilateral outline and bounded by parallels of latitude and meridians of longitude. Unfortunately the means at hand are not always sufficient to cover such quadrangles, and the work is perforce confined to the parts that are of greatest commercial importance. Such is the case in the accompanying map (Pl. II, pocket) of the Controller Bay region.

The maps and text of this volume present many details of the geology. If, as is often the case, a tentative rather than a final conclusion is presented, it should be regarded as being due both to the lack of comprehensive knowledge of the whole Alaska-Pacific coast

[a] Martin, G. C., The petroleum fields of the Pacific coast of Alaska: Bull. U. S. Geol. Survey No. 250, 1905. Moffit, F. H., and Stone, R. W., Mineral resources of Kenai Peninsula, Alaska: Bull. U. S. Geol. Survey No. 277, 1906.

province and to the lack of bed-rock exposures, which is so characteristic of much of the region, rather than to a lack of refinement in field methods. The succession of Tertiary rocks in the northwestern Pacific-coast province of America is but very imperfectly known, and the included floras and faunas have been but little studied. Mr. Martin had, therefore, very little except the position of the beds to aid him in his interpretation of structure, which is very intricate. Though the stratigraphic sequence, as here presented, leaves much to be desired, yet it is undoubtedly the best that can be done until the Tertiary rocks are studied in adjacent provinces.

Though the region lies near the coast yet it is by no means easy of access. The heavy timber and swamps of the lowlands, the fewness of roads and trails, and the excessive rainfall made the work exceedingly arduous. In view of these facts, Mr. Martin and his assistants deserve great credit for the results obtained.

GEOLOGY AND MINERAL RESOURCES OF THE CONTROLLER BAY REGION, ALASKA.

By G. C. Martin.

INTRODUCTION.

LOCATION.

Controller Bay is a shallow indentation in the Pacific coast of Alaska, sheltered chiefly by Kayak and Wingham islands. It lies in latitude 60° north, longitude 144° west, being about 1,250 miles northwest of Seattle, 400 miles northwest of Sitka, and 15 miles east of the mouth of Copper River (Pl. I). The region here to be described includes the shores of Controller Bay, the islands in and around it, and an area extending for about 25 miles inland, including the entire drainage basins of Bering River and of the other streams emptying into Controller Bay, and parts of the headwater areas of the neighboring streams. This region, which extends for maximum distances of 37 miles from north to south and 28 miles from east to west, covers a total land area of about 430 square miles. It is an isolated region of lowlands and hills of moderate altitude, hemmed in between the Chugach Mountains and the sea on the north and south and between Bering Glacier and the Copper Delta on the east and west.

HISTORY OF INVESTIGATIONS.

EARLY EXPLORATIONS AND SURVEYS.

When Bering led the first exploratory voyage across the North Pacific in 1741, Cape St. Elias was his first landfall and either Kayak or Wingham Island his first landing place. The first exploration of this province thus dates back to the beginning of Alaskan history. But this beginning, although of historical interest, was of little importance, for Bering merely sent boats ashore for water, and then went back across the Pacific without extending his explorations or even touching on the mainland.[a]

[a] Steller, Georg Wilhelm, Beschreibung der See-Reise von Kamschatka nach Amerika, Frankfurt, 1774.

The Russians probably made other visits to Controller Bay during the beginning of settlement and fur trade from 1762 to 1783, but if so they left no records which are accessible. Other explorers sent out by the Russians, French, and Spaniards sailed past this coast, but there is no record of their having landed here.

Vancouver and Puget, returning from Cook Inlet in 1794, entered Controller Bay, and the latter spent considerable time there while attempting to sail out through the channel between Kayak Island and Okalee Spit. Puget's account of this work and his descriptions of the regions [a] are especially complete.

Controller Bay and the coast eastward were visited in 1837 by Sir Edward Belcher, who wrote [b] some rather elaborate but nonscientific descriptions of Bering and Malaspina glaciers.

Lieut. H. W. Seton-Karr, after attempting to climb Mount St. Elias in 1886, cruised westward in a small boat, spent some time at a settlement on the north end of Kayak Island and near Katalla, and crossed the Copper Delta. He published a very complete narrative [c] of his journey, with general descriptions of the country and with sketches.

All the charts of Controller Bay and the neighboring coast published prior to 1903 were based on early surveys, probably by Tebenkof. The United States Coast and Geodetic Survey mapped the Copper Delta in 1898 and made detailed surveys of parts of the shore line and waters of Controller and Katalla bays in 1903, 1905, and 1906. The results of this work are embodied in chart No. 8513.

GEOLOGIC AND TOPOGRAPHIC SURVEYS.

The earliest authentic references to the geology and mineral resources of this region were by Oliphant,[d] Eldridge,[e] Spurr,[f] Kirsopp,[g] Stoess,[h] and others.[i]

The facts to be presented in this volume have been gathered chiefly during visits to the region made by the writer during each of the last

[a] Vancouver, Capt. George, Voyage of discovery to the North Pacific Ocean, etc., in the years 1790–1795, London, 1798, 3 v. (maps).

[b] Belcher, Capt. Sir Edward, Narrative of the voyage of H. M. S. Sulphur during the years 1836–1842, London, 1843.

[c] Seton-Karr, H. W., Shores and Alps of Alaska, London, 1887, pp. 138–168.

[d] Oliphant, F. H., Petroleum, in Mineral Resources U. S. for 1897; Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (cont.), 1898, p. 110.

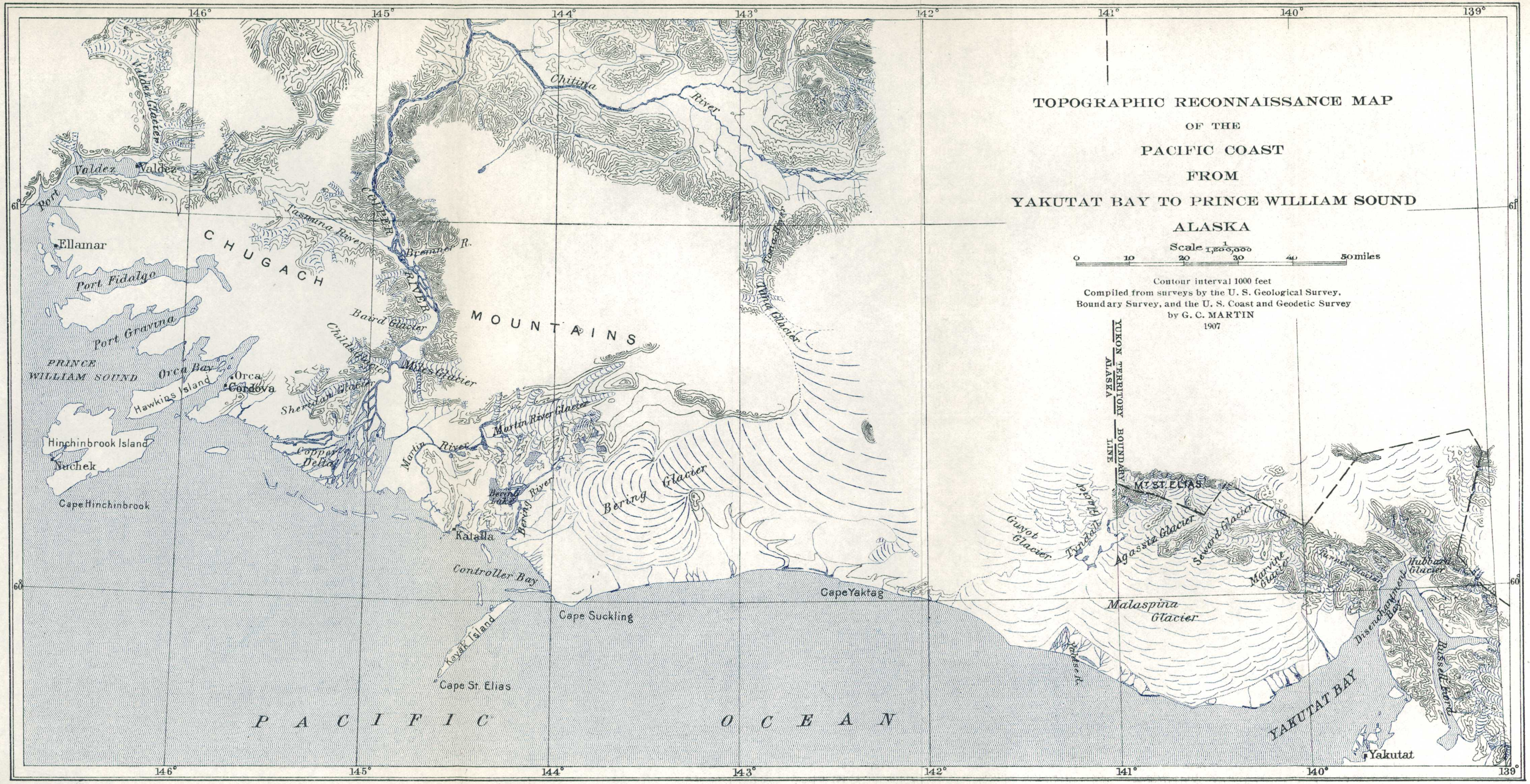
[e] Eldridge, G. H., The coast from Lynn Canal to Prince William Sound: Maps and descriptions of routes of exploration in Alaska in 1898, a special publication of the U. S. Geol. Survey, 1899, pp. 103–104.

[f] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 263–264.

[g] Kirsopp, John, jr., The coal fields of Cook Inlet, Alaska, U. S. A., and the Pacific coast: Trans. Inst. Min. Eng. (England), vol. 21, 1901, pp. 556–559.

[h] Stoess, P. C., The Kayak coal and oil field of Alaska: Min. and Sci. Press, vol. 87, 1903, p. 65.

[i] See bibliography on p. 130.



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four years. A four weeks' reconnaissance was made in the summer of 1903, the results of which were published both in abstract[a] and in detail.[b] In 1904 about ten days were spent in supplementary reconnaissance, the results of which were incorporated in the detailed report[b] on the preceding season's work and were also presented more fully[c] by themselves.

More detailed surveys and investigations were made during the field season of 1905, when a combined geologic and topographic party of ten to twelve men was at work in the region from May 21 to October 27. The objects were to prepare a detailed topographic map, to plat the geology upon this base map, and to make the other detailed studies of the geology and mineral resources on which this report is based.

The topographic mapping, which was carried over an area of about 430 square miles, included all of the area within which there are indications of petroleum, and all of those parts of the coal field within which there have been actual or attempted developments. The work of the topographers was much aided by the use of the primary triangulation made by the Coast Survey and by detailed topographic maps of the coal and oil lands of the Alaska Development Company and the Pacific Coal and Oil Company made by Mr. J. L. McPherson. These maps were thoroughly tested in the field by both the topographers and the geologists and were found to be of rare accuracy and excellence. Accordingly the areas covered by them were not resurveyed, and Mr. McPherson's maps were reduced to the scale of and incorporated in the topographic map here published. This map (Pl. II, pocket) was surveyed on the scale of 1:45000 and is here published on the scale of 1:62500, or about 1 mile to the inch, with a contour interval of 50 feet. Bad weather prevented the extension of primary triangulation into the northeastern part of the area. The control of this section was consequently based on secondary plane-table triangulation and is subject to more or less correction. It is hoped that the errors will not be appreciable.

The approximate positions of the Coast Survey triangulation stations are shown on Pl. III, and are also stated in the following table:

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[a] Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382.

[b] The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, 64 pp.

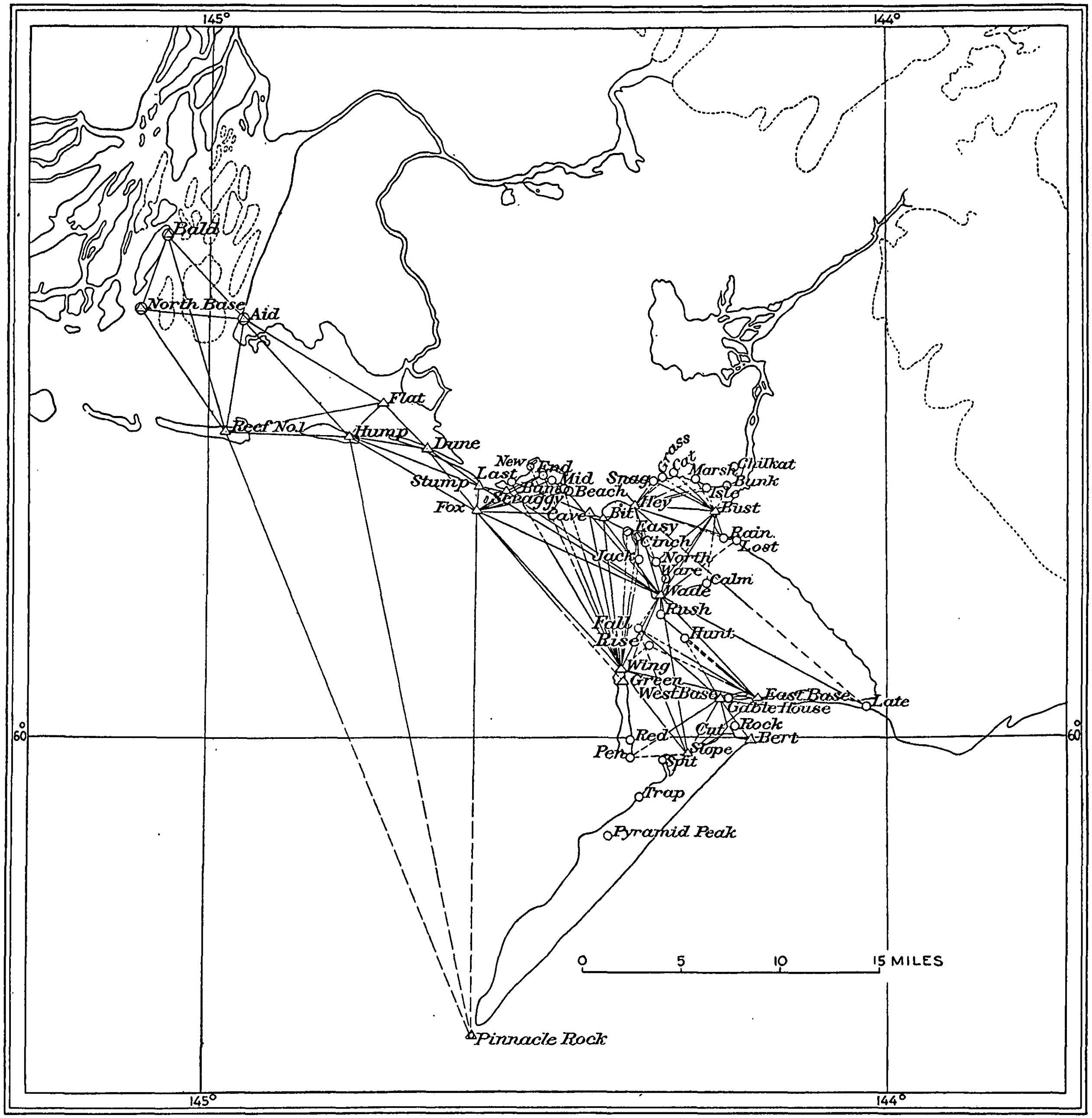
[c] Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–139. Bering River coal field: Bull. U. S. Geol. Survey No. 259, 1905, pp. 140–150.

Latitude and longitude of Coast Survey triangulation stations.

Name of station.	Latitude.			Longitude.		
	°	′	″	°	′	″
Aid	60	17	56.390	144	56	13.535
Bald	60	21	33.511	145	02	43.403
Beach	60	10	37.890	144	28	31.280
Bert	59	59	58.428	144	12	02.568
Bit	60	09	26.360	144	25	16.853
Bum	60	10	40.147	144	28	37.502
Bunk	60	10	46.956	144	14	25.716
Bust	60	09	40.967	144	15	21.464
Calm	60	06	37.45	144	16	03.124
Cat	60	11	20.25	144	19	00.464
Cave	60	09	37.993	144	26	28.033
Chilcat	60	11	33.882	144	13	36.102
Cinch	60	08	44.345	144	21	54.708
Cut	60	00	23.074	144	13	51.720
Dune	60	12	22.550	144	40	50.626
East Base Controller Bay	60	01	40.487	144	11	42.532
Easy	60	08	52.866	144	23	07.608
End	60	11	35.404	144	31	01.397
Fall	60	04	46.166	144	22	09.977
Flat	60	14	23.135	144	44	48.838
Fox	60	09	48.358	144	36	29.732
Gable House	60	01	48.043	144	14	14.533
Grass	60	11	12.33	144	20	02.204
Green	60	02	28.554	144	23	21.701
Hey	60	10	00.653	144	22	28.436
Hump	60	13	02.513	144	46	39.901
Hunt	60	04	18.672	144	17	54.685
Isle	60	10	43.80	144	16	03.484
Jack	60	07	41.626	144	22	02.189
Last	60	10	58.981	144	33	17.610
Late	60	01	27.520	144	02	06.774
Lost	60	08	29.64	144	13	27.564
Marsh	60	11	05.99	144	17	06.604
Mid	60	11	07.248	144	29	48.081
North	60	07	32.62	144	20	14.624
North Base	60	18	31.349	145	05	10.598
Pen	59	59	08.63	144	22	39.164
Pinnacle Rock	59	47	25.018	144	36	36.745
Pyramid Peak	59	55	45.6	144	24	43.4
Rain	60	08	33.948	144	14	42.987
Red	59	59	55.824	144	22	34.089
Reef No. 1	60	13	10.599	144	57	45.140
Rise	60	04	00.952	144	21	03.974
Rock	60	00	28.07	144	13	41.15
Rush	60	05	17.244	144	20	03.101
Scraggy	60	10	35.330	144	33	46.962
Slope	59	59	23.033	144	17	42.692
Snag	60	11	05.03	144	20	48.264
Spit	59	59	17.045	144	19	47.045
Stump	60	10	46.955	144	36	06.068
Trap	59	57	38.422	144	22	08.110
Wade	60	06	12.277	144	20	03.958
West Base Controller Bay	60	01	44.389	144	14	53.313
Wing	60	02	59.539	144	23	33.608

About 45 miles of precise levels were run in the course of the detailed topographic work and 11 permanent bench marks were left. The line of levels extends from tide at Katalla to the mouth of Canyon Creek via Bering River, with branches up Shepherd Creek to Canoe Landing and up Stillwater Creek to Lake Kushtaka.

The following table gives the position and elevation of bench marks which were established by this precise leveling. All are marked by aluminum tablets set in rock, and the position is also indicated on the topographic map.



SKETCH MAP OF CONTROLLER BAY REGION, SHOWING POSITION OF TRIANGULATION STATIONS.

(After Coast and Geodetic Survey.)

Bench marks in Controller Bay region.

Location.	Elevation stamped on tablet.	Adjusted elevation.[a]
	Feet.	*Feet.*
Katalla, 300 feet west of post-office; tablet set in top of large bowlder (5 by 10 by 10 feet)	10	10.095
Point Hey; tablet set in outcrop of sloping smooth sandstone	10	9.909
Mouth of Bering River; tablet set in base of cliff between waterfall and office of Pacific Coal and Oil Co	8	8.052
Bering River, west bank, 1 mile southeast of Bering Lake and ¼ mile west of mouth of Gandil River; tablet set in sandstone	7	6.648
Shepherd Creek, west bank, near mouth; tablet set in sandstone 20 feet from water line, on low grassy swale between hills	6	6.067
Shepherd Creek, west side, on trail at base of steep hills; tablet set in sandstone outcrop 100 feet south of cabin at tunnel	47	47.049
Bering River, north bank, 4½ miles west of mouth of Stillwater Creek; tablet set in sandstone ledge at base of 20-foot cliff in first timbered hill above Bering Lake	21	21.094
Bering River at mouth of Stillwater Creek; tablet set in sandstone at base of 20-foot cliff, 50 feet south of gully on west side of creek	23	23.020
Stillwater Creek, 2¾ miles above its mouth; tablet set in sandstone on edge of trail ¾ mile above Cunningham's warehouse	49	49.160
Lake Kushtaka at outlet; tablet set in sandstone 20 feet from edge of water	85	84.728
Bering River, about 500 feet north of mouth of lower fork of Canyon Creek; tablet set in black sandstone on wooded point at west side of gravel flat, about 500 feet north of point where trail leaves Bering River	45	45.010

[a] The determination of mean tide at Katalla is based on observations extending for only twenty-four hours, and consequently is only approximate. The adjusted elevations of the bench marks as given in the table are regarded as correct within 0.1 foot with reference to the Katalla bench, but are subject to a probably greater correction on more accurate determination of mean tide.

Reconnaissance surveys were also made in 1905 to connect with the maps of the Copper River region. During the following season the reconnaissance topography was extended to the north and east. The data thus obtained were used in the preparation of Pl. I, in compiling which earlier maps by the Geological Survey in neighboring regions and by the coast and boundary surveys were also employed.

The geologic work of 1905 was carried over the same area as the topography, and a geologic map showing the distribution of the several formations was prepared (Pl. V, pocket). Numerous sections were measured and coal samples were collected at most of the more important openings. The results of this work have already been published in abstract,[a] but are given more completely on subsequent pages. Part of the season of 1906 was spent in completing the geologic work begun in the preceding year. The results of that year's work were also incorporated in an abstract report [b] which has already appeared.

ACKNOWLEDGMENTS.

The writer wishes to express his indebtedness and thanks to Mr. Alfred H. Brooks and Mr. W. W. Atwood, who were in consultation with him in the field; to his geologic assistants, A. G. Maddren, Lawrence Martin, Sidney Paige, R. W. Stone, and C. E. Weaver; and to

[a] Distribution and character of Bering River coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 65–77.

[b] Petroleum at Controller Bay, Alaska: Bull. U. S. Geol. Survey No. 314, 1907, pp. 89–103.

E. G. Hamilton and W. R. Hill, who made the topographic survey, and their assistants, F. E. Laube and W. J. McDonald.

Acknowledgments should also be made to the other members of his parties and to the many prospectors, operators, and engineers who by the aid and information they have given and the unfailing kindness they have shown have contributed much both to the value of the work and to the ease and pleasure of its accomplishment. The list of these men is too long to publish here, but the writer wishes to assure them that it is not too long for him to remember.

COMMERCIAL DEVELOPMENTS.

The first white men who settled in this region were traders who were attracted by the sea otters which the natives had for a long time been catching around the rocks off Kayak and Wingham islands. Trading posts were established during the Russian occupation, and soon after the transfer the Alaska Commercial Company is said to have had a station here. After the decline of the sea-otter industry attempts were made to establish salmon canneries, but they were not successful, although a cannery on Prince William Sound still finds it profitable to send steamers to Bering River for fish.

The existence of coal and petroleum was probably learned from the natives. However that may be, these materials began to attract attention in 1896 and soon brought in large numbers of prospectors. The first oil well was begun in 1901, and drilling has been in progress more or less actively ever since. (See p. 113.) A producing well was obtained in 1902 and an oil boom resulted. Companies were floated on cheap stock and promises, large areas of mud and ice were staked and sold, and drilling was begun wherever any kind of rig could be procured and landed. A large number of the oil companies never progressed beyond the sale of stock, and some possibly never intended to do so. Others began operations without obtaining competent advice and with no idea of the problems before them. A few started in a conservative, intelligent way to thoroughly test the field. None have thus far secured any return. It is now realized that oil drilling in a new field is uncertain, and at best requires time and money, and that Alaska oil fields are at a greater disadvantage than more accessible localities. It is still doubtful how and where producing wells are to be obtained and uncertain whether even successful wells will justify the present high cost of drilling and operating in this region.

The coal was discovered at about the same time as the petroleum. Probably all of the coal land within easy reach has now been located. The lands have been for the most part surveyed for patent application by deputy mineral surveyors. A large number (probably several hundred) of surface prospect openings have been made, and about 20 tunnels have been begun.

Complete title[a] has not, so far as is known to the writer (1907), been obtained by any of the locators, either here or elsewhere in Alaska.

The importance of transportation has been realized from the beginning of the development of the region. The building of trails and roads has gone on from year to year until foot travel is now easy. Railroad preliminaries have been in progress at intervals for several years, the following routes having been surveyed: From the east shore of Controller Bay to the valley of Shepherd Creek; from Point Hey to Shepherd Creek via Katalla Valley; from Whale Island, via Katalla Valley, to Lake Charlotte and thence to Copper River and into the interior; from Katalla Bay to Copper River and thence up Copper River; and from Canyon Creek to Controller Bay.

Construction of wharves and breakwaters at Katalla Bay and at Whale Island and of two railroads was begun in 1907.

GENERAL CHARACTER OF THE COUNTRY.

TOPOGRAPHY.

The Controller Bay region constitutes an area of lowlands and of hills of moderate height, lying between the Chugach Mountains and the sea on the north and south and between Bering Glacier and the Copper Delta on the east and west.

The Chugach Mountains are high and rugged (see Pl. IV, *A*), most of the prominent peaks having elevations of from 6,000 to 12,000 feet, and send out long spurs toward the southwest, which gradually decrease in height as they approach the sea. The hills and mountains of the northern and western parts of this region are such spurs. Most of the other hills stand as isolated peaks and ridges or as isolated groups, which are either surrounded by water, as the ridges on Kayak and Wingham islands, or by mud and gravel flats, as Mount Campbell, Nichawak Mountain, Gandil Mountain, and the group of hills south of Bering Lake. The elevation of the mountains within the area described in this report is in general less than 2,000 feet, and does not exceed 2,500 feet, except in the western and northern parts of the region, where numerous peaks rise to heights of from 2,500 to 4,150 feet. The highest of the summits are in the extreme northeastern part of the region, close to the Chugach Mountains. The hills are in general characterized by steep, canyon-gashed slopes below timber line, rounded peaks and flattish areas between timber line and an elevation of 1,800 to 2,000 feet, and sharp peaks and ridges above 2,000 feet.

[a] See Coal-land laws and regulations thereunder (a pamphlet issued by the General Land Office April 12, 1907), pp. 12–19.

GLACIERS.

Bering Glacier, which borders the region on the east, is a huge, even-surfaced, stagnant mass of glacial ice, which is fed by many valley glaciers coming from the high mountains north of it. It is a piedmont glacier of the same general character and of about the same size as Malaspina Glacier. Portions of its surface form a good highway to some of the coal camps in the east end of the Bering River coal field, but most of it is so covered by irregular masses of rock and gravel and so much crevassed that travel over its surface is difficult and dangerous.

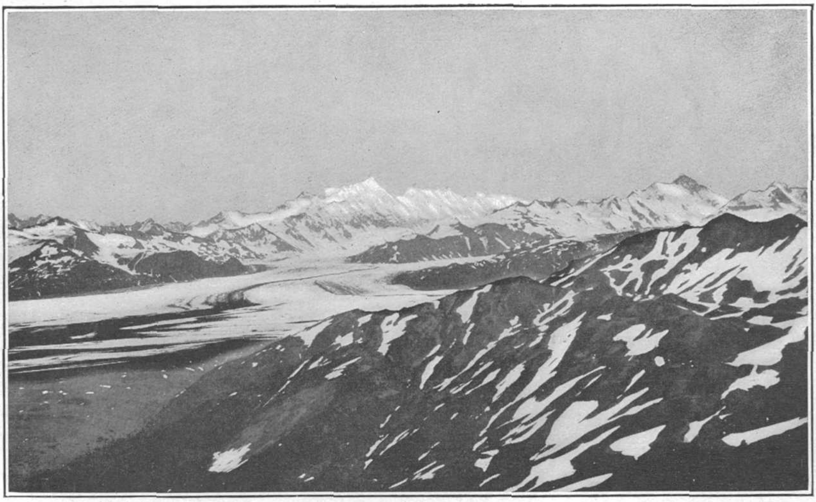
Martin River Glacier, which lies north of the coal field, is intermediate in size and character between Bering Glacier and the typical valley glaciers. It is formed by the union of several valley glaciers, which come out from the high mountains (see Pl. IV, *A*), and expand into a bulb-shaped terminus on reaching low ground. Much of its surface is deeply buried by moraine and is flat, but most of it is deeply crevassed. Two lobes of this glacier extend into the valleys occupied by Kushtaka Lake and Lake Charlotte. The former is known as Kushtaka Glacier.

Several small glaciers occupy positions on the colder slopes of higher mountains within the area here described. The largest of these is in the east end of the coal field and is known as Slope Glacier. Three very small ones are near it, and an unknown number of small glaciers of various sizes occupy the high valleys on the west slopes of Ragged Mountain.

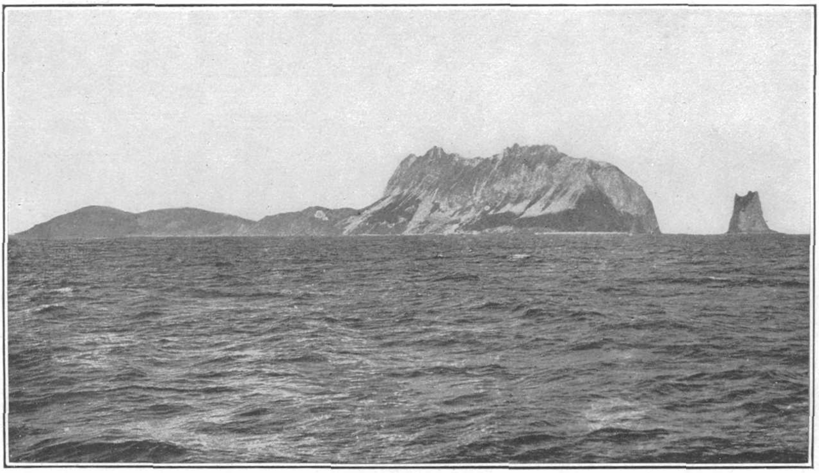
STREAMS.

The streams of this region have their supply partly from local rainfall and partly from the melting of the glaciers. Both sources are large, and the streams are all of great volume in proportion to their length and are subject to severe floods.

Bering River drains the greater part of the region. This stream has its source in lakes on the margin of Bering Glacier. (See Pl. VI, *A*, p. 46.) It flows southwestward for about 12 miles until it approaches Bering Lake, where it spreads into a broad delta. The water passes in part through the delta without entering the lake, and in part into the lake and out again at its southeast corner, where the river is reunited and flows southward for 8 miles to the northeast corner of Controller Bay. The lower course of Bering River is tidal, the current running in both directions at rates of 3 to 5 miles per hour with the tide. The water of Bering Lake has a rise and fall of 1 to 3 feet. Bering River above the lake is nontidal, the current running from 8 to 10 miles per hour in the upper part and about 3 miles per hour in the vicinity of the lake. The tributaries of Bering River above the lake include Canyon Creek, which has its source on the southern margin of Martin River Glacier; Stillwater



A. CHUGACH MOUNTAINS AND MARTIN RIVER GLACIER FROM MONUMENT MOUNTAIN, LOOKING NORTHEAST.



B. VOLCANIC PLUG AT THE SOUTH END OF KAYAK ISLAND.

Creek, which drains Lake Kushtaka and receives a large part of its supply from the Kushtaka lobe of Martin River Glacier; and Shepherd Creek, which drains Lake Charlotte and several other small lakes on the margin of the same glacier. The chief tributaries below the lake are Gandil and Nichawak rivers, which drain parts of the margin of Bering Glacier.

The other streams include Campbell and Edwardes rivers, which rise on the southwest margin of Bering Glacier and enter the east shore of Controller Bay; Katalla River, which rises in the hills west of Bering Lake and flows into Katalla Bay; and several of the headwater tributaries of Martin River. The latter rises on the western margin of Martin River Glacier and in Tokun Lake, and flows westward until it reaches the east edge of the Copper Delta. The waters there divide, part entering the delta of the Copper, and part flowing along the edge of the mountains close to the delta and entering the tidal sloughs behind Softuk Bar.

CLIMATE.

Few meteorologic observations have been made at points within the region here described, and so the following discussion is partly based on the records at neighboring stations, supplemented by the writer's general knowledge of weather conditions during the summers of 1903 to 1906, inclusive.

The following local meteorologic records were made and have been furnished by the Katalla Company:

Temperature, cloudiness, and precipitation at Katalla, 1907.

	Temperature (°F.).			Cloudiness (number of days).				Precipitation (inches).		
	Maximum.	Minimum.	Mean.	Clear.	Partly cloudy.	Cloudy.	Rain.	Rain.	Snow.	Total.
January	42	4	19.0	24	2	5	7	No record.		
February	36	2	23.5	13	2	13	13	No record.		
March	35	4	23.1	14	9	8	11	No record.		
April	50	23	35.8	8	10	12	12	7.5	2.0	--------
May	67	30	44.2	11	6	14	17	4.85	--------	4.85
June	80	41	50.0	6	9	15	16	8.29	--------	8.29
July	78	42	55.0	1	8	22	23	14.95	--------	14.95
August	84	44	59.4	5	11	15	17	11.41	--------	11.41
September	76	37	52.0	8	11	11	19	12.34	--------	12.34
October	54	22	41.7	1	7	23	29	25.52	1.25	25.62
November	52	20	34.4	3	9	18	23	11.44	15.5	12.44
December	44	4	32.0	5	7	19	23	10.2	15.75	11.48
The year	84	2	39.2	99	91	175	210	--------	--------	[a]101.38

[a] Eight months.

The nearest stations at which meteorologic records have been made are Orca, 45 miles to the northwest; Nuchek, 70 miles to the west; Fort Liscum, 90 miles to the northwest, and Sitka, 400 miles to the southeast of Katalla.

All of these stations, as well as the region here described, are included in what Brooks and Abbe [a] have designated the "Pacific coast

[a] Brooks, A. H., and Abbe, C., jr., General climatology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 148–149.

climatic province," which is characterized by heavy rainfall and cloudy weather and by moderate winter and low summer temperatures. General conditions throughout the province are well illustrated in the following tables,[a] giving the temperatures and rainfall at Orca, Nuchek, Fort Liscum, and Sitka:

Temperature (°F.) at stations nearest Controller Bay.

	Maximum.				Minimum.				Mean.		
	Sitka.[a]	Nuchek.[b]	Orca.[c]	Fort Liscum.[d]	Sitka.[a]	Nuchek.[b]	Orca.[e]	Fort Liscum.[d]	Sitka.[a]	Orca.[c]	Fort Liscum.[d]
January	51	48	49	45	−2	20	5	−14	34.2	25.9	23.8
February	54	47	45	42	−3	16	8	−12	33.0	30.1	15.5
March	65	45	61	52	−1	27	2	−8	37.2	34.5	30.8
April	70	54	70	52	19	27	25	2	41.9	40.0	31.6
May	80	54	72	62	28	30	28	25	46.9	44.8	39.4
June	80	70	83	79	33	39	35	32	51.6	52.4	49.6
July	87	69	90	77	35	47	33	32	54.4	57.6	50.5
August	82	70	80	70	39	46	40	30	56.6	55.8	46.6
September	74	......	84	64	32	......	30	25	52.3	52.2	......
October	67	65	64	53	25	22	25	18	45.7	40.3	......
November	59	45	48	45	5	10	11	0	39.8	31.8	22.4
December	59	41	47	41	7	13	7	−13	36.0	29.4	21.6
The year	87	70	90	79	−3	10	2	−14	44.5	41.2	......

[a] November, 1867, to May, 1877; April, 1881, to September, 1887; July, 1898, to February, 1899; May, 1899, to December, 1902.
[b] October, 1883, to August 31, 1884.
[c] Broken record from June, 1899, to October, 1905.
[d] January, 1901, to December, 1902.

Precipitation at stations nearest Controller Bay.

	Number of days with rain exceeding 0.01 inch.				Rainfall (including melted snow), inches per month.			
	Sitka.[b]	Nuchek.[c]	Orca.[d]	Fort Liscum.[e]	Sitka.[b]	Nuchek.[c]	Orca.[d]	Fort Liscum.[e]
January	16.8	23.0	14.0	17.5	12.17	27.07	12.58	9.67
February	15.9	8.0	9.7	5.0	7.47	9.15	7.49	1.01
March	18.0	21.0	16.7	14.5	6.70	18.02	18.69	5.54
April	12.6	18.0	14.7	9.0	5.61	16.92	12.70	4.50
May	16.1	18.5	18.0	9.0	4.17	18.92	12.06	2.26
June	13.6	10.5	10.7	8.0	3.31	4.17	5.55	0.68
July	14.9	18.5	10.8	14.5	3.55	9.93	4.65	4.21
August	16.8	13.0	14.8	28.5	5.84	14.13	14.35	12.38
September	19.5	19.0	14.5	22.5	9.67	22.96	15.26	14.22
October	21.7	22.0	21.2	22.0	11.96	21.50	21.53	14.25
November	19.6	1[illegible].0	13.0	11.5	9.80	10.51	9.97	6.63
December	18.9	19.0	14.7	13.0	7.84	16.81	14.52	5.95
The year	207.9	203.5	172.8	175.0	88.10	190.09	149.33	81.33

[a] Compiled from reports of voluntary observers of the weather bureau of Alaska as published in the reports of Prof. C. C. Georgeson on agricultural investigations in Alaska.
[b] November, 1867, to May, 1877; April, 1881, to September, 1887; July, 1898, to February, 1899; May, 1899, to December, 1902.
[c] October, 1883, to August 31, 1884.
[d] Broken record from June, 1899, to October, 1905.
[e] January, 1901, to December, 1902.

Monthly temperature and precipitation at Orca from June, 1899, to October, 1905.

	Temperature (° F.).					Precipitation.	
	Extremes for term of record.		Averages by months.				
	Maximum.	Minimum.	Maximum.	Minimum.	Mean.	Days with rain or snow.	Amount (inches).
January, 6 years	49	5	44.0	11.2	25.90	14.0	12.58
February, 6 years	45	8	41.3	16.3	30.07	9.7	7.49
March, 5 years	61	2	53.0	12.0	34.47	16.7	18.69
April, 8 years	70	25	64.0	27.3	40.04	14.7	12.70
May, 2 years	72	28	68.0	29.0	44.81	18.0	12.06
June, 2 years	83	35	80.0	36.0	52.35	10.7	5.55
July, 3 years	90	33	83.0	40.7	57.63	10.8	4.65
August, 4 years	80	40	76.25	41.5	55.83	14.8	14.35
September, 5 years	84	30	75.0	34.8	52.23	14.5	15.26
October, 6 years	64	25	56.3	28.8	40.30	21.2	21.53
November, 6 years	48	11	46.0	20.0	31.78	13.0	9.97
December, 6 years	47	7	45.2	13.0	29.43	14.7	14.52
Term of record	90	2					
Average for year					41.24		
Total for year						172.8	149.33

These tables show a maximum of precipitation and of winter temperature and a minimum of summer temperature on the seaward border of Prince William Sound in the vicinity of Nuchek and Orca. The precipitation becomes gradually less and the range of temperature greater away from the open sea, as is shown by the very much decreased rainfall and the slightly cooler summer and much colder winter temperatures at Fort Liscum. In the direction of Sitka the change consists of a decrease in rainfall, with higher summer and lower winter temperatures.

The climatic conditions on Controller Bay probably differ little if any from those at Orca and Nuchek. The rainfall is enormous, possibly even rivaling that at Nuchek and Orca, where there are records of 198 and 143 inches of precipitation in single years. May and June are sometimes, but not always, somewhat drier than the rest of the summer. There is almost invariably clear weather with and following a west or southwest wind, and rainy weather with an east wind. The severe storms all blow from the east and northeast.

VEGETATION.

The vegetation of this region is closely related to its topographic features. The three following types may be recognized:

Swamps and meadows: These are developed upon the alluvial flats and their growth consists predominately of grass and small bushes. Trees are restricted to willow and cottonwood on the borders of the watercourses, and spruce and hemlock on the drier sandy places, such as abandoned beaches and watercourses.

Evergreen forests: Spruce and hemlock predominate in the denser forests, which are located on the lower slopes of the hills and mountains. They extend from the edges of the alluvial flats to an elevation of 800 to 1,000 feet, where they begin to gradually thin out. The interspaces between the groups and areas of trees, which widen toward the higher altitudes, are filled with grass and with dense thickets of alder and willow. The general upper limit of the forests is at an altitude of about 1,200 feet, and the extreme upper limit of good trees is 1,700 feet. The trees on the lower slopes are very large and densely spaced, and the quality of the lumber is fair.

Mountain-top vegetation: The upper slopes and summit of the hills and mountains above the tree line, as defined above, are partly bare (see Pl. IV, *A*, p. 16) and partly covered with grass, small herbs and bushes, and stunted alders and spruce. It is worthy of note that vegetation of this type descends far lower in this region than is usual in this latitude. The importance of this characteristic lies in the fact that it restricts the area of valuable timber and affords easy travel in considerable areas above timber line.

SETTLEMENTS.

The post-office and chief trading center for the entire Controller Bay region is Katalla, which is situated on the shore of Katalla Bay and is now the landing place of the steamers. Chilkat, near the mouth of Bering River, is a mixed settlement of whites and natives and is a stopping place on the way up the river to the coal field. The town of Kayak, on Wingham Island, which was formerly a post-office and steamer landing, is now practically abandoned. There are no other settlements except the camps of the various coal and oil companies, which are scattered throughout all parts of the region.

TRANSPORTATION.

EXISTING FACILITIES.

The only communication with other regions is by water. Katalla is a regular stopping place for steamers from Seattle to Valdez and Seward, there being five or six boats a month. The voyage from Seattle to Katalla requires three and a half to four days "outside route" or seven to eight days "inside route" via Juneau. The nearest large towns are Juneau, which is from two to three days' journey to the east, and Valdez and Seward, which are from ten to eighteen hours and from twenty-four to thirty-six hours, respectively, to the west. There are telegraph and cable offices[a] at these towns. Valdez and the other Prince William Sound ports can also be reached by crossing the Copper Delta in a small boat to Orca, a two-day journey, from which place there is regular and frequent communica-

[a] Plans are also under way to connect Katalla with the existing cable.

tion with Valdez and the other Prince William Sound towns by launches, in addition to the ocean-steamer service.

There is regular transportation of passengers and freight from Katalla to all parts of Controller Bay and to Bering Lake by launches, and much of the rest of the region is accessible by means of canoes. Bering River as far as the mouth of Canyon Creek, Stillwater Creek, Shepherd Creek, Gandil, Nichawak, and Katalla rivers, and others of the larger streams are navigable for canoes and poling boats. Most of the local transportation is consequently effected in this way.

Land travel is not practicable except where trails have been built, because of the dense vegetation, the swampy character of the flats, and the large number of streams. Most of the trails are indicated on the maps (Pls. II, V, VIII). The most important of these trails include those from Katalla to Mirror Slough, from Katalla along the beach to Strawberry Harbor and to the head of Katalla Slough, from the mouth of Bering River to the head of Katalla Slough (which is practically a well-built wagon road), from the mouth of Dick Creek to Lake Tókun, from Canoe Landing up Shepherd Creek to Lake Charlotte with a branch from Carbon Creek across Kushtaka Ridge to Kushtaka Lake, from Canoe Landing direct to Kushtaka Lake, from the mouth of Stillwater Creek to Lake Kushtaka with branches up Clear and Trout creeks, from the mouth of Stillwater Creek up Canyon Creek, and across Carbon Mountain to First Berg Lake. From this last point the shores of Berg Lakes (see Pl. VI, *A*, p. 46) and a portion of the surface of Bering Glacier affords a highway into all the valleys opening on the lobe of Bering Glacier, which borders the five Berg Lakes. Other shorter trails reach practically all the camps which are not accessible by water. Short tramroads have been built from the head of Katalla Slough and from the mouth of Redwood Creek to neighboring oil wells and from Canoe Landing to a coal opening.

RAILWAY ROUTES.

Reference has already been made (p. 15) to the railway surveys which have hitherto been made or which are in progress. The object of these proposed roads is to make the Bering River coal accessible for shipment, or to provide a route [a] to the copper deposits and other resources of the Copper River region, or both. The conditions which will govern the selection of the route include the character of the harbor at the terminus, the cost of construction and operation of the road, and the prospective freight tonnage.

[a] Brooks, Alfred H., Railway routes: Bull. U. S. Geol. Survey No. 284, 1906, pp. 10–17; Railway routes in Alaska: Nat. Geog. Mag., 1907, pp. 16–190.

HARBORS.

The harbors which have been considered by the various interests purposing to build a railroad include Controller Bay, Katalla Bay, the shelter afforded by Fox and Whale islands, and Orca Bay.

Controller Bay gives good shelter for large vessels, but is often too rough for small boats. The anchorage is good and the channel deep, but the deep water is a long distance from shore. The broad shoals which border the bay on the north and east sides, the lack of shelter for small boats in the steamer anchorage, and the fact that the bay is more or less filled with ice in severe winters all count against Controller Bay as a railway terminus, although its use is admitted to be possible.

Katalla Bay has sufficient depth of water, good anchorage, and is entirely free from ice in all seasons. It is open between the south and southwest, but has good shelter from the north and east. Inasmuch as all severe storms come locally from the east and northeast, it is claimed by many that Katalla Bay in its present condition is a good harbor and that steamers could tie to wharves in it under all conditions. The deep-water anchorage is not safe for small boats in bad weather, but Katalla River and Slough give perfect shelter and can usually be entered at high tide by anything drawing less than 10 feet, although the bar is often dangerous for open boats except at flood tide. Plans have been made to build breakwaters which will give shelter from all directions at the proposed wharves.[a] Katalla Bay is perfectly practicable as a harbor, provided that severe storms do not come from the southwest or west, or that breakwaters can be built at reasonable cost.

Fox and Whale islands give good shelter except from the southwest and west, and have deep water close to the islands. The proposed plan [a] is to connect Whale Island with the mainland by a causeway (this interval is dry at half tide) and to build wharves from the west shore of Whale Island. A further suggestion is to build breakwaters connecting Whale and Fox islands and westward from the latter. This proposition is similar to that at Katalla Bay, except that deep water is nearer shore at the islands, but the area of natural shelter is smaller. Here, as at Katalla Bay, it is a question of safety from possible southwest storms and of cost of breakwaters.

Orca Bay is a good harbor, being large, deep, and perfectly sheltered. No harbor improvements would be necessary, except buoys and wharves. Its disadvantage as a harbor lies in its distance from the open sea, the entrance being around Cape Hinchinbrook (see Pl. I). As far as its possible use as port for the Controller region is concerned, it has the further disadvantage of distance by rail. This point will be discussed later (pp. 23–24).

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[a] Work was begun on this project in 1907.

ROUTES.

The possibilities of railway construction from any of the above-mentioned local harbors to the Bering River coal fields are well shown on the accompanying topographic map (Pl. II, pocket), and are also indicated by the lines of levels represented by the list of bench marks on page 13.

It can readily be seen from the map that grades are insignificant and that the only problems will be those connected with ballasting and bridges. The broad alluvial flats are swampy and are underlain by muck, consequently much ballast and ditching will be necessary.

A road from either harbor [a] in the vicinity of Katalla to the coal field will naturally follow the broad valley of Katalla River, cross the 65-foot (more or less) divide to Bering Lake, and trestle or fill across Bering Lake (which barely exceeds 5 feet in greatest depth and is for the most part much shallower). The bridges over Shepherd, Stillwater, and Canyon creeks will be small, but severe floods must be allowed for in building abutments.

If Controller Bay is used as the harbor the wharves might be built either from the south end of Kanak Island or from the east shore of the bay. In the former case a long bridge must be built to the mainland. The road could then go by the Katalla River route already described. From wharves on the east shore of the bay the road would naturally cross the flats on the east side of Bering River to a point opposite Shockum Mountains. A large amount of ballasting would be necessary on these swampy flats unless the road is located well to the east, where the flats are made up in part of sand and gravel. Many bridges, most of them small, would be required, the largest being over Bering River.

A railway from this region into the interior would either go west from Katalla along the ocean shore and up the east side of the Copper delta, or would go up Shepherd Creek (see Pls. I and II), over the 350-foot pass northwest of Lake Charlotte, and down the valley of Martin River to the Copper. Neither will encounter great difficulties until the site of the proposed [b] Copper River bridges, at Miles and Childs glaciers, is reached. The construction of bridges over glacial streams must always be a problem.

The route from Orca [c] to the coal field follows the foot of the mountains on the west side of Copper Delta until the bridge site, mentioned above, is reached. It would then follow the route, described above, from Copper River to the coal field. The disadvantages of this route consist in its length and its crossing Copper

[a] A railroad from each of these harbors was begun in 1907.

[b] Brooks, Alfred H., Railway routes: Bull. U. S. Geol. Survey No. 284, 1906, pp. 13–15; Railway routes in Alaska: Nat. Geog. Mag., 1907, pp. 182, 190.

[c] Construction was begun on a railroad from Cordova, a new town situated near Orca, in 1906.

River. A road from Orca to the interior[a] would cross Copper River twice, while one from a local harbor would cross it but once to reach the interior.

All the plans considered above are possible, and the choice must depend on questions of cost, including both the actual cost of operating the road and the interest on the original investment. There are no difficulties connected with building a railroad from any point on Controller Bay or Katalla Bay to the coal field, and the projects for a road from Orca to the coal field or from either terminus into the interior present no greater difficulties than have been overcome elsewhere. The important factors in the problem are, on one hand, the relative merits of a local harbor, questions of depth of water, holding ground, shelter from storms and from ice, and cost of improvements being considered; and, on the other hand, the cost of a longer road to a possibly better harbor farther west.

GEOLOGY.

GENERAL FEATURES.

The general succession of rocks in this region is shown in the following table:

General section of rocks of the Controller Bay region.

Age.	Formation name.	Character of rocks.	Thickness.
			Feet.
Quaternary.		Stream deposits, probably in part underlain by marine sediments.	0-500±
		Sediments and abandoned beaches of glacial lakes.	0-200±
		Morainal deposits.	0-100±
		Marine silt and clay.	100
Tertiary or later.		Diabase and basalt dikes.	
Tertiary	Tokun formation.	Sandstone.	500
		Shale.	2,000+
	Kushtaka formation.	Arkose with many coal beds.	2,500±
	Stillwater formation.	Shale and sandstone.	1,000±
	Katalla formation.[b]	Conglomerates, and sandstones and shales, some of which are conglomeratic.	2,500
		Sandstone.	500
		Shale, concretionary and with a glauconitic bed at the base.	2,000
		Sandstone.	1,000
		Shale.	500+
Pre-Tertiary.		Graywacke, slates, and igneous rocks.	

[a] Brooks, Alfred H., loc. cit.

[b] The position of the Katalla formation with reference to the other Tertiary formations is not definitely established. See discussion on pp. 37-41.

As the surface of the country is about equally divided between flat lowlands and hilly districts, so also the area of rock is equally divided between unconsolidated alluvial deposits and indurated complexly folded rocks. The geologic features in this respect exactly coincide with the topographic features, the hard rocks being entirely restricted to the hilly areas and the alluvium to the flats.

The hard rocks, except two areas of metamorphosed pre-Tertiary deposits and the dikes, are Tertiary sediments largely of marine origin. They have been completely indurated, and involved in complex structural disturbances in which close folding and faulting of diverse character have taken part. Igneous intrusion has taken place, but has played a small part. Both the intensity of the folding and the abundance of dikes are greatest in the northeast part of the district toward the high mountains.

NEIGHBORING PROVINCES.

As this province is topographically a foothill region on the edge of the Chugach Mountains, so in its stratigraphy and structure it partakes of the general geologic conditions bordering that mountain range.

The Chugach Mountains[a] consist of closely folded slates, schists, and gneisses, with large intrusive masses of granitic rocks. The detailed structure and stratigraphic succession are not known. In the Prince William Sound region the rocks consist of two metamorphosed sedimentary groups,[b] the Valdez "series" and the Orca "series," of undetermined but probably Paleozoic age. The latter is associated with greenstones derived from basic lava flows. Granitic masses and other intrusives are represented. In the Mount St. Elias-Yakutat Bay region [c] the rocks composing the high mountains comprise crystalline rocks, including schists and gneisses of undetermined but probably early Paleozoic age, granitic intrusives, slightly altered sedimentary rocks (Russell's "Yakutat system") of disputed age, but probably Mesozoic or late Paleozoic, and late Tertiary or post-Tertiary sediments (Russell's "Pinnacle system").

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[a] Brooks, Alfred H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 29–32, 227–228, 253–256. Schrader, F. C., and Spencer, Arthur C., The geology and mineral resources of a portion of the Copper River District, Alaska. A special publication of the U. S. Geol. Survey, 1901, pp. 32–39.

[b] Schrader and Spencer, op. cit. Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey No. 284, 1906, pp. 79–80.

[c] Russell, I. C., Nat. Geog. Mag. vol. 3, 1890, pp. 130–131, 140, 167, 170; Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 24–26, 34, 52, 90. Novarese, Inge Vittorio, Rocks and minerals of south Alaska: The ascent of Mount St. Elias, Appendix E, 1900, pp. 232–239. Tarr, R. S., The Yakutat Bay region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 61–63; Glacial geology and physiography of the Yakutat Bay region with a chapter on the bed-rock geology (in press). Blackwelder, Eliot, Reconnaissance on the Pacific coast from Yakutat to Alsek River: Bull. U. S. Geol. Survey No. 314, 1907, pp. 82–87.

The nature of the rocks in that part of the mountain belt which lies immediately behind the Controller Bay region is not known, except as the glaciers bring out fragments of a variety of granitic rocks, schists, gneisses, and greenstone.

The character of the contact of the rocks of the high mountains with those of the lower coastal belt is known only in Yakutat Bay region, where Russell and Tarr report the coarse crystallines as separated from the sedimentary rocks south of them by a fault. At the base of Mount St. Elias the crystallines are overthrust upon the younger rocks. The contact has not been studied between Mount St. Elias and Copper River, as most of the region has not been visited, while in the vicinity of Controller Bay the contact lies beneath glaciers. On Prince William Sound the high mountains run out into the sea and the coastal foothills are absent.

The Tertiary rocks of the Controller Bay region extend eastward beneath Bering glacier, and similar beds appear on the coast half way between Controller and Yakutat bays at Cape Yaktag, where gently folded shales and sandstones have been described [a] as outcropping in an anticline near and parallel to the coast.

DESCRIPTION OF THE ROCKS.

PRE-TERTIARY.

The metamorphic rocks of the Controller Bay region outcrop in two areas. One of these covers all of Wingham Island except the narrow southeast point. The other is west of Katalla in Ragged Mountain and in the low hills between it and the Copper Delta. The rocks consist of black slates having well-developed cleavage, graywacke, chert, a variety of highly colored fine-grained rocks of uncertain origin, and greenstone and other igneous rocks which probably include both bedded and intrusive masses. The observed contacts with the Tertiary rocks are faults, and these rocks are probably in both areas overthrust upon the Tertiary sediments.

The amount of metamorphism which these rocks have undergone as compared with the Tertiary rocks, which though in direct contact with them are entirely unmetamorphosed, proves a much greater age for the former and a great unconformity between them and the Tertiary rocks. The only fossils which have been discovered are numerous but poorly preserved *Globigerina* indeterminate species. The occurrence of *Globigerina* (assuming that the lower range of *Globigerina* has been finally determined) shows the rocks to be post-Carboniferous,

[a] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 264. Martin, G. C., The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, pp. 26–27; The Cape Yaktag placers; Bull. U. S. Geol. Survey No. 259, 1905, pp. 88–89.

while the degree of metamorphism shows them to be pre-Miocene. More definite evidence of their age is lacking.

The lithologic similarity of these older rocks to certain rocks at Orca,[a] Kodiak,[b] and Yakutat Bay,[c] is suggestive of a possibly corresponding age.

The correlation[d] of the rocks at Orca, Kodiak, and Yakutat is, in the writer's opinion, not positively established, while their reference[e] to the Lower Jurassic is based upon evidence which he regards as both insufficient and open to a different interpretation from that which has been drawn from it. The weight of the existing evidence concerning the age of the slaty rocks of the coast of the Gulf of Alaska from Yakutat to Kodiak is, in the writer's opinion, that they are almost certainly older than the Upper Triassic, and are probably, in part at least, late Paleozoic. The fragmentary evidence on the age of the slate and graywacke of the Controller Bay region suggests that these, too, may belong in the same general stratigraphic position.

TERTIARY.

KATALLA FORMATION.

DESCRIPTION.

The Katalla formation occupies the hilly area south of Bering Lake between Bering and Katalla rivers and the low hills between the base of the steep eastern slope of Ragged Mountain and Katalla River. Rocks which are probably, in part at least, equivalent to these outcrop in Gandil Mountain, Nichawak Mountain, Mount Campbell, and the neighboring small hills of the Nichawak region, on Kayak Island and on the southeast point of Wingham Island, in the low hills west of Bering Lake, and possibly in parts of the region north and northeast of Bering Lake.

The bulk of the formation is composed of soft, dark, argillaceous shales, in places with many limestone concretions and with at least one bed of glauconitic sand.

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[a] Schrader, F. C., and Spencer, Arthur C., The geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1901, pp. 33–40. Brooks, Alfred H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 225–230. Grant, U. S., Copper and other mineral resources of Prince William Sound: Bull. U. S. Geol. Survey No. 284, 1906, pp. 79–80.

[b] Brooks, Alfred H., loc. cit. Ulrich, E. O., Fossils and age of the Yakutat formation: Harriman Alaska Expedition, vol. 4, 1904, pp. 125–146.

[c] Ulrich, E. O., loc. cit. Brooks, Alfred H., loc. cit. Tarr, R. S., The Yakutat Bay region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 61–63; Glacial geology and physiography of the Yakutat Bay region, with a chapter on the bed-rock geology (in press). Blackwelder, Eliot, Reconnaissance on the Pacific coast from Yakutat to Alsek River: Bull. U. S. Geol. Survey No. 314, 1907, pp. 82–87.

[d] Emerson, B. K., Harriman Alaska Expedition, vol. 4, 1904, pp. 11–54.

[e] Ulrich, E. O., loc. cit.

Two[a] massive and prominent sandstones are present. One of these is at the top of the thickest and most prominent bed of shale. The other[a] is below the same shale, and is underlain by a bed of shale of the same character as the thicker shale above it.

The upper sandstone is overlain by conglomerates, sandstones, and shales, apparently of great thickness. The conglomerates, though massive, are of irregular extent and position, and grade locally into pebbly sandstone or shale, or lose their pebbles entirely. The more typical of the conglomerates contain usually well-rounded but unsorted pebbles of granite, greenstone, gneiss, and a variety of other rocks and minerals. The material ranges in size from that of very coarse sand up to a diameter of several feet, but is usually less than 6 inches in diameter. No glacial facets or scratches have been seen. The matrix consists of fine shale, sandstone, and arkose.

FOSSILS.

The following molluscan forms, obtained from the lower sandstone member, were determined by W. H. Dall:

From a prominent exposed rock just above the Chilkat Indian village on the west bank of Bering River: (4313) *Chionella, Cardium, Glycymeris, Macoma, Mya, Litorina,* and *Purpura,* too badly preserved to be specifically identified, but doubtless of Miocene age.

West shore of Bering River, just above Chilkat village: (4317) *Chionella, Macoma,* and *Acila.*

West shore of Bering River, one-half mile below Greene's cabin, or 1¼ miles above Chilkat: (4311) Young *Lunatia* (?).

West shore of Bering River, one-fourth mile below Greene's cabin, or 1½ miles above Chilkat: (4318) Fragments of extinct crab, starfish, echinoid, and ophiuran, and species of *Turbo* (?), *Isapis* (?), *Lunatia* (?), *Fusus* (?), a ribbed *Dentalium, Marcia* (?), *Chionella, Solen, Thracia, Mya, Periploma, Macoma, Acila,* and *Nucula.*

Bering River, west bank, 2 miles north of Chilkat: (4435) *Spisula* near *albaria* Conr., *Yoldia, Leda, Dentalium, Macoma* (?), *Angulus* (?), *Lunatia* sp., and indeterminable gastropods.

West bank of Bering River, opposite lower end of first island going upstream: (4320) *Macoma, Nucula, Leda,* and *Yoldia* sp. badly preserved; (4327) *Chionella* (?) in concretion; Miocene (?); (4314) *Phacoides* sp. and indeterminable gastropods.

Bluff on west bank of Bering River where the river flows from Bering Lake: (4315) *Scala, Neverita, Fusus, Chione* (?), *Phacoides, Spisula, Macoma,* and *Yoldia.*

Beach on south shore of Bering Lake, on first point west of its outlet: (4316) *Macoma, Neverita* (?); probably Miocene.

Split Creek, 100–200 yards above branch that heads against the Redwood Creek divide: (4323) *Pecten.*

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[a] There is a possibility that the writer is in error in regard to the existence of two sandstones and that there is but one, which is on top of the shale, the apparent lower one, with its underlying shales, being a repetition of the upper sandstone and shale by faulting. The evidence on this point will be discussed under Age and correlation (pp. 37–41) and Structure (p. 44).

The following echinoderms were determined by W. B. Clark:

Gulch back of Greene's cabin, Bering River: (4119) *Asterias* sp. This specimen is evidently a species of *Asterias*, although some of the finer diagnostic characters are lacking. In general outline and other characters it closely resembles the species which ranges from the middle Mesozoic to the Recent and is a common form throughout the Tertiary.

West shore of Bering River, 1½ miles above Chilkat: (4318) *Schizaster* sp. There are many specimens of this form, and although again some of the finer diagnostic characters are absent I know of no other genus to which I could as satisfactorily refer it. I am inclined to think it belongs here. The range of this genus is from the Eocene to the present, and it is a common form throughout the Tertiary. It is very similar to a common undetermined species of *Schizaster* from the upper Eocene of the Gulf, of which I have a good number of specimens from localities in Mississippi. It is hardly probable that it is actually the same species, although it is closely related.

I should be inclined to regard the beds as Tertiary, possibly later Eocene or early Miocene in case there is other corroborative paleontologic evidence. I am sorry that the Echinoderm forms lack some of the essential features to make their determination sure. There is a bare possibility that the supposed *Schizaster* might be a rather unusual form of a simpler Spantangoid, either *Hemiaster* or a related genus, in which case the deposits might be pre-Tertiary as far as the Echinoderm evidence is concerned. The fasciole, which is an external character of the test, is so poorly preserved that I can not determine with certainty all of its characters, and for that reason there must be some doubt in the matter.

The following plants obtained from the lower sandstone were identified by F. H. Knowlton:

South shore of Bering Lake, 1 mile east of Sinclair's cabin: Aside from a few fragments of dicotyledons there is but a single complete leaf. This appears to be *Liriodendron Meekii* Heer, at least so far as size and shape go, but as there is no nervation preserved it is impossible to identify it positively. If it is this species, the age should be Upper Cretaceous, but if not, it is impossible to state.

Bering River, 1 mile above Chilkat Village: A single specimen representing the base only of a leaf. Apparently *Daphnogene Kanii* Heer. Age Kenai.

Gulch back of Greene's cabin, Bering River: A number of dicotyledonous leaves but poorly preserved. Seem to represent species of *Quercus*, *Betula*, etc., but impossible to be positive. The age is presumably Kenai.

Mollrsks from the upper concretionary shale were identified as follows by W. H. Dall:

Mouth of Bering River, west bank, 100 feet east of waterfall: (4312) Miocene shales much crushed, containing species of *Chionella* (?), *Petricola*, *Thracia*, *Phacoides*, *Macoma*, *Thyasira*, *Yoldia*, *Acila*, *Neverita* (?), and *Buccinum*. (4436) *Phacoides*, probably *multilineata* Conrad, a large *Leda*, *Solemya*, *Limopsis*, *Dentalium*, some indeterminable gastropods, *Thracia ?*, *Petricola ?*, *Bela ?*, *Saxicava ?*, *Leda ?*.

Creek 1 mile below Greene's cabin, west bank of Bering River; elevation, 150 feet: (4328) Miocene shale with *Venericardia* near *ventricosa* Gould; a smooth *Dentalium* and species of *Bullaria*, *Lunatia*, *Mulinia* (?), and *Acila*, with fragments of crab.

West bank of Chilkat Creek, 2 miles above road: (4322) *Chrysodomus* (?), *Lunatia*, *Macoma*; probably Miocene.

Left bank of Burls Creek, ¾ mile south of a bare knoll and just opposite the mouth of two small streams that join as a fork just before emptying into Burls Creek: (4321) *Pseudamusium*, numerous but crushed so as to be indeterminable, and fragraments of Yoldia (?) Miocene (?).

Mitcher Creek, a tributary of Redwood Creek; elevation, 700 feet: (4326) Extinct crab in concretion.

Head of west fork of Arvesta Creek: (4325) *Pecten*, *Spondylus* (?), *Dentalium*, *Hemithyris*, and indeterminable coral recalling *Astrangia*.

The following mollusks from the upper sandstone and conglomeratic beds were determined by W. H. Dall:

Crest of ridge, 4 miles north of Point Hey: (4437) *Yoldia* sp. near *montereyensis* Dall.

Three-fourths of a mile northwest of Point Hey: (4324) Hard shale with fragments of *Neverita*, probably Miocene.

Near end of Point Hey: *Phacoides* (?) sp., *Callista* (?) sp., *Conus* sp., *Fusus* sp., A (medium), *Fusus* 2 sp. (small), *Turritella* sp., *Dentalium* sp. "Poor material, but the *Conus*, *Fusus*, and *Dentalium* look like Eocene forms."

Between Point Hey and Strawberry Point: *Astrodapis* (?) sp., *Semele* (?) sp., *Dentalium* sp.

South shore of Wingham Island: (4310) Small crab, of extinct species, and indeterminable species of *Solen*, *Macoma*, *Thracia*, *Leda*, *Yoldia*, and *Lunatia* (?). Probably Miocene.

Beach on northwest shore of Kayak Island. The signal station at south end of Wingham Island bears N. 8 E. (mag.) : (4390 *Marcia* like *subdiaphana* (not in place).

Near cabin on Kayak lagoon, Kayak Island: (4391) Crushed specimen of elongated *Unio*.

The rocks exposed on the northwest shore of Kayak Island consist of beds of conglomerate, sandstone, and shale, with a marine fauna, in which W. H. Dall and Ralph Arnold have identified the following species: *Leda* sp. A. (smooth), *Yoldia* aff. *scissurata* Dall, *Yoldia* aff. *thraciaformis* Dall, *Macoma* cf. *calcarea* Gmel., *Callista* sp., *Natica* sp., *Chrysodomus* sp. A., *Chrysodomus* sp. B., *Rostellites* cf. *indurata* Conrad.

STILLWATER FORMATION.

DESCRIPTION.

The Stillwater formation occupies the entire valley of Stillwater Creek and extends for some distance up the valleys of Trout and Clear creeks, eastward to Canyon Creek, and westward probably throughout the entire area of Shockum Mountains. Other areas are on the northern and western shores of Berg Lakes, on the west shore of Kushtaka Lake, and in the mountain north of Bering Lake.

The formation consists of shale and sandstone without characteristic beds so far as is now known. No detailed sections have been measured, but the thickness apparently exceeds 1,000 feet. The base of the formation has not been recognized.

FOSSILS.

The following fossils were determined by W. H. Dall:

Maxwell Creek, east of Grade Trail and one-half mile south of Lake Charlotte: (4380) Fragment of a smooth *Dentalium;* apparently the same species as is found in the rocks above the coal.

Tributary of Clear Creek, about 1 mile northeast of Cunningham's warehouse; elevation, 275 feet: (4384) Same as 4377.

Stillwater Creek, east bank, one-half mile below Clear Creek: (4434) *Crassatellites? Spisula?*

Float in bed of Maxwell Creek, one-half mile below Lake Charlotte: (4385) *Mactra? Cardium? Lunatia?* (Same fossils as found above the coal, marine.)

East side of moraine at head of Lake Charlotte, one-fourth mile from lake; elevation, 510 feet: (4381) *Cyrene?* and *Anodonta?* (freshwater), *Fusus? Arca? Macoma? Mactra? Saxidomus?* and *Dosinia?* (marine), shark tooth.

Eastern edge of glacier moraine, 200 feet above the level of Lake Charlotte: (4379) Single valve, recalling *Clementia.*

Lower eastern tributary of Sheep Creek, 200 yards below waterfall, and 1 mile from Sheep Creek: (4393) *Fusus? Leda, Yoldia, Macoma? Mactra?*

Lower eastern tributary of Sheep Creek, one-half mile above the mouth of the creek (float specimens): (4387) *Dentalium, Lunatia? Fusus? Yoldia, Solen, Spisula? Dosinia?* (4392) *Dentalium, Buccinum? Fusus? Leda, Mactra,*

Head of Bering River, just below upper falls: (4397) *Fusus? Lunatia? Spisula?*

Bering River, one-fourth mile below gorge: (4394) *Fusus? Mactra?*

KUSHTAKA FORMATION.

DESCRIPTION.

The Kushtaka formation occupies part of the crest and much of the eastern slope of Kushtaka Ridge, and extends westward throughout the valley of Carbon Creek and up the east side of Shepherd Creek to Lake Charlotte. The largest known area extends in a broad belt from the eastern edge of Kushtaka Glacier to the northeast corner of the area mapped. There are two or more small areas in the southern part of Carbon Mountain. A large area lies on the north shore of Bering Lake and extends across the mountain from Shepherd Creek to Dick Creek. Another large area reaches from near the south end of Lake Charlotte to the east end of Lake Tokun and extends south on the mountain side for about 2 miles.

The Kushtaka formation overlies the Stillwater formation, probably conformably, although as the contacts are in many places faults the exact relations are none too well known.

It consists predominantly of coarse arkose, although some sandstone and much shale are present. It contains a large but unknown number of coal beds. Marine conditions are not known to be represented.

The thickness exceeds 2,000 feet, the exact total not being known. The following sections represent the upper part of the formation and are probably characteristic in a general way of the entire thickness.

Section of upper part of Kushtaka formation in valley of Carbon Creek.

	Ft.	in.
Black shale (overlain[a] by Tokun formation).		
Coal		4
Dark blackish shale	9	
Coal		10
Dark blackish shale	15	
Coal		4
Dark blackish shales with several more or less carbonaceous layers	26	
Thin-bedded arkose with shale	26	
Sandy shale	86	
Arkose	535	
Sandy shale	141	
Arkose	27	
Sandy shale	35	
Flaggy and thin-bedded arkosic sandstone with thin calcareous beds	398	
Thin-bedded arkose sandstone	44	
Thin-bedded sandy shale with calcareous concretions	167	
Coal with shale; outcrop obscured, about 6 feet of clean coal estimated	14	2
Shale	25	
Carbonaceous shale	1	
Coal	2	8
Shale		4
Coal	1	11
Shale	1	
Sandy shale with concretions	84	
Carbonaceous shale, somewhat crumpled	2	
Sandy shale	20	
Carbonaceous shale	1	
Sandy shale (bluish)	34	
Coaly beds or carbonaceous shale	4	11
Sandy shale with calcareous concretions	39	
Base of section in bottom of Carbon Creek at an elevation of 1,250 feet, but the coal series continues on downward.		
	1,741	6

Section of Kushtaka formation on crest of Kushtaka Ridge.[b]

	Ft.	in.
Shale, carbonaceous (overlain by Tokun formation)		2
Shale		6
Coal (shaly at bottom for 1 foot)	3	2
Shale (dark, but weathers brownish red)	9	
Coal	4	8
Shale (dark, with some coal)	9	4

[a] See footnote, p. 35.
[b] The uppermost bed is 80 feet below U. S. L. M., Kayak No. 4.

	Ft.	In.
Shale, blue, sandy	48	
Arkose	231	
Shale, dark	9	
Shale, carbonaceous (with bands of coal 6 to 12 inches thick—exposure poor)	45	
Arkose, flaggy and fine-grained	93	
Shale, carbonaceous	2	
Coal	2	3
Shale, carbonaceous		5
Arkose, flaggy and fine-grained	127	
Fine-grained blue shale	291	
Coal (exposure not good, estimated with shale)	11	7
Shale	5	
Arkose, flaggy	41	
Shale	4	
Carbonaceous shale with coal (exposure obscure)	23	
Arkose, flaggy	163	
Shale, dark (with thin coal streaks ½-inch thick)	5	
Coal		6
Shale	1	
Coal		6
Shale	2	
Coal		5
Shale	9	
Arkose, flaggy	29	
Shale	2	
Shale, carbonaceous	5	
Arkose, flaggy	4	
Shale	14	
Arkose, flaggy	11	
Shale	7	
Coal	3	
Shale		6
Coal		6
Shale		6
Coal	1	
Shale	2	
Arkose, flaggy	36	
Shale	4	
Arkose, flaggy	24	
Shale, dark	2	
Coal, clean	8	
Shale, carbonaceous	1	
Shale	35	
Arkose, flaggy	77	
Shale	2	
Arkose, flaggy	74	
Shale, sandy	15	
Arkose, flaggy	25	
Shale, with coal streaks	5	
Coal	1	
Shale	2	
Coal, clean	5	

	Ft.	in.
Shale	287	
Arkose	130	
Shale	87	
Base of section at anticlinal axis on divide at head of Carbon Creek.		
	2,041	

Section of upper part of Kushtaka formation on southern end of Cunningham Ridge.

	Ft.	in.
Arkose, possibly with thin beds of coal	60	
Coal (5 to 6 feet thick with shale)	10	
Arkose	37	
Thin-bedded arkose	46	
Coal	1	
Thin-bedded shaly arkose	92	
Dark shale	29	
Coaly shale		5
Coal	1	
Dark shale with calcareous concretions	50	
Shale	1	
Coal		4
Shale		4
Coal	10	
Shale	1	
Coal	2	4
Shale	2	
Dark shale with concretions, several thin beds of arkose, and several beds of coal whose thickness could not be determined	153	
Thin-bedded arkose	33	
Dark shale	12	
Measurement stopped because of irregularity of the beds.		
	541	5

FOSSILS.

The following molluscan forms were identified by W. H. Dall:

Coal opening[a] near Grade Trail Cabin, 15 feet west of coal. (4386) *Mactra or Spisula? Nassa?*

The following plants were identified by F. H. Knowlton:

Grade Trail Cabin coal opening, along west contact of shale with coal: *Aralia* sp. cf. *A. Jorgensi* Heer, dicotyledonous leaves, fragments of large leaves, stems. *Aralia Jorgensi* Heer is of Miocene age, and while the *Aralia* in this collection is not quite the same it is pretty close, and for this reason I should incline to regard the age as Miocene.

About 150 feet southwest of U. S. L. M., Kayak No. 4. One specimen with good outline but no nervation. Probably a *Sapindus*, or something of the kind. Not sufficient to determine age.

About 100 yards southeast of group of four small lakes, about 1¼ miles northeast of Lake Charlotte: Two specimens with fairly good outline, but no nerva-

[a] See section No. 66, p. 78, and Pl. VIII.

tion. Probably leaflets of some leguminous plant, but not sufficient to settle age.

Bed of creek flowing into head of Canyon Creek from Mount Chezum, at an elevation of 2,000 feet: *Dryopteris* sp. cf. *Pteris frigida* Heer, *Cornus* sp., *Juglans* sp. "*Pteris frigida*" is normally a Cretaceous species, but the particular specimen with which this is compared was from a Tertiary (Miocene?) horizon. The generic reference is undoubtedly wrong. The two dicotyledons mentioned are very modern in appearance, and on this insecure basis I should incline to regard the age as Miocene.

Lower eastern tributary of Sheep Creek, one-half mile above its mouth: A single broken specimen. Suggests *Andromeda grayana* Heer. The age is uncertain, but if this species is correctly identified it should be Kenai.

Elevation of 1,000 feet on creek emptying into First Berg Lake, where trail from Happy Hollow passes around the shore. *Dryopteris* sp., *Quercus* sp., *Ficus* sp., *Ulmus* sp., *Juglans* sp., *Cornus* sp. This material is ample in amount and beautifully preserved. The fern is a splendid species and appears to be new, as, indeed, do all the other forms. So far as I am able to determine, this is not Kenai in age, but just what the age is I am uncertain. I should think it ought to be Miocene, but without an extensive comparison with known Miocene floras its exact position is in doubt.

Lower eastern tributary of Sheep Creek, one-half mile above its mouth: *Quercus?* sp., *Ficus?* sp. Age unknown, possibly Kenai.

Near head of Bering River (float specimens collected by Prof. W. O. Crosby). *Salix* sp. cf. *S. varians* Heer, *Corylus Macquarrii* (Forbes) Heer, *Betula prisca* Ett., *Betula grandifolia* Ett.: These are well-known forms found in the so-called Arctic Miocene, and indicate this age for the beds whence they came.

TOKUN FORMATION.

DESCRIPTION.

The Tokun formation outcrops on both shores of Lake Tokun and extends thence north and northeast to the edge of the flats bordering Martin River Glacier and to Lake Charlotte. It also covers large areas on the crests and northwest slopes of Carbon and Charlotte ridges, on the west slope of Kushtaka Ridge, on the ridge north of Mount Hamilton, and on the northwest slope of Cunningham Ridge.

These beds overlie the Kushtaka formation conformably, the transition apparently representing a change from fresh-water to marine conditions. The formation is at least 2,500 feet thick, the lower 2,000 feet consisting chiefly of sandy shales, which are well shown in the following section:

Section of the Tokun formation[a] *on the crest of Carbon Ridge.*

	Ft.	In.
Sandy shale, poorly exposed, possibly more above	248	8
Sandy shale (top of this makes highest point of Carbon Ridge)	46	5
Fine shaly sandstone	17	5
Fine sandy shale	72	1
Sandy shale	139	5
Fine-grained shaly sandstone	40	4

[a] The section of the Kushtaka formation on pp. 32–34 underlies this without a break.

	Ft.	in.
Dark-gray fine-grained shales	135	11
Gray fine-grained shale with some thin sandstone and beds of calcareous concretions	163	2
Gray sandy shale	421	6
Fine sandy shale with some limestone beds	278	3
Arkose	285	6
Fine, gray, sandy shale	13	7
Arkose (coarse at base, fine-bedded at top)	150	10
Black shale, somewhat crumpled (underlain by the Kushtaka formation	5	
	2,018	1

The shales (not all of which are represented in the section) are overlain by a bed of sandstone several hundred (possibly 500) feet thick. This sandstone is well exposed on the hills northeast of Lake Tokun and west of Lake Charlotte. The beds overlying this sandstone contain some shale, but are not well exposed.

FOSSILS.

The following mollusks were identified by W. H. Dall:

One-half mile northeast of Summit Cabin, Kushtaka Ridge, 250 feet above large coal seam on Queen Creek and near the base of the Tokun formation: (4440) *Spisula, Fusus, Lunatia, Leda, Solen, Lucina* probably *multilineata* Conrad, *Molopophorus* sp.? (4378) Same as 4377, with the addition of the print of a large *Semele?*

Fine-grained flaggy sandstone with thin calcareous beds, 1,000 feet S. 60° E. of Queen coal opening; elevation, 1,600 to 1,700 feet. (4377) *Fusus* or *Latirus, Litorina? Nassa? Yoldia, Leda, Lunatia? Mytilus, Macoma, Solen, Mactra* or *Spisula,* and *Cytherea?* or some Veneroid form.

One-half mile northeast of locality No. 4440, on crest of Kushtaka Ridge (on the strike from locality No. 4440): (4441) *Leda, Yoldia? Spisula?*

Southeast edge of Kushtaka Glacier, about 1¾ miles from Kushtaka Lake; elevation, 350 feet: (4382) Fragments of the arms of an ophiuran.

Southeast edge of Kushtaka Glacier, about 2 miles from Kushtaka Lake; elevation, 480 feet: (4383) *Haminea* or *Bullaria, Yoldia,* and *Macoma.*

Gap between Mount Chezum and Monument Mountain: (4395) *Fusus? Lunatia? Mactra* or *Spisula?*

One-fourth mile northeast of Mount Chezum, in deep canyon: (4438) *Lunatia, Diplodonta? Dentalium, Fusus, Spisula, Mactra? Macoma?*

Middle fork of Trout Creek near its head: (4396) *Fusus?* fragm. of bivalves.

UNDIFFERENTIATED TERTIARY.

The areas represented on the map (Pl. V, pocket) as undifferentiated shale and sandstone probably consist predominantly of the rocks of the Katalla formation, except on the south end of Carbon Mountain, where they represent either the Stillwater, Kushtaka, or Tokun formations. These areas are those in which the geologic work was not finished with sufficient detail to show the boundaries of the formations.

AGE AND CORRELATION.

The Tertiary sediments, as shown in the preceding pages, consist of monotonous repetitions of shales and sandstones, with an included mass of coal-bearing arkose and one or more massive conglomerates. The total thickness, as shown in the following table, is many thousand feet. The structure of the region in which these rocks outcrop is complex; exposures at critical points are often wanting; and neither the lithologic character of the beds nor the fossils which they contain are sufficiently distinctive to make it possible to recognize with certainty the complete stratigraphic succession.

The presence of two easily recognized horizons, the arkose and the conglomerate, give distinctive character to two parts of the stratigraphic column. The arkose, with its associated coal, is restricted in areal distribution to the region north of Bering Lake, and the conglomerate to the region south of the lake. Between these regions are areas of no outcrops, and none of the beds of either region can be recognized with certainty in the other.

Section north of Bering Lake.

		Feet.
Tokun formation.	*a.* Sandstone	500
	b. Shale with thin, flaggy sandstones and with occasional calcareous concretions	2,000+
Kushtaka formation.	*c.* Arkose with many coal beds and with some shale and sandstone	2,500±
Stillwater formation.	*d.* Shale and sandstone	1,000+

Section south of Bering Lake.

Katalla formation.	*e.* Conglomerate and conglomeratic sandstones interbedded with shale and sandstone	2,500
	f. Flaggy sandstone	500±
	g. Soft shale with calcareous concretions and with bed of glauconitic sand near base	2,000
	h. Sandstone	1,000
	i. Soft shale	500+

The succession in each of these sections may be assumed as reasonably correct, although there is a possibility that the thicknesses are too great because of there having been repetition of the less characteristic beds by faulting. The correlation of the beds of one section with those of the other rests at present upon evidence which is incomplete and unsatisfactory, and must be regarded as suggestive rather than conclusive. It is probable that one of two correlations is true: The shale and sandstone of the Stillwater formation (*d*) may overlie the conglomerates (*e*) of the Katalla formation with a concealed interval of unknown extent between them, or *a* and *b* may be identical with *h* and *i*. In the former case the conglomerates underlie the coal field; in the latter case the coal underlies all, or nearly all, of the entire region under discussion. The stratigraphic and structural field evidence proves nothing either way, but suggests, as the most probable relation, that the entire section north of Bering Lake overlies the section south of the lake.

The Tertiary rocks contain fossils at many localities, but they are usually poorly preserved or not characteristic. They consist chiefly of leaves and of marine Mollusca, but include also a few echinoids, Crustacea, fish, and fresh or brackish water Mollusca.

The strata and localities which yielded the more important fossils are as follows:

1. Sandstones of the lower part of the Tokun formation, yielding abundant marine Mollusca at several localities.
2. Arkose and coal beds of the Kushtaka formation, yielding fossil leaves at many localities.
3. Shales and sandstones of the Stillwater formation, yielding poorly preserved Mollusca of both marine and fresh-water types.
4. Shale and sandstone associated with conglomerates at localities on Kayak Island and elsewhere, yielding marine Mollusca. The localities on the mainland are in the upper part (*e*) of the Katalla formation. The conglomerates on Kayak and Wingham islands are correlated with the other conglomerates on purely lithologic evidence.
5. Sandstone (*f*) underlying the conglomerate of the Katalla formation, yielding a few marine fossils.
6. Soft shales (*g*) of the Katalla formation, yielding marine Mollusca, Crustacea, and fish.
7. Lower sandstone (*h*) of the Katalla formation, yielding marine Mollusca and echinoids at several localities on the banks of Bering River and elsewhere.

Dr. W. H. Dall, after examining the fossils collected in 1905 in the region north of Bering Lake from the Tokun and Stillwater formations, said:

> In regard to the fossils themselves it should be premised that they consist of crushed and distorted shells in a very tough and hard matrix which wholly conceals the muscular impressions and hinges of bivalves, and the aperture and pillar of gasteropods, so that in most cases even the genus is uncertain, and in the present state of our knowledge it is impossible to make specific identifications. Hereafter when we shall know the Tertiary faunas of the Pacific coast thoroughly it may be possible to identify several of these species, but not till then.
>
> I may add that there are no characteristic Eocene or Miocene types in the specimens collected; that the fauna below the coal appears to be identical with that above it; that the *Marcia* and *Clementia* point in the direction of Oligocene age; that the mixture of fresh water and salt water forms indicates a location near salt water but with fresh water near by, as in a river delta. I may express the suggestion that the fauna is marine Oligocene corresponding to the marine phase of the Kenai group, hitherto unknown. It is certainly not Eocene, and if Miocene, not the same fauna as the Astoria or Coos Bay (Empire beds)

Miocene fauna, and apparently not that of the *Crepidula* bed which overlies the leaf beds at Unga and on Popoff Island, Shumagins. However, the fauna of the latter is meager and one may not be positive as to its relations to the Controller Bay beds.

Doctor Dall submitted the following comments on the material collected in the same year from the various members of the Katalla formation:

The material is apparently all of one age and contains but one fauna, which seems to be Miocene. The bad condition of the fossils, which have been crushed and distorted, makes it impracticable to identify most of them specifically, but there are several Miocene species among them.

The prevalence of types closely recalling recent species of the same region leads to the belief that it is upper Miocene, and possibly might be even Pliocene in age, though the latter is unlikely. The rock varies from very hard tough shale to a crumbling soft sand rock, not resembling any Pliocene matrix I have seen from the coast.

Doctor Dall's report on the material collected in 1906 from the Tokun and Katalla formations is as follows:

The rocks in which these fossils are contained have been much heated, crushed, and consolidated; hence the fossils have been disturbed and broken, and, in the majority of cases, retain only impressions which, in the case of bivalves, show neither the hinge nor the muscular impressions. In many cases even the genera can only be guessed at, and the species is determinable for only one or two forms, and then except in one case, with some doubt. There is a strong probability that somewhere in the vicinity the same rocks may exist in better condition, containing recognizable fossils which, when worked out, would enable us to recognize those in worse condition, but at present this is not practicable. The fauna, so far as it can be determined, seems to be nearly or quite the same in all the localities mentioned, with the possible exception of No. 4434. Unfortunately there is very little that is characteristic in any of it. With the exception of No. 4434 the aspect is Miocene and there are two species which resemble Astoria Miocene forms very closely. No. 4434 is possibly Oligocene.

The paleontologic evidence may be summarized as follows:[a]

1. The marine Mollusca from the sandstone of the Tokun formation are either so poorly preserved as not to admit of specific identification or belong to undescribed species.[b] They are almost certainly Miocene, but can not be definitely correlated with any known Miocene faunas of other regions.

2. The plants from the coal-bearing rocks include poorly preserved individuals which suggest species of the Kenai formation of Cook Inlet, generally considered to belong in the upper Eocene or Oligocene. The best preserved specimens, however, represent species which are not known in the Kenai and which are suggestive of later Tertiary age. There is no positive evidence that the exact equivalent of the Kenai occurs in this region.

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[a] Data furnished by W. H. Dall and Ralph Arnold on the Mollusca, F. H. Knowlton on the plants, and by W. B. Clark on the echinoids.

[b] This statement applies to all the faunas of this region.

3. The fossils of the Stillwater formation are poorly preserved, few, and not characteristic. There are no positive points of difference between this fauna and that of the Tokun formation, and it does not indicate age more closely than Tertiary.

4. The marine Mollusca from the shales of the conglomeratic beds on Kayak Island are better preserved than most of the other faunas of the region. They include among other forms a species of *Rostellites* which is considered characteristic of the Oligocene. The conglomeratic beds at the top of the Katalla formation on the mainland have not yielded characteristic fossils and are to be correlated with those on the island only on lithologic evidence.

5. The sandstones (*f*) underlying the conglomerates have yielded no fossils of positive significance in indicating age. Dall and Arnold have suggested [a] that some of these look like Eocene forms.

6. The marine Mollusca from the shales of the Katalla formation (*g* of the section on p. 37) are later than Eocene and are possibly Oligocene, though probably Miocene.

7. The marine Mollusca of the lower standstone (*h*) of the Katalla formation, as exposed on the banks of Bering River, are Miocene, and Dall suggests that they are of the same age as the fauna of the Tokun formation. The echinoids from the same beds and localities are not distinctive.

It may be seen from the preceding paragraphs that the faunas and floras are of little aid in correlating these beds with those of other regions and yield no satisfactory evidence as to the relation of these beds among themselves. There is no doubt that the entire sequence is Tertiary and post-Eocene; i. e., Oligocene or younger. The rocks of the coal field (Tokun, Kushtaka, and Stillwater formations) may with reasonable certainty be placed in the Miocene, with their base probably extending down into the Oligocene. The section south of Bering Lake presents more difficulties. If the lower beds of this section be correlated with the higher beds of the coal field the section would be all Miocene or younger. We must then conclude either that the conglomerates of the hills south of Bering Lake belong at the top of the section and are late Miocene or younger (in which case they can not be the same as the Oligocene conglomerates of Kayak Island), or that they have been placed in an abnormal position by an undetected fault, or that the determination of the Oligocene *Rostellites* is incorrect. If, on the other hand, it be assumed that the sequence in the section south of Bering Lake, as given on p. 37, is correct and that this entire section belongs below the section exposed in the coal field, then the reference of the conglomerate to the Oligocene would fit in with the reference of the rocks overlying the coal to the Miocene, and of

[a] Bull. U. S. Geol. Survey No. 250, 1905, p. 14.

the coal measures to the Miocene or Oligocene. The difficulty would then be with the lower part of the section south of the lake, and it must be assumed either that the reference of these faunas to the Miocene is incorrect and that they are Oligocene or older, or that they have been displaced by a fault of which the existence and position have been overlooked.

The stratigraphy and structure are complicated and are none too well known, but on their evidence, taking it for what it is worth, the author would be inclined to place all the rocks south of Bering Lake, with the conglomerates (correlated with those on Kayak and Wingham islands) at their top, below the section exposed in the coal field. He would then interpret the paleontology to mean that the rocks south of Bering Lake are Oligocene, that the coal measures are Oligocene with a possible transition to the Miocene, and that all the rocks above the coal are Miocene. The faunal discrepancies would then be explained as due to the insufficiency of the material at hand from these localities, and of the data for correlation with faunas representing similar geographic conditions in other localities. But if the paleontology requires it, if further study confirms the suggestion of correlations made above, then the stratigraphy and structure can and should be interpreted to meet the requirements of the paleontology. It would be strange indeed if the writer's interpretation of such structure as this should be supported in all respects by more refined methods of work.

IGNEOUS ROCKS.

Small dikes and sills are very abundant in the Tertiary rocks, especially north and east of Stillwater Creek. None were recorded between Stillwater Creek and Bering Lake, but several were seen in the region south of Bering Lake. Most of these masses are less than 1 or 2 feet thick, and none could be followed along the surface for any considerable distance. The largest and most noticeable are indicated on the geologic map (Pl. V, pocket).

Basalt is the predominant kind of rock, although three of the larger dikes were found to be of diabase. One of these, on the crest of the hill between Katalla River and Clear Creek, has a width of about 20 feet and a length of several hundred feet, and is the largest dike seen in the Tertiary rocks of the mainland.

The small basalt sills are especially interesting for the reason that they were frequently intruded along coal beds, and have altered the coal for a few inches from the contact to a dense coke with well-marked columnar joints normal to the surface of the sill.

A large mass of basaltic glass, with augite and olivine phenocrysts, was seen on the west shore of Kayak Island. It is associated with Tertiary shale and conglomerate and is probably extrusive.

Another large mass of extrusive material was seen at the north end of Kayak Island. It is of tuffaceous character, but the mineralogic composition and the stratigraphic relations were not determined.

The high southern peak of Kayak Island, known as Cape St. Elias (see Pl. IV, *B*, p. 16), and the neighboring rocky spire are seen, from the passing steamers, to be composed of a white rock, with well-developed basaltic columns, apparently of igneous character, and different from anything seen elsewhere in the region. The neighboring beaches are also composed of white pebbles which extend in gradually diminishing proportion as far as the north end of the island, where specimens were collected which proved to be dacite.

The metamorphic rocks on Wingham Island and in Ragged Mountain are associated with large numbers of igneous masses of diverse character. Most of them are much altered, in some cases to greenstone. No attempt has been made to show on the map the distribution of the various masses or to determine their microscopic character.

STRUCTURE.

The pre-Quaternary rocks of this region have a general northeast strike; have steep dips, which are northwestward throughout the

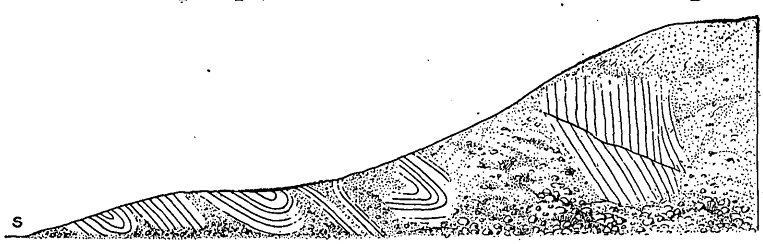


FIG. 1.—Structure on a creek in the northeast part of Bering River coal field.

greater part of the region; and are faulted. The northeast strike and northwest dip are the dominant structural features of the region. The strike varies from the northeast most markedly between Kushtaka Lake and Berg Lakes, where it is east and west, and at points in and north of the valley of Burls Creek, where it is northwest.

Monoclinal northwest dip holds throughout the greater part of the region east of Kushtaka Glacier and Kushtaka Lake. In the northeast part of this region the structure is not as simple as the uniform strike and monoclinal dip seem to indicate. The folds are in part overturned, in places complexly so, and a complicated system of overthrust faults, shown in fig. 1, adds to the complexity of the structure, which gradually increases from southwest to northeast.

The structure between Kushtaka Lake and Shepherd Creek is somewhat more simple than in the eastern district described above. In the greater part of this region the folds are open, the strike northeast, and the dip northwest, although southeast dips occur in several areas and there is considerable variation in strike along the valley of Shepherd Creek. The structural features of this region can readily be seen by inspection of the geologic map and structure sections (Pl. V, pocket). At least four faults traverse this area. An overthrust near the crest of the southern end of Kushtaka Ridge has cut out the Kushtaka formation and brought the Tokun and Stillwater formations in contact with each other. Another fault of somewhat uncertain character extends along the western side of and about half way down Kushtaka Ridge. Along the eastern side of the valley of Shepherd Creek, from a point near the northern end of Lake Charlotte to 1½ miles below the lake, two faults bound a block of southeastward-dipping Kushtaka formation between northwestward-dipping rocks of the Tokun formation. An anticline has its axis on Carbon Creek, and another, which is probably a prong of the former, on Queen Creek. Between these a synclinal mass of the Tokun formation lies transversely across the crest of Kushtaka Ridge.

The region west of Shepherd Creek presents a variety of features. The belt of Tokun formation extending northeast and southwest from Lake Tokun contains regular structure with northeast strike and northwest dip. South of this is a syncline containing the rocks of the Kushtaka formation. This fold has an axis oblique to the general neighboring structure, is cut off on its northwest side by a fault, and has a steep northward pitch. Farther south the fault, already described as extending along the western side of Kushtaka Ridge, crosses this ridge diagonally from Shepherd Creek to Dick Creek, and along it the Stillwater formation is overthrust upon the Tokun formation. South of this fault are several folds, most of which are open. Faults probably are present, but were not detected.

The peninsula south of Bering Lake shows considerable diversity of structure. The region east of Burls Creek has north and northeast strikes, and both east and west dips. An anticline extends along the canyon of Chilkat Creek, its western flank being broken by a fault. East of this fold are several minor ones, the most noticeable being a closely compressed syncline extending diagonally across the southern end of the ridge east of Chilkat Creek, and shown on the map by the position of a belt of sandstone. It is highly probable that the western bank of the lower north and south course of Bering River is on the line of a fault.

The valley of Burls Creek and the hills northeast of it contain several folds which are revealed by the sinuous boundary of the shale and sandstone. These folds descend into the valley of Burls Creek and die out or are cut off by a fault against the steep western side of the valley.

The hills between Burls and Redwood creeks have an anticline extending northeast and southwest through the headwaters of Split

Creek. North of this is a spoon-shaped syncline, divided from the anticline by a fault. South of the anticline the monoclinal southward dip continues to the edge of the flats bordering Controller Bay. The structure of this area is shown on Pl. V (pocket). Possibly the valley of the upper east fork of Redwood Creek contains a fault which has caused a repetition of the shales and sandstones. In this case the shale in the valley of Split Creek is the same as that on the headwaters of Redwood Creek, and the sandstone on the ridge north of Redwood Creek is the same as the sandstone underlying the conglomerate on the ridge south of it. Another possibility is that the upper valley of Redwood Creek and the ridge north of it each contain a closely compressed and overturned anticline and syncline, which would cause a repetition of the beds similar to that which would occur by faulting. The shales and sandstones are near enough alike to admit of this possibility, but the fault or folds have not been found, and the presence of two shales and sandstones is indicated in other localities. These possibilities have been alluded to in the description of the Katalla formation on page 28.

The fact that the sandstones and conglomerates east of Redwood Creek are not found west of it indicates that a fault of considerable magnitude extends along the course of the creek. The hills between Redwood Creek and Katalla River have an irregular syncline on their southern end, and several small, closely compressed folds immediately west of it. An anticline lies southeast of this fold, extending southwestward from near the oil-drillers' camp at Redwood, where it is probably cut off by the Redwood Creek fault, to near the head of Katalla Slough. The northern end of the ridge west of Redwood Creek has monoclinal southeast dip.

The rocks of the crescent-shaped hill, extending from Cave Point to Point Hey, have curving strike parallel to the crest of the hill and dip toward its concave, seaward face. This appears to be the end of a seaward-pitching syncline, of which only the nose remains above the ocean. The rocks between Katalla River and the base of the steep eastern slope of Ragged Mountain have a general northeast strike and a diversity of dips which have not been interpreted.

The base of the steep mountain slope mentioned above lies on the line of contact between the Katalla formation and metamorphic rocks. The latter strike east and west, have steep and diverse dips, and are considered to be overthrust upon the younger shales of the Katalla formation.

Similar relations hold on Wingham Island, between the same metamorphic rocks and the Tertiary sandstone which is in contact with them. The sandstone and the slate here have parallel strike.

The rocks of Kayak Island strike parallel to the length of the island and have steep, often vertical, dips.

The structure of the Nichawak region has not been determined.

The structural features as described above show that these rocks have been involved in very violent crustal movements. The rocks, in spite of the apparent simplicity of structure in areas of uniform monoclinal dip, show, on closer study, that much of the simplicity is only apparent, and that extreme complexity dominates the structural features. The problems involved are illusive, and it must be admitted not only that our present knowledge of the structural details in most of the area is incomplete and unsatisfactory, but that even the broader scheme of the structure is not definitely known.

The presence of numerous faults has been alluded to above. Other faults are doubtless present, and faulting has probably played a large and important part in the development of the structure.

Certain facts concerning the presence and distribution of petroleum, which will be described later (p. 115), call for structural theories, which are not required by the distribution and attitude of the rocks at the surface. The facts difficult of explanation are (1) the presence of light-gravity petroleum, which yields on distillation a large proportion of naphthas and kerosene, in Tertiary rocks which have been highly folded, and (2) the distribution of the oil seepages in a narrow belt which is diagonal both to the structure and to belts of outcrop of rocks of different kinds.

The theory suggested in explanation of these facts will be presented in greater detail below (p. 115). This theory supposes (1) that there was, in late Tertiary or in post-Tertiary time, a zone of intense deformation in the present position of the Chugach Mountains, but that these conditions did not extend into the coastal part of the region here described; (2) that the rocks now outcropping on the shore of Controller Bay were then well to the north of their present position and were involved in these intense movements; (3) that, as a final stage in this deformation, the Tertiary rocks rode southward in one or more great overthrusts and came to rest upon Mesozoic strata, which were at a distance from the zone of intense deformation and hence not affected by it. This theory, although not directly supported by any known facts of structural detail, fits in with many facts which are otherwise unexplained. It gives significance to the straight shore of this part of the Pacific Ocean and to the clearly defined line parallel to it, which separates the high Chugach Mountains from the lower foothills. It accounts for the local absence of the Mesozoic rocks, which are so well developed (see p. 115), both north of the Chugach Mountains and in the Cook Inlet and Alaska Peninsula regions. It explains the presence of light-gravity petroleum in rocks of this age and degree of deformation, and also the distribution of the petroleum at variance with the surface stratigraphy and structure. It is not contradicted or made improbable by any known facts of the local geology, but is supported by the fact that at the base of Mount St. Elias,[a] not far to the east and in the same position relative to the Chugach Mountains and to the Pacific shore, gneisses are known to be overthrust upon the younger and possibly upon Pliocene or Pleistocene rocks.

QUATERNARY.

MARINE SILT AND CLAY.

These deposits are best exposed on the west shore of the southeast point of Wingham Island, where they out crop in the sea cliff for one-third of a mile. They are bounded on the east by vertical conglomerate and on the west by steeply dipping sandstone. The eroded surface of the upturned edges of these Tertiary rocks have been cut or warped into a shallow trough in which the younger beds lie in a gentle syncline, with maximum dips of about 20°.

The base of these beds is below tide in the center of the trough. They extend up to a maximum of about 100 feet above high tide. The lower beds are of clay and silt, containing some sand and pebbles, with glacial scratches, and have a maximum exposed thickness of about 30 feet. Abundant, but poorly preserved, marine fossils are present. The upper beds are from 30 to 50 feet thick. They consist chiefly of coarse sand, but contain several bands, each from 6 inches to 2 feet thick, composed of gravel and bowlders with glacial scratches. They rest conformably upon the lower beds.

Similar clay, with marine fossils and scratched pebbles, were seen on the east shore of Wingham Island about 2 miles north of Kayak. They were poorly exposed at this locality. Beds of this character doubtless underlie much of the alluvial flats of the region, but, although carefully searched for, were not seen at any point except on Wingham Island. It seems probable that no other part of the region has been raised from beneath the sea in recent time.

The following report was submitted by W. H. Dall on a small collection of fossils from the west shore of the southeast point of Wingham Island:

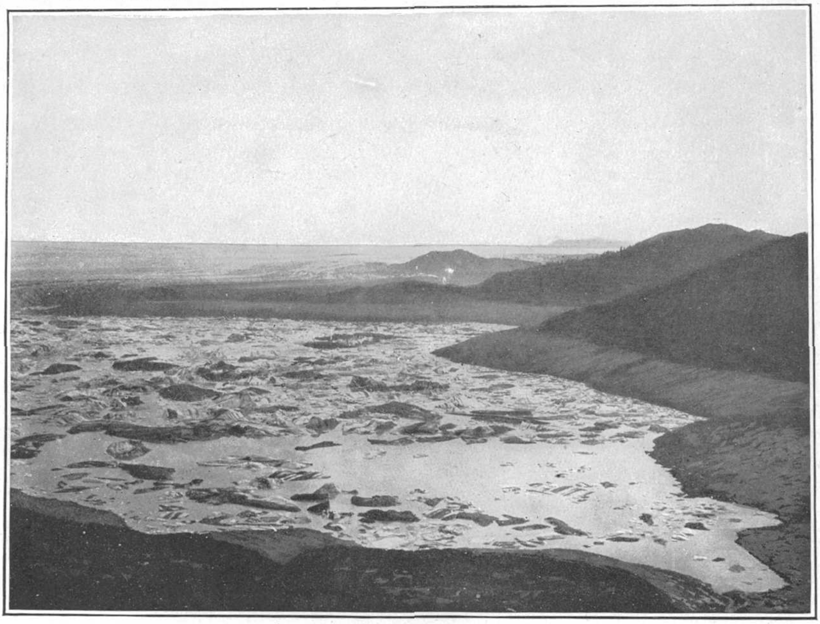
(4309) Bowlder clay fossils, much crushed and broken; contains *Serripes grönlandicus* and species of *Macoma, Mya* near *arenaria, Astarte* (?), *Tellina* (?), *Modiolus, Bela, and Balanus*, too imperfect to determine specifically.

GLACIERS.

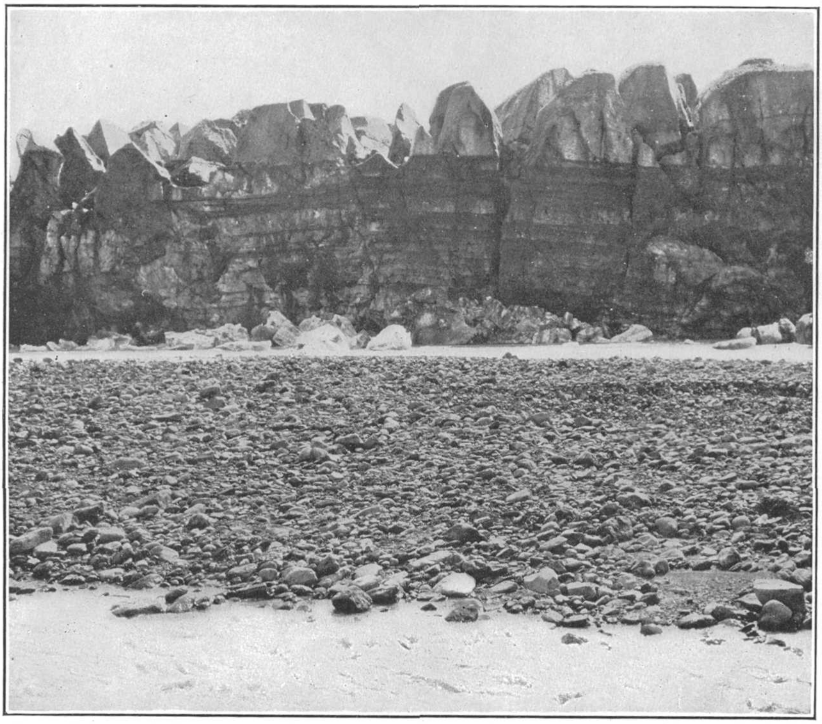
BERING GLACIER.

Description.—Bering Glacier occupies the coastal belt between the Chugach Mountains and the ocean, from the eastern border of the

[a] Russell, Israel C., Second expedition to Mount St. Elias: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 35.



A. FIRST BERG LAKE WITH BERING GLACIER IN BACKGROUND, LOOKING SOUTH.



B. BERING GLACIER, SHOWING ICE CLIFFS ON THE EDGE OF BERING RIVER.

Controller Bay flats for a distance of about 70 miles eastward. Its area is probably between 1,000 and 1,500 square miles, thus closely approaching, if not equaling, in size Malaspina Glacier, the area of which was estimated by Russell to be 1,500 square miles.

This glacier, like the Malaspina Glacier not far east of it, is of the piedmont type, and as such represents the expended and coalesced termini of many valley glaciers. These tributaries originate in the high snow fields of the Chugach Mountains, flow out through all the valleys, and unite on reaching the lower levels to form a vast plateau of ice, which covers the flats from the base of the mountains to the sea. The largest of these tributaries is probably the one which heads on the divide at the source of Tana River, the largest southern tributary of the Chitina. These tributaries differ little, if any, from valley glaciers of other regions.

The most striking feature of Bering Glacier, aside from its size, is the flat surface of its main area. (See Pl. VI, *A*.) This feature, which it has in common with Malaspina and Grand Plateau glaciers, is an essential characteristic of piedmont glaciers. The tributaries come out from the high valleys on steep grades and reach the main glacier at an elevation of about 1,500 feet. From this general elevation the glacier slopes gradually toward the sea, descending both in low, even grades, characterized by a relatively smooth ice surface without wide crevasses, and in steeper slopes on which the ice is much crevassed. The western edge of the glacier is well to the west of any of the tributaries and is at a much lower level than the central part. This descent is attained chiefly by a number of steep grades, each at the end of a mountain spur, the surface of the ice being almost level between them. Good examples of such ice falls are those at the end of Carbon Mountain and at the end of the ridge east of Berg Lakes.

Moraine.—Enormous amounts of detritus are accumulated on the margin of the glacier, especially along the western and southern fronts. A large part of this moraine is on the surface of the glacier, the ice in many places being so buried as not to be visible except in the ice cliffs on the borders of lakes or in the deepest crevasses. (Pl. VI, *B*.) This surface moraine is in many places covered by dense forests which are in general restricted to a belt along the margin not more than a mile wide.

The lateral moraine, where it rests against the hills, consists usually of a ridge separated from the neighboring hillside by a water course.

Marginal lakes.—The five Berg Lakes, situated on the margin of Bering Glacier (Pl. II), near the northeast corner of the region under discussion, present some interesting features. These lakes are bordered on their landward sides by steep banks, which are in general barren of vegetation and which are covered chiefly with glacial débris.

(Pl. VI, *A*.) These banks extend to an elevation of about 1,000 feet above tide, or about 200 feet above the level of the lakes. They are cut and built into well-developed terraces, which mark former stages in the elevation of the lakes. The lower terraces are entirely barren of vegetation, but the upper ones have a scant growth of grass, herbs, and small bushes, which are only a few years old.

The surface of the four western lakes is known to be at the same altitude (about 810 feet in 1905), and Fifth Lake probably is at the same level.

These lakes are certainly connected by water channels through the crevasses of the glacier, and possibly by open spaces under the ice. The surface of the ice is level, except where it rests against the land on the points between the lakes. The identity in the altitude of the lakes, the level surface of the ice between the lakes, and the way in which bergs break off on the margin of First Lake show that this arm of the glacier is floating in one large lake, of which the five Berg Lakes are only open areas. The surface of the glacier, after a gentle slope, descends in a low, crevassed icefall to its floating level.

The level of the lake is oscillating. The absence of vegetation on the lower terraces shows that it has fallen in recent years. In June, 1905, it was rising several inches per day. The outlet of the lake, which is beneath the ice at the end of the long point south of First Lake, becomes choked with débris at irregular intervals. The water then rises until the pressure clears the outlet or till the water can flow on the surface around the end of the point, when the lake is emptied, causing severe floods in the valley of Bering River.

Conditions are similar to those at the Märjelen See,[a] except that at Berg Lakes a large area of glacier is floating in one large lake, which appears on the surface as five small ones. Lake Cætani, Mirror Lake, and the numerous other marginal lakes [b] at the head of Yahtse River, between the edge of Malaspina Glacier and the sides of Chaix Hills, possibly offer a closer resemblance, though Russell has not stated whether any of these lakes are at the same level and possibly connected. Most of them, however, are described as not at the same level.

A series of chains of small marginal lakes, of somewhat different type, extends along the western margin of the glacier between Bering River and Nichawak Mountain. These lakes are bordered on one side by the margin of the ice and on the other by the terminal moraine.

MARTIN RIVER GLACIER.

Description.—This glacier, which is situated between the hills north of Bering River (Pls. I, p. 10; IV, *A*, p. 16) and the base of the

[a] Lyell, Sir Charles, Principals of geology, 10th ed., 1867, vol. 1, pp. 376–379.

[b] Russell, Israel C., Second expedition to Mount St. Elias, 1891; Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 76–80.

Chugach Mountains, has an area of about 100 square miles, not counting its uttermost tributaries, some of which extend for an unknown distance into the mountains. It resembles Bering Glacier, in being situated at the base of the Chugach Mountains, in having its longest dimension parallel to the mountains, and in being the united dissipator of many smaller glaciers, which descend from the high mountains.

It differs from the Bering and Malaspina glaciers in having a range of hills along its southern margin. It is consequently, in shape and position, somewhat like a large valley glacier, although it differs from valley glaciers of the usual type, and resembles piedmont glaciers, in being a nearly stagnant mass of ice along the front of the mountains which supply the reservoirs of its tributaries, and in having those tributaries on only one side. But for the nonessential position of the hills of the Bering River coal field between it and the coast, it would be a piedmont glacier. It may, perhaps, best be placed in an intermediate class.

The tributaries come out from the mountains on steep grades, joining others, swelling their volumes at almost every valley they pass. From each of these points of juncture, below snow line, a band of medial moraine is formed from the lateral moraines of the uniting glaciers (Pl. IV, *A*, p. 16). The formation of the main glacier takes place in the same way as its immediate tributaries, and long lines of medial moraine extend down from each juncture point. These moraines spread out and become scattered over the broad surface of the flat expansion of the lower end of the main glacier. The condition of much of this surface is not unlike that of the Bering Glacier, being flat, not much crevassed, covered with a heavy coating of moraine, and having forests over a considerable part of it. Descending lobes extend into the valleys of Kushtaka Lake and Lake Charlotte.

Moraine.—The lateral moraine on the southern margin of the glacier consists of heavy accumulations of débris, separated from the bordering hillsides by watercourses, between which and the general surface of the glacier the moraine forms a high sharp ridge.

The terminal moraine across the western end is a broad, hummocky mass of detritus, which grades imperceptibly, as far as the surface is concerned, into the moraine-buried and forested end of the glacier.

Marginal lakes.—There are two small marginal lakes on the northern edge of the glacier. Like Berg Lakes, each of them is imprisoned between a mountain spur and the edge of the ice.

MINOR GLACIERS.

Slope Glacier, three small glaciers near it, and an unknown number of small glaciers on the west side of Ragged Mountain (only one of which is shown on the map) are of interest in showing the favorable conditions for the formation of glaciers which now exist in this region, and in showing what the probable conditions were during the maximum local extension of the ice.

These glaciers come from snowfields, which in some cases do not extend above an elevation of 2,700 or 2,800 feet, and in general melt away at elevations of from 2,000 to 2,500 feet. They thus establish the fact that the present local snowline is below 2,700 feet, and this is confirmed by the medial moraines on the larger glaciers, which appear at an elevation slightly less than 2,500 feet.

GLACIAL DEPOSITS.

MORAINE.

The maximum known glaciation of this region is represented by the moraine shown on the geologic map (Pl. V, pocket) as bordering Martin River Glacier, and by numerous small cirques which are quite generally distributed over the higher ridges.

The old moraine of Martin River Glacier extends for a varying distance up the northwest slope of Cunningham Ridge, descends into the valley of Stillwater Creek, encircles Kushtaka Lake, rides over the sides and northern end of the group of mountains between Kushtaka Lake and Lake Charlotte, and borders the northern flank of the group of hills west of Lake Charlotte. The position of this moraine on low ground is on the line of little hills at the southwest end of Kushtaka Lake, one-half mile below the outlet of Lake Charlotte in the Shepherd Creek valley, and about three miles beyond the present front of the glacier in the Martin River valley. It extends up the hillside to maximum elevations of 600 or 700 feet above the present position of the edge of the glacier. The corresponding moraine of Bering Glacier has not been mapped, but foreign morainic material is known to be absent from the valleys bordering on Berg Lakes at elevations exceeding about 1,000 feet, or about 200 feet above the present vertical position of the glacier, and also from the north banks of Bering River on both sides of Stillwater Creek at distances of one-half mile and one-third mile from the present margin of the ice.

These facts indicate that conditions of maximum glaciation were represented by an increase in the extent of Martin River Glacier to the limits indicated above, by little if any extension of Bering Glacier (at least along its northwest margin), and by the presence of a large number of small glaciers in sheltered valleys. The vertical position of the latter, compared with the present distribution of such glaciers in this region, shows that the snow line was then about 1,000 feet lower than it now is. This might mean, as far as the evidence from existing glaciers and abandoned cirques is concerned, that either general climatic changes, or a change of 1,000 feet in the elevation of the land, caused the change of 1,000 feet in snow line. Other lines of evidence, such as the depth of alluvium-filled valleys, indicate that change in level has been responsible for the rise in the snow line and the retreat of the glaciers.

The restriction of morainic material to the limits indicated above might be explained according to the following hypotheses:

1. That moraine formerly existing has been removed by erosion.

2. That the region was submerged during maximum glaciation to such an extent that the glaciers entered the sea at the present lower limits of the moraine.

3. That extreme glacial conditions were so mild as not to send the ice beyond the present known extent of the moraine.

4. That the land was elevated during the maximum glaciation, and that the large glaciers went out through valleys now submerged or filled with alluvium.

The first hypothesis fails in that the complete removing of all material (even in sheltered places) over most of the area is unexplained and most improbable, especially in the presence of the large, untouched moraines bordering the present position of Martin River Glacier and of many small, untouched moraines composed of local material in other places. We have to deal with the presence of large moraines composed of foreign material at the lower altitudes and near the Martin River Glacier, and of small moraines composed of local material at high altitudes and in localities sheltered from melting, and with the absence of all moraine at intermediate altitudes. The distribution calls for an explanation of genetic origin. Destructional agencies could not be so complexly selective in the distribution of their fields of operation.

The second hypothesis fails by the absence of any physiographic or sedimentary evidence of such submergence. There are no wave-cut benches; no elevated beaches, except the lake beaches described on p. 52; and no unconsolidated marine sediments, except those occurring at a low level on Wingham Island. (See p. 46.)

The third hypothesis can be accepted as far as it refers to the upward limit of the moraine of the larger glaciers and to the extreme limits of the small, local, cirque-bound glaciers. The possibility of further extension of the large glaciers beneath the present alluvium must, however, be admitted. This will be considered under the fourth hypothesis, which is more comprehensive than the third.

The fourth hypothesis is harmonious with all the evidence at hand. If the land were elevated 1,000 feet the snow line would fall the same distance and local glaciers would form in the now abandoned glacial cirques. The lowering of the snow line would increase the reservoir area of the larger glaciers, and hence their flow. They would rise on the hillsides, presumably to some such elevation as that of the high moraines bordering Martin River Glacier. They would extend their valley tongues, but this extension would be buried by river deposits during subsequent depression. The broad alluvial flats are known to be filled with unconsolidated material to depths exceeding 280 feet in Katalla Valley and exceeding 580 feet on the east bank of Bering River, the total depth in both cases (pp. 119, 121) being unknown. The glaciers, during such an elevation, could consequently have extended far beyond the present ocean shore. In this connection there is significance in Dawson's suggestion[a] that the bowlder clay described by him from Middleton Island was laid down in the sea during a hypothetical extension of Pleistocene glaciers from the mainland. Middleton Island is 76 miles southwest of Katalla and 50 miles from the nearest shores of Montague and Hinchinbrook islands. It lies inside the 100-fathom curve, as given on the present charts, and hence would probably be connected with the mainland during any such elevation as is supposed above.

LAKE DEPOSITS.

The five Berg Lakes on the margin of Bering Glacier, the physiographic features of which have been already described (p. 47), are bordered on their landward sides by banks which, up to an elevation of about 200 feet above the level of the lakes, are cut and built into terraces which mark stages in the former elevation of the lakes. These terraces are composed of glacial débris which has been reworked by the waters of the lakes. These deposits are known to be very thin in places, where ledges of rocks are exposed, but their maximum thickness is not known.

STREAM AND BEACH DEPOSITS.

The eastern shore of Bering River, and of Controller Bay, from the margin of Bering Glacier to the ocean, is a flat plain of mud, sand, and gravel, constantly growing by the addition of sediment which the glacial streams carry and deposit along their courses and at their mouths. Nichawak Mountain, Mount Campbell, Gandil Mountain, and the Suckling Hills rise like islands from this plain, and it seems certain that a very short time ago they were islands in an older extension of Controller Bay, which was then, as now, being filled by the sediment of these glacial streams. These younger fluviatile Quaternary deposits cover large areas in the valleys of Canyon and Stillwater creeks, and extend along the northern bank of Bering River from Shockum Mountains to Bering Lake. They also extend up the valley of Shepherd Creek to one-half mile below Lake Charlotte and to the moraine across the southwest end of Lake Kushtaka. The valley of Katalla River and of the streams which head near it and flow into Bering Lake is floored with the same material, as are also

[a] Dawson, George M., Notes on the Geology of Middleton Island, Alaska: Bull. Geol. Soc. Am., vol. 4, 1892, pp. 427–431.

the lower courses of most other streams which enter Controller Bay. These unconsolidated deposits, an unknown amount of which are of fluviatile origin, are known to have a thickness of over 580 feet at one point on Bering River, and of over 280 feet in the Katalla Valley.

The beaches, bars, and islands, which the ocean waves are building along these shores, are composed largely of reworked fluviatile and glacial material, and are in part contemporaneous with the stream deposits. Good examples of these are: Okalee Spit, all of Kanak Island, the beach from Strawberry Point to Katalla, Softuk Bar, and the long line of islands which extend in line with the last named across the entire front of the Copper Delta.

Not only are these deposits building now but they have formed in the past, and some of the older ones are still in existence. The beach from Cave Point to Katalla is a broad, gently curving stretch of sand, concave toward the ocean. Its dry crest is covered with a narrow but dense growth of spruces. Behind it is Katalla Slough, a muddy, winding channel whose general course is parallel to the beach. Another line of spruces, parallel to the outer beach, is situated behind the slough. These spruces grow in beach sand, and behind them is another swamp area containing a winding slough. A view from one of the neighboring hills reveals the fact that Katalla Valley, for a distance of several miles inland, is made up of alternating sandy strips and muddy areas; each of the former with a line of spruces, each of the latter with a winding slough or a line of small ponds. The sandy strips are former beaches, which grew as the outer beach at Katalla has grown, across the valley from a rocky foreland. The trees are older as one goes inland, and their age (if the oldest of each beach were still there) would tell us the age of the beaches. The sloughs are more poorly preserved at a distance from the coast, and the distribution of trees is less regular. This means that sediment from the river and wash from the smaller streams are filling the sloughs and spreading gravel and sand on the mud of their banks. The original trees are dead and their descendants have spread out a bit where only grass grew at first. Farther inland the sloughs are filled and the stream wash has buried the beaches. Perhaps even there a line of trees may mark one of these old skirmish lines which the land threw out in its fight with the ocean.

DESCRIPTION OF LAND FORMS.

ADJACENT REGIONS.

The southern coast of Alaska from the shores of British Columbia to the Alaska Peninsula lies on an arc, concave toward the ocean, having a radius of about 500 miles and with its center at approximately longitude 146° W., latitude 53° N. The contour of the ocean bottom, the larger aspect of the trend of shore line, the coastal mountains, and range after range of interior mountains all lie approximately parallel to this arc.

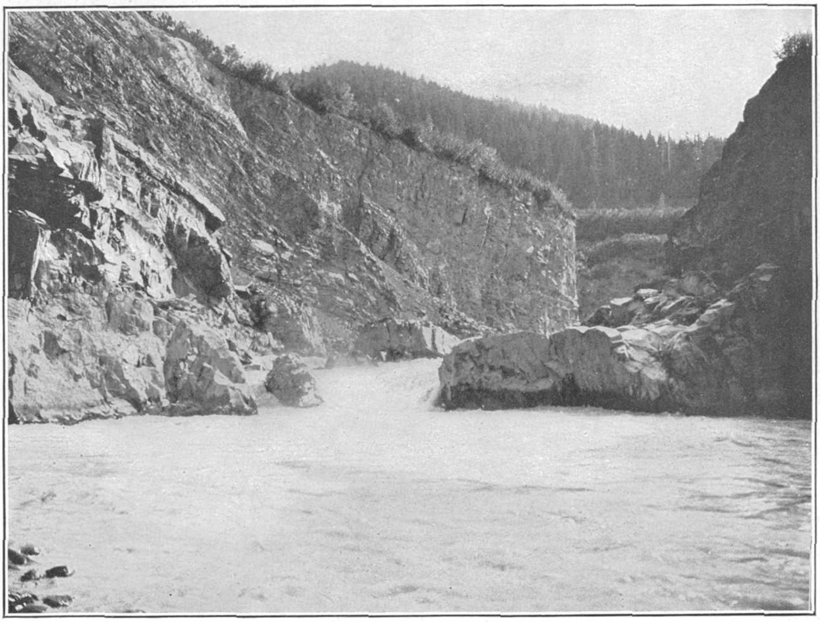
The coastward front of the Pacific Mountain system includes the Kenai Mountains on the Kenai Peninsula and the west shore of Prince William Sound, the Chugach Mountains on the north shore of Prince William Sound and in the vicinity of Copper River, and the Fairweather Mountains from near Mount St. Elias to Cross Sound. These mountains rise, for the most part, sharply from the sea. They are not cut through by tidal waterways between Cook Inlet and Cross Sound, though deeply embayed at Prince William Sound and Yakutat Bay. West of Copper River and east of Icy Point the coast is fiorded, but this condition does not hold between these points except at Yakutat and Lituya bays. The coastal mountains are not cut through by river courses between the Copper and the Alsek. It is significant that east and west of these two rivers the mountains approach closely to the sea and the coast is fiorded. Between these rivers the mountains lie farther inland and the fiords are absent (except at Yakutat Bay). In this interval the region between the mountains and the sea includes mountains of less relief than the main range, and is made up of rocks which are younger, in general less closely folded, and always less indurated and altered.

The high mountains from Copper River to Cross Sound are the gathering ground for the greatest system of low-altitude, low-latitude glaciers in the world. These glaciers pour out toward the sea from every gap and pass between Copper River and Cross Sound. They have overflooded the coastal hills and lowlands and have formed a series of broad, flat-topped, stagnant, piedmont glaciers, of which the Malaspina has long been regarded as a unique type, but which has companions rivaling it in size in Grand Plateau Glacier to the east and Bering Glacier to the west.

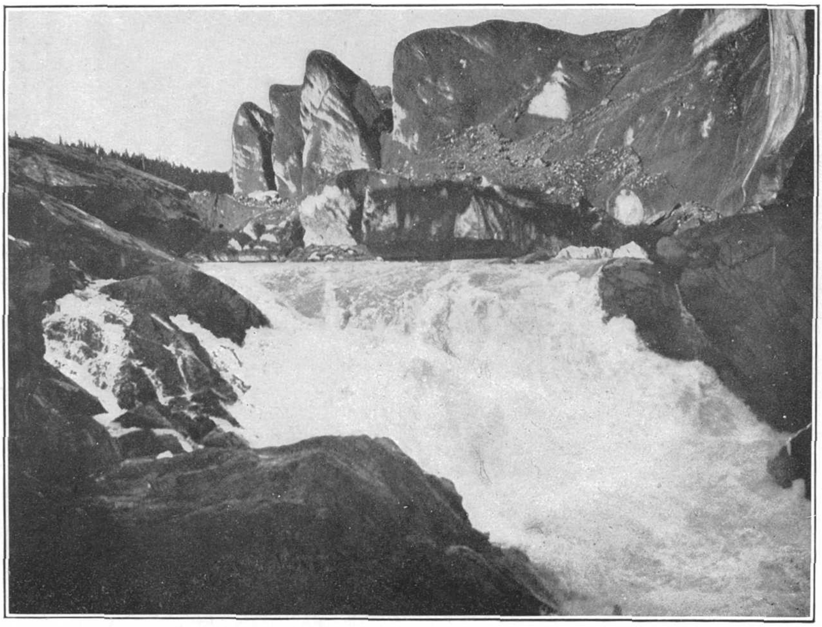
At the western extremity of the coastal lowlands described above, and just east of Copper River, is Kayak Island. West of Kayak Island is Wingham Island, and north of them is Controller Bay.

SHORE LINE.

Kayak Island almost joins the mainland at its north end, from which it extends as a narrow rocky mass for 20 miles out to sea. Cape Suckling is a rocky promontory on the mainland about 12 miles east of the northern end of Kayak Island. West of it the shore curves slightly northward for about 4 miles, to where Okalee Spit, a low strip of sand about 9 miles long and from 500 to 3,000 feet wide, reaches westward, dividing the waters of Controller Bay from those of the ocean. The spit is the product of the waves working on débris from the seaward face of Bering Glacier, and its direction is that of the prevailing winds.



A. LOWER END OF BERING RIVER CANYON.



B. HEADWATERS OF BERING RIVER AT THE UPPER END OF THE CANYON AT THE SOUTH END OF CARBON MOUNTAIN.

Behind Okalee Spit the east shore of Controller Bay extends northwest to the mouth of Bering River. In this interval it is broken by the mouths of many rivers, which are pouring out with their water vast quantities of mud and sand. This sediment is derived from the southwest side of Bering Glacier, and is fast extending the low shores between which it flows and reducing both the area and the depth of the bay. The north shore of Controller Bay, between Bering River and Point Hey, is likewise bordered by muddy flats. Kanak Island, which lies across the west side of the bay, opposite the mouth of Bering River, is composed of similar material.

Katalla Bay, between Strawberry Point and Whale Island, is bordered by a gently curving beach, which is the outermost and youngest of a series of beaches (see p. 53) by which the land has here advanced, reclaiming the present Katalla Valley from the sea.

Softuk Bar, 2 miles northwest of Whale Island, is a long, narrow spit which is similar to Okalee Spit in size, shape, position, and direction. It is situated at the eastern end of a long line of low, sandy islands which extend across the entire front of the Copper Delta.

DRAINAGE.

RIVERS.

The streams of the Controller Bay region have their supply in part from local rainfall and in part from the glaciers which have invaded the region and which melt away on its borders. The supply from both sources is large. The rainfall, as was shown above (pp. 17–19), probably exceeds 150 inches a year, while the glaciers contribute the precipitation of many hundred square miles. The streams are consequently large in proportion to their length and drainage area, and are all subject to severe floods.

The greater part of the region lies in the valley of Bering River. This stream has its source on the margin of Bering Glacier (Pl. VII, *B*) in the northeast part of the area covered by the map. It flows southwest for about 12 miles until it approaches Bering Lake, where it spreads into a broad delta. Part of the water passes directly through the southeast corner of the delta without entering the lake. The other part enters the lake through many channels along its eastern margin, then turns directly back along the south shore of the lake and joins the streams which cut past the lake without entering it. The reunited waters then flow south for about 8 miles and enter the northeast corner of Controller Bay. The lower course of Bering River is tidal, the water of Bering Lake rising and falling from 1 to 3 feet, and the currents running in and out at from 3 to 5 miles per hour. Above Bering Lake the river is nontidal and has a strong current of from 3 miles per hour in the vicinity of the delta to 6 to 10 miles per hour in the upper part.

The tributaries of Bering River above the lake include Canyon Creek, which has its source on the southern margin of Martin River Glacier; Stillwater Creek, which drains Lake Kushtaka and receives a large part of its supply from the Kushtaka Glacier; and Shepherd Creek, which drains Lake Charlotte and several other small lakes on the margin of the Martin River Glacier. The chief tributaries below the lake are Gandil and Nichawak rivers, which drain parts of the margin of Bering Glacier.

The other streams include Campbell and Edwardes rivers, which rise on the southwest margin of Bering Glacier and enter the east shore of Controller Bay; Katalla River which rises in the hills west of Bering Lake and flows into Katalla Bay, and several of the headwater tributaries of Martin River. The latter rises on the western margin of Martin River Glacier and in Tokun Lake, and flows west until it reaches the eastern edge of the Copper Delta. The waters divide here, part entering Copper River, and part flowing along the edge of the mountains close to the delta and entering the tidal sloughs behind Softuk Bar.

LAKES.

Bering Lake is a former arm of Controller Bay which has been cut off from the bay by the growth of the deltas of Bering River and its lower tributaries.

Charlotte and Kushtaka lakes have dams, composed of the terminal moraine of a former glacial expansion, across their southern ends. The former drains out through a breach in the dam, the latter at a point near the other end of the lake, either over a sapped col or over a lateral wall of moraine.

Lake Tokun was formed as a marginal lake on the former expansion of the Martin River Glacier. The lateral moraine deposited across the end of the lake during this expansion still holds the waters of the lake.

A series of lakes along the southern side of Martin River are of considerable interest, because they are still in process of formation. Martin River is a heavily loaded stream and is building flood plains along its course. It is carrying and depositing more sediment than its nonglacial tributaries and is building up its flood plain across the mouths of these tributaries. The result is to pond each clear-water tributary and to form a lake in the lower part of its valley. The present growth of these lakes is shown both by the continuation of the processes which caused them and by the fact that they have no beaches and that the forests on their margins are being submerged and killed by the rising waters. A similar lake is now in the initial stage of formation at the mouth of Shepherd Creek. Other lakes intimately associated with the glaciers are discussed on pages 47, 49

RELIEF.

DISTRIBUTION OF THE HILLS.

The shores of Controller Bay include broad areas of marshes in which are island-like masses of hills, many of which have a northeast-southwest trend like Kayak Island. Together they constitute a group with the same general trend, which rises gradually toward the northeast until it merges with the higher mountains farther inland. These hills thus constitute a spur which, extending southwest from the high mountains far toward the continental shelf, has turned aside the glaciers coming from the mountains, so that its landward parts, with the recesses between its members, are bare of ice, though on the very edge of the Bering Glacier. Its seaward parts give some protection from the ocean and make a slight break in the strip of unprotected coast which in general marks the glacier-covered lands east of it.

The Chugach Mountains, although they have the appearance of a range with an east and west axis and are bordered both on the north and south by straight east and west lines, and composed, locally at least, of minor ranges which extend in a northeast-southwest direction. This feature is well shown on the reconnaissance map (Pl. I) and in Pl. IV, *A* (p. 16). Some of the smaller ranges in the vicinity of Mount St. Elias (see Pl. I) have a similar trend.

The region is about half hilly and half lowland. The lowlands are flat and swampy and rise but a few feet above tide. The hills are in general less than 2,000 feet high, but reach a maximum of about 4,000 feet in the northeast corner of the region. They include a range extending throughout the region from northeast to southwest and several detached areas; two of the latter are in the ocean and form Kayak and Wingham islands. The others, including the Suckling Hills, the four detached masses of hills in the Nichawak region, and the peninsula south of Bering Lake, rise like islands out of the swampy flats.

ACCORDANCE OF ELEVATIONS.

CREST LINES.

The crests and summits of the ridges in various parts of this region possess much diversity in altitude, yet close observation shows that the elevations are grouped within certain bounds, that there are more or less definite heights to which certain groups of hills rise, and that between these elevations steep slopes are found, but seldom hilltops and almost never groups of hilltops or ridges with anything like uniform altitudes.

The general or average elevations of the ridges or groups of hills which possess such uniformity are shown in the following table:

General levels of ridge crests.

Position.	Elevations in feet.									
Carbon Mountain	3,500		2,450		1,800					
Between Canyon Creek and Kushtaka Lake			2,450	2,100	1,800					
Charlotte and Kushtaka ridges			2,450							
Shockum Mountains						1,500			800	
Ridge west of Shepherd Creek			2,450	2,100	1,800					
Hills west of Bering Lake				2,100					800	
Hills south of Bering Lake				2,100	1,800	1,500				
Ragged Mountains		3,000	2,450	2,100			1,250			
Gandil Mountain									800	
Nichawak Mountain							1,250	1,000		
Mount Campbell							1,250			
Suckling Hills							1,250		800	
Kayak Island					1,800		1,250			600

The highest summits in this region are on the northern end of Carbon Mountain, in the extreme northeast end of the area covered by the map, where a small group of peaks attains altitudes of from 3,800 to 4,150 feet, and large adjacent areas (not shown on the map) are even higher. The crest of Carbon Mountain from this group of peaks westward along the southern margin of Slope Glacier holds a general uniform altitude with the summits ranging from 3,450 feet to 3,600 feet, averaging 3,550 feet; the cols from 3,300 feet to 3,500 feet, averaging 3,450 feet; and the general crest line averaging 3,500 feet. The ridge then drops sharply to a lower level almost 2,000 feet below.

Nothing like this higher level is attained elsewhere in the region, although a few peaks on Ragged Mountain have elevations of about 3,300 feet, and similar elevations may be found in some of the peaks along the southern flank of the Chugach Mountains.

The next lower general level is slightly above 3,000 feet and is seen in the serrated top of Ragged Mountain, which holds this general elevation for about 6 miles of linear crest until it approaches, at the south end, within 3 miles of the sea. It then drops sharply in three steps to general elevations of about 2,450 feet, 2,100 feet, and 1,200 feet.

The 2,400-foot level may be seen in the central part of the ridge west of Shepherd Creek, in the higher crests and summits of Charlotte and Carbon ridges, and possibly in Cunningham Ridge (although in the latter case two peaks, Monument Mountain and Mount Chezum, reach elevations of 2,650 and 2,850 feet, respectively), and in some of the lower spurs of Carbon Mountain.

A very distinct level at about 2,100 feet is represented in the northern end of the ridge between Clear and Canyon creeks, in the ridge west of Shepherd Creek (except north of the Tokun-Charlotte pass and in the central group of high peaks discussed above), in the high ridge west of Bering Lake, on the higher ridges south of Bering Lake, on parts of Ragged Mountains, and in many of the lower spurs and ridges along the southern front of the Chugach Mountains (see Pl. IV, *A*, p. 16). This is, in its wide distribution and in the usual perfection of its development, perhaps the most striking level of accordant summits in the entire region.

A 1,700 to 1,800-foot level is reached by many of the peaks on the southern end of Carbon Mountain, by the southern end of the ridge west of Canyon Creek, by the ridges between lakes Charlotte and Tokun, and by the ridge east of Katalla River.

Lower levels at 1,200 feet, at 800 feet, and at 500 feet are held by many of the lower ridges, especially those near the coast.

TERRACES AND BENCHES.

The hillsides in all parts of the region have been cut into benches and terraces, some being broad and flat, and others being narrow shelves, small flat areas on the spurs of the hills, or locally widened or gently graded places along the streams. The better developed of these features can be followed at a constant level for considerable distances along the hillsides, but some are of local extent and perhaps give way to others at somewhat greater or less elevation. The altitudes of the benches in the several valleys are shown in the following table:

Elevations of terraces and benches.

Position.	Elevations in feet.						
Berg Lakes	2,000	1,750	1,450				
Canyon Creek		1,700	1,450	1,250	1,000	750	
Clear Creek		1,700	1,450	1,250	1,000		
Trout Creek					1,000		
Shockum Mountains				1,200			500
East side of Kushtaka Ridge				1,200	1,000		
Shepherd Creek, east side		1,600			1,050	800	
Shepherd Creek, west side			1,450	1,250	1,000	750	
Lake Tokun					950		
Dick Creek				1,200	950	750	
Bering Lake, south shore				1,250	1,000	750	500
Bering River, below lake				1,250			500
Chilkat Creek				1,250	1,000		
Burls Creek					1,000		500
Puffy Creek					1,000		
Redwood Creek					1,000		600
Katalla Valley, east side					1,000	750	
Katalla Valley, west side				1,250		750	
West of Ragged Mountain						750	

Many of the divides are broad and flat and have lakes and meandering drainage upon them, this condition being well illustrated between Dick Creek and Lake Tokun and between Lake Tokun and Lake Charlotte. The divides there stand at very distinct terrace levels. Besides existing lakes, the Dick Creek-Tokun Lake divide possesses the further interesting feature of a drained lake bed with the beaches and lacustrine silts which were formed while the lake was there. The drainage of the lake was probably caused by piracy of the creeks tributary to Tokun Lake.

SIGNIFICANCE OF CREST AND BENCH LEVELS.

It may be seen that these elevations accord approximately with those of some of the ridges. The levels of the benches, like those of the ridges, are in part independent of the character and attitude of the rock. They are, consequently, to be interpreted as due to past erosional conditions, which were determined by different positions of base-level from those existing now. They show that, subsequent to the indurating and folding of the rocks, erosion progressed so far that topographic conditions approached or attained those of a peneplain. It can not be assumed, however, that each of these levels represents a peneplain, nor can it be assumed that any definite level represents one. The number of the approximate levels shows that the history of denudation has been complex, but the age of the rocks shows that the length of time in which it was accomplished was very short, and it may well be that at no time has the topographic relief approached closely to maturity. Repeated cuttings of straths and coastal benches, after each of which the land rose a little, might easily produce such features as now exist. On the other hand, it may be that the higher levels were produced by complete peneplanation, while the lower ones each represent a less complete reduction after a renewal of uplift; or that one of the intermediate levels represents a dissected peneplain, with the higher elevations as unreduced residuals. However this may be, it is certain that the region has been nearer to a condition of topographic maturity in the past than it is now.

The present land forms were produced by the uplift and erosion of those older surfaces without known warping. The older surfaces extend over and through this region in levels or in steps, and not in curves. The surfaces extend northward until they run into the southern front of the Chugach Mountains. This shows that they are younger than the high mountains, unless a recent fault or very abrupt flexure marks the very edge of the range. The latter possibility is contradicted by the fact that there is little accordance of summits and that no flat areas appear on the crest of this part of the Chugach Mountains. The foothills have, consequently, a history somewhat different from the high range, and have been reduced to levels which did not cut far back from shore.

VALLEYS.

The presence of the broad alluvium-filled valleys which extend throughout most of the region is one of its most striking physiographic features. These valleys are very broad in proportion to the size of the streams occupying them, and suggest at once that they are deeply filled and were produced when the land stood much higher than now. This is confirmed by the fact that a drill hole on the east shore of Bering River opposite the lower island and another on Katalla River went to depths of 580 feet and 280 feet, respectively, without reaching bed rock. Further evidence concerning the former position of the snow line (p. 50) suggests that the valleys were cut when the land stood about 1,000 feet higher than at present. In this case the rock floor in the centers of the valleys and at their lower ends should be almost 1,000 feet below sea level.

Many of the smaller streams have their headwater courses down to about 1,000 feet above sea level in glacial cirques. The problem which these present will be discussed later. The lower courses of these streams from an elevation of about 1,000 feet down to the edge of the alluvial flats are usually in box canyons. The descent from the cirques or terraces into the lower canyons is usually in one or more waterfalls.

HISTORICAL GEOLOGY.

The earliest geological event of which there is a definite record in this region was the deposition of the material which now constitutes the slate, graywacke, and associated rocks on Wingham Island and Ragged Mountain. This material was derived from the destruction of other rocks of unknown character. The date of deposition is also somewhat uncertain, but the weight of evidence indicates (see p. 27) that it was toward the end of the Paleozoic era. These rocks were deposited in the sea, for they contain marine fossils. The fineness of much of the material shows that the shore was at times distant. The presence of volcanic material, some of which is probably interbedded with the other rocks, indicates that land may have been near at other times, and that there were volcanic vents, either continental, insular, or submarine, which probably were not far away.

These deposits were elevated, consolidated, folded, and metamorphosed at a date or dates concerning which there is little evidence. Similar and probably contemporaneous rocks in other regions in this part of Alaska are known to have been folded and metamorphosed prior to Upper Triassic time. Igneous material has been introduced into these rocks, but there is no evidence as to the date of the intrusion. It may have been soon after the deposition or not until long after the main folding.

No record of the Mesozoic, unless it be in the slaty rocks referred to above, has been preserved in this region. The evidence from other provinces, barring the possibility [a] of the slaty rocks on the coast from Yakutat to Kodiak being Mesozoic, indicates that much of the area of the Chugach Mountains and probably of their extension through the southern part of Kenai Peninsula and through Afognak and Kodiak Islands may have been land during Mesozoic time. Triassic seas

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[a] See discussion of the age of these rocks on p. 27.

extended through part of the region north of Chitina River and in the Cook Inlet and Alaska Peninsula region. A period of folding and probably of mountain building came at or somewhat after the close of Triassic time. Deposition was apparently somewhat restricted during the Lower Jurassic, for sediments of that age are known only from Cook Inlet and the Alaska Peninsula. The sea probably covered larger areas in the Middle Jurassic, when deposits were laid down in the present position of the Alaska Range, the Matanuska Valley, Cook Inlet, and the Alaska Peninsula. Upper Jurassic seas widened still more, for deposits of that age are known throughout much of southeastern Alaska, the valleys of Copper and Matanuska rivers, Cook Inlet, the Alaska Peninsula, and the Yukon Valley.[a] The post-Triassic unconformity and period of folding may have lasted until the beginning of Upper Jurassic time, for the evidence of the unconformity is seen in the relation of Upper Jurassic to Upper Triassic rocks.

The great Mesozoic granitic intrusions, which began after the close of the Triassic, were probably over in at least part of Alaska before the beginning of the Upper Jurassic, though they extend in other districts into the Cretaceous. In the Cook Inlet region the granitic intrusions do not cut rocks younger than the Triassic, the Jurassic intrusions and flows being of andesite, and the Tertiary and post-Tertiary intrusion of andesite and basalt. Lower Cretaceous sedimentation took place in widely scattered provinces and apparently over broader areas, especially in the northern part of Alaska, than were covered by the Middle and Upper Jurassic seas. The Upper Cretaceous beds of Alaska are restricted, so far as we now know, to points on the Alaska Peninsula, on the Yukon, and possibly on the Anaktuvuk in northern Alaska. The lands were apparently growing and the seas narrowing after the close of Lower Cretaceous time.

None of the deposits of these Mesozoic epochs have been recognized in the Controller Bay region, or elsewhere on the Pacific coast between Cook Inlet and the Alexander Archipelago. This entire region may have been land during all of Mesozoic time, or it may be that erosion has removed the deposits. The possibility of Jurassic and other Mesozoic rocks underlying the Tertiary rocks of this region is discussed elsewhere. (See pp. 115–116.)

Areas of Tertiary rocks are widely scattered throughout all parts of Alaska, but the character of the deposits and other evidence, both physiographic and paleontologic, shows that these beds were laid down for the most part in or near estuaries and to some extent along rivers. The ocean extended over very little of what is now Alaska during Tertiary time. Large areas in many parts of Alaska were

[a] Jurassic rocks are known also at Cape Lisburne, but their exact stratigraphic position is uncertain.

exposed to long-continued erosion and were reduced at least to a non-mountainous condition before the middle of the Tertiary. Peneplains or at least broad areas of fairly low relief were developed.

The Tertiary deposits of Alaska are of four types: The marine Eocene, the Tertiary coal-bearing rocks,[a] the marine Miocene, and the marine Pliocene.

Marine Eocene deposits are known only at Stepovak Bay,[b] on the Alaska Peninsula, where they consist of terrestrial and volcanic detritus deposited in the sea and carrying marine fossils. They show that the ocean covered part of the Alaska Peninsula in Middle Eocene time and that volcanic agencies were active. Most of Alaska was doubtless land.

The Tertiary coal-bearing rocks cover large areas in many parts[c] of Alaska. They are known in southeastern Alaska, in the vicinity of Mount St. Elias, on Bering River, in the valley of Copper River, on Cook Inlet, in the Matanuska and Susitna valleys, on Kodiak Island, on Alaska Peninsula and the neighboring islands, throughout the valley of the Yukon and its tributaries, on the coasts of Bering Sea, and on the rivers of the Arctic slope. Not all the Tertiary coal-bearing rocks are of the same age, and the exact position of most of them is not very well known. It is probable that conditions favorable for the formation of coal existed in one part of Alaska or another during the greater part of Tertiary time.

Marine Miocene rocks occur at Cape Yaktag, Controller Bay, the Shumagin Islands, and other scattered places. They indicate that Miocene waters did not cover broad areas in Alaska, but were restricted to narrow arms of the sea.

Marine Pliocene rocks are apparently of very limited extent, the most important areas being at Lituya Bay and on the Arctic slope.

Returning to the interpretation of the local section, we find that marine conditions existed during much of the deposition of the Katalla formation. The Stillwater formation was laid down partly in the sea and probably in part in brackish or fresh water. The Kushtaka formation represents fresh-water conditions, probably in a shallow estuary or on a river. The transition from the Kushtaka to the Tokun formation represents the return of marine conditions, probably without unconformity. There is no evidence as to whether the upper part of the Tokun formation represents marine or fresh-water conditions. These four formations represent the local Tertiary

[a] This term includes rocks of considerable diversity of age, the exact position of some of which has not been determined.

[b] Palache, Charles, Geology about Chichagof Cove, Stepovak Bay: Harriman Alaska Expedition, vol. 4, 1902, pp. 69–88.

[c] Martin, A. C., The Alaska coal fields: Bull. U. S. Geol. Survey No. 314, 1907, pp. 41–44. Brooks, Alfred H., Geography and geology of Alaska, Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 237–244.

sedimentation, and were probably all laid down during Oligocene and Miocene time. (See pp. 37–41.)

The folding of all these rocks took place in very late Tertiary time or in post-Tertiary time, and was probably accompanied by the intrusion of small dikes and sills of diabase and basalt. It has been suggested above (see p. 45) that this folding may have taken place in or on the border of the Chugach Mountains and was followed by the southward overthrusting of the vast mass of rocks to their present position on the ocean shore. The folding was accompanied or closely followed by uplift, which has probably continued intermittently until recent time. Orogenic movements are known to be still in progress along the western base of the Chugach Mountains on Yakutat Bay,[a] although none so recent have been detected at Controller Bay.

The uplift of the region has been accompanied by vigorous erosion. Several halts in the downcutting are recorded in the existing topographic forms. Each of the levels of accordant summits and hillside benches represents a time when the uplifting ceased and erosion reduced considerable areas to near base-level. Such periods existed when the land stood about 3,500, 3,000, 2,450, 2,000 to 2,100, 1,750 to 1,850, 1,450 to 1,500, 1,200 to 1,250, 950 to 1,050, 750 to 800, and 500 to 600 feet lower than at present. At some of these times the halt was of short duration and the streams merely widened their valleys a bit. At other times, as when the land stood 2,000 or 2,100 feet lower than now, the halt was long, and the greater part of the area of soft rocks was reduced to an even plain. The uplifting was then resumed and the rivers trenched the plain, destroying much of it, and sinking their channels deeper until the next halt in the uplift enabled them to widen their valleys again and produce new plains and terraces.

The upward movement thus continued intermittently until the land stood at least 600 feet and probably at least 1,000 feet higher than at present, when the now submerged and alluvium-filled valleys were cut. The succeeding movement was a depression of the land to near its present level.

At an unknown time during the Quaternary a movement along a fault on Wingham Island resulted in the elevation of a small body of unconsolidated marine sediments to a maximum height of about 100 feet above sea level. There was no general uplift at this time, and similar local movements are not known to have taken place in other parts of the Controller Bay region.

Glaciers invaded the region at an undetermined time and probably attained their maximum extent when the land stood about 1,000 feet higher than at present. This maximum extension represents a surprisingly small increase over the present development of the glaciers.

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[a] Tarr, R. S., and Martin, Lawrence, Bull. Geol. Soc. America, vol. 17, 1904, pp. 29–64.

The retreat of the glaciers to their present limits was probably brought about by the depression of the land to its present position. The glaciers are now probably melting slowly back, but their recession has probably not been rapid for a considerable time, and readvances, such as that which is now taking place in the Malaspina [a] and other glaciers in the vicinity of Yakutat Bay, are possible at any time.

The waters of Controller Bay extended over a large part of the present lowland area in very recent geologic time, and one of the latest episodes in the history of the region has been the filling of this greater Controller Bay by deposits from the heavily loaded glacial streams. It was this process which transformed Bering Lake from a salt-water bay into a fresh-water but tidal lake. This process is still going on with probably undiminished activity, and is now restricting Bering Lake and Controller Bay to shallower depths and narrower areas.

MINERAL RESOURCES.

COAL.

AREAL EXTENT.

The surface extent of the Bering River coal, as known at present, is restricted to the area of outcrop of the Kushtaka formation, as represented on the maps (Pls. V and VIII, pocket). The area of such territory which is believed to be underlain by workable coal is given below:

Areas underlain by coal.

	Square miles.
Anthracite and semianthracite:	
Carbon Mountain, north end	25.6
Carbon Mountain, south end	1.0
	26.6
Semibituminous (with some semianthracite):	
Between Canyon Creek and Kushtaka Glacier	8.7
Kushtaka Ridge and valley of Carbon Creek	3.6
Southeast of Lake Charlotte	.6
Southeast of Tokun Lake	2.6
North shore of Bering Lake	4.7
	20.2

In addition to this, 21.6 square miles, divided as in the following table, is covered at the surface by the rocks of the Tokun formation, which overlie the coal-bearing rocks and which are underlain by coal at a greater or less depth.

[a] Tarr, Ralph S., Second expedition to Yakutat Bay, Alaska: Bull. Geog. Soc. Philadelphia, January, 1907, pp. 1–14.

Areas covered at the surface by the Tokun formation, parts of which may be underlain by workable coal.

	Square miles.
North of Cunningham Ridge	4.2
Between Lake Charlotte and Kushtaka Glacier	5.6
Kushtaka Ridge, north end	.1
Kushtaka Ridge, south end	1.6
Northeast of Tokun Lake	2.8
South of Tokun Lake	2.7
Between Shepherd and Dick creeks	4.6
	21.6

Part of the area of this formation may contain workable coal, but the depth at which such coal will be found is in most places uncertain, and in much of the area it is known to be so deep that the coal can never be mined. The southern end of Carbon Mountain, colored on the map as "undifferentiated," is reported to contain some coal, but the area in this region is not known.

The coal is known to extend eastward beyond the area shown on the map into the high, glacier-covered mountains, but the boundaries of this extension are uncertain. The value of such coal is also doubtful because of the complexity of the structure and the difficulties of transportation. Coal has been reported as far as the vicinity of the eastern end of Bering Glacier, but the discovery has not been confirmed, nor the amount and character of the coal reported. No coal has been found west of the area represented as Kushtaka formation on the map. There is, however, a good possibility that areas of coal exist in the hills between Dick Creek and the north end of Ragged Mountain, and this region ought to be more carefully prospected.

STRATIGRAPHIC POSITION.

The coal beds are distributed throughout the entire thickness of the Kushtaka formation. They are also restricted to it, for both the overlying Tokun and the underlying Stillwater formation are entirely barren. The position of many of the beds is indicated in the stratigraphic sections on pages 32–34.

DESCRIPTION OF THE COAL BEDS.

The following pages contain measured sections of all the coal beds which were accessible either in natural exposures or in prospect openings or tunnels. The location of the sections is shown by the numbers, which correspond to those on the map (Pl. VIII, pocket). No attempt has been made to correlate the beds, as the complex structure, the abrupt changes in thickness, and the fact that most of the beds have not been actually traced from point to point, usually makes this impossible. The sections are arranged in order from northeast to southwest.

The exposures of anthracite at the extreme eastern end of the area mapped are for the most part well up the mountain sides and inaccessible. The following seams were measured and were also sampled when thus indicated:

Section on crest of Carbon Mountain 2½ miles north-northwest of Fourth Berg Lake (1).

	Feet.
Coal (hard and clean)	3

Section 1⅔ miles up creek from Fourth Berg Lake; elevation 1,850 feet (2).

	Ft.	in.
Dark shale roof.		
Coal [a]		8
Coaly shale		4
Coal [a]		11
Coaly shale		3
Coal [a]		8
Shale floor.		
	2	10

Strike N. 76° W., dip 55° SW.

About a mile above this on the north side of the valley and just below the hanging glacier a 7-foot bed of anthracite is reported. The sample shown to the writer is very bright, hard, and not crushed at all.

Section in gulch at head of Second Berg Lake (3).

	Ft.	in.
Sandstone roof.		
Coal, bony		6
Coal, hard and bright [b]	2	2
Sandy shale floor.		

Strike N. 85° W., dip 32° NE.

The best exposures of anthracite seen by the writer are in Carbon Mountain, where the following sections were measured:

Section in third (eastern) opening on hillside trail on east side of Carbon Mountain (4).

	Ft.	in.
Shale roof.		
Coal	10	6
Shale floor.		

Strike N. 60° E., dip 28° NW.

Section on east side of Carbon Mountain, second opening from west end of hillside trail (5).

	Feet.
Shale roof.	
Coal [c]	15+
Shale floor.	

Strike N. 77° E., dip 22° NW.

[a] Included in sample No. 2, p. 84. [b] Included in sample No. 3, pp. 84–87.
[c] Included in sample No. 5, pp. 84–87.

It was not possible to obtain a complete measurement of this coal, which is reported as being 23 to 25 feet thick.

Section on east side of Carbon Mountain, first opening from west end of hillside trail (6).

	Ft.	in.
Coal [a]	10	6

The above three sections are all probably on the same seam, which the owners claim to have followed along the mountain side for 2 miles, in which distance they found thickness ranging from 9 to 25 feet.

About 200 feet below this is another seam, which is said to vary in thickness from 4 to 11 feet. The following section was measured by the writer:

Section of seam 200 feet below hillside trail on east side of Carbon Mountain (7).

	Ft.	in.
Shale roof.		
Coal [b]	4	8
Shale floor.		
Strike N. 80° W., dip 30° NE.		

Several other seams are exposed lower down the face of the mountain.

An important and apparently very persistent seam is exposed along the west side and near the top of Carbon Mountain. It is possibly the same as the upper seam, referred to above, on the east side of the mountain. The following sections were measured:

Section at north end of hillside trail on west side of Carbon Mountain (8).

	Feet.
Shale roof.	
Coal [c] (bright, clean, and often iridescent)	15+
Shale floor.	
Strike N. 84° W., dip 25° NE.	

Section at south end of hillside trail on west side of Carbon Mountain (9).

	Feet.
Shale roof.	
Coal [d]	10
Shale floor.	
Strike N. 52° E., dip 6° SE.	

The two following sections, which are a little farther south on the west side of the same ridge, show a coal which has the physical characteristics of the anthracite at the other openings in the vicinity, but whose analyses indicate a semianthracite. From the structural relations it seems probable that one of the seams corresponds to the lower coal described from the eastern side of the mountain.

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[a] Included in sample No. 6, pp. 84–87.
[b] Included in sample No. 7, p. 84.
[c] Included in sample No. 8, pp. 84–87.
[d] Included in sample No. 9, pp. 84–87.

Section in opening near crest (west side) of Carbon Mountain between trails (10).

	Ft.	in.
Shale roof.		
Coal [a]	5	3
Shale floor.		

Section in opening 50 feet below No. 10 (11).

	Ft.	in.
Shale roof.		
Coal, impure		3
Coal [b] (good and hard)	2	10
Shale floor.		

Strike N. 82° E., dip 38° NW.

Numerous outcrops of anthracite (mostly poorly exposed) were seen on the banks of Canyon Creek for a distance of 2 or 3 miles below the glacier. The two following sections represent the best of these outcrops:

Section at source of Canyon Creek (west bank) (12).

	Feet.
Coal	5

Section on west bank of Canyon Creek, 500 feet below glacier (13).

	Feet.
Coal	3

Section on tributary to Canyon Creek, on east side and next below Hunt's cabin; elevation, 630 feet (14).

	Ft.	in.
Coal [c]	6	9

Strike N. 55° W., dip 31° NE.

Section on same creek as No. 14; elevation, 450 feet (15).

	Feet.
Shale roof.	
Coal	3
Shale floor.	

Strike N. 65° E., dip 60° NW.

Section on same creek as Nos. 14 and 15, about 100 feet above creek; elevation, 520 feet (16).

	Ft.	in.
Firm shale roof.		
Coal [d]	2	7
Shale floor.		

Strike N. 55° E., dip 46° NW.

Section in tunnel on east bank of Canyon Creek, near Hunt's cabin, 2⅔ miles above mouth of creek (17).

	Ft.	in.
Shale roof.		
Coal [e]	4	2
Shale floor.		

Strike N. 40° E., dip 60° NW.

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[a] Included in sample No. 10, pp. 84–87.
[b] Included in sample No. 11, pp. 84–87.
[c] Included in sample No. 14, pp. 84–87.
[d] Included in sample No. 16, pp. 84–87.
[e] Included in sample No. 17, pp. 84–87.

Section in east bank of Canyon Creek, 2 miles above its mouth (18).

	Ft.	in.
Sandstone roof.		
Coal	2	9
Shale floor.		
Strike N. 70° W., dip 35° NE.		

This bed is very variable in thickness and pinches out higher in the bluff.

Section in creek on west slope of Carbon Mountain opposite the mouth of Canyon Creek; elevation, 950 feet (19).

	Ft.	in.
Shale.		
Coal	1	
Shale	1	
Coal [a] (ranges from 3 to 21 inches)	1	5
Shale (ranges from 1 to 18 inches)		1
Coal [a] (ranges from 14 to 24 inches)	1	2
Hard shale floor.		
Strike (on floor) N. 25° E., dip 53° NW. (variable).		

Section on same creek as No. 19; elevation, 900 feet (20).

	Ft.	in.
Arkose roof.		
Coal [b] (ranges from 8 to 22 inches)	1	8
Arkose floor.		
Strike N. 90° E., dip 33° NW.		

At the south end of Carbon Mountain there is a high bluff, where Bering River was formerly pushed against the end of the mountain by Bering Glacier, and here the following section was measured:

Section at south end of Carbon Mountain (21).

	Feet.
Sandstone	30
Coke	1
Sandstone and shale cut by diabase sills	20
Coke	2
Diabase sill	2–6
Coke [c]	1–5
Diabase sill	3
Coke	1
Diabase sill	8
Coke	1¾–2¼
Shale	120
Strike N. 50° W., dip. 20°–25° N.	

The coke and sills at this point are shown in Pl. IX, *B* (p. 92).

The valley of Clear Creek contains many good exposures of semianthracite and semibituminous coal. The following sections represent part of the exposures and openings:

Section in small tunnel on north bank of Clear Creek; elevation, 750 feet (22).

	Ft.	in.
Shale roof.		
Coal	2	10
Shale floor.		

[a] Included in sample No. 19, pp. 84–87. [b] Included in sample No. 20, pp. 84–87.
[c] Included in sample No. 21, p. 84.

Section in tunnel on north bank of Clear Creek near top of falls (23).

	Feet.
Shale roof.	
Coal [a]	18
Shale floor.	

Section in stripping on northwest bank of Clear Creek above falls (24).

	Feet.
Coal	47

Section in stripping south of No. 24 (25).

	Feet.
Coal	31

Section at base of Clear Creek Falls (26).

	Feet.
Shale.	
Diabase sill.	
Coke (ranges from 6 to 12 inches)	1
Coal [b]	5
Coal	11
Shale.	

Strike N. 65° E., dip 45° NW.

This seam varies considerably in thickness within short distances, A measurement at the base of the falls showed 8 feet 2 inches of coal, while one at the tunnel a few yards away gave a total of about 16 feet.

Section on tributary to Clear Creek, heading southeast of Monument Mountain, elevation 1,450 feet (27).

	Ft.	in.
Firm shale roof.		
Coal	1	4
Hard shale		7
Soft shale with some coal	1	2
Shale	2	3
Coal [c]	3+	
Sandstone floor; fault at floor cuts off coal above it.		

Strike (on roof) N. 85° E., dip 32° NW.

Section on same creek as No. 27; elevation 1,200 feet (28).

	Ft.	in.
Firm shale roof.		
Coal [d]	1	10
Bone		4
Coal [d]		11
Bony coal		7
Coal [d]		3
Shaly coal		3
Coal [d]	3	3
Shale horse	5	
Shaly coal	2	
Coal	1	

Strike N. 67° E., dip 30° NW.

[a] Included in sample No. 23, pp. 84–87.
[b] Included in sample No. 26, pp. 84–87.
[c] Included in sample No. 27, pp. 84–87.
[d] Included in sample No. 28, pp. 84–87.

Section on east bank of Clear Creek, 2.9 miles above its mouth (29).

	Feet.
Flaggy sandstone.	
Sandy shale	3
Coal [a]	4
Diabase sill	4
Sandy shale.	
Strike N. 90° E., dip 67° N.	

This is the lowest coal exposed on Clear Creek, although two lower ones are reported on a near-by tributary from the north. There is no physical evidence that the intrusion has altered the coal.

Section in prospect opening on crest of ridge between Trout and Clear creeks, south of Trail Gap; elevation 1,885 feet (30).

	Ft.	in.
Shale	1	
Coal		4
Shale		4
Coal	10	
Shale	1	
Coal	2	4
Shale	2	
Strike N. 70° E., dip 34° NW.		

Section on crest of same ridge as No. 30, 500 feet farther south.

	Feet.
Shale, dark	12
Coal	12
Shale	8
Strike N. 70° E., dip 34° NW.	

Several workable seams are exposed on Trout Creek. The following sections, arranged in stratigraphic order beginning with the highest, were measured:

Section in tunnel on Trout Creek opposite house (33).

	Feet.
Shale roof.	
Coal [b]	8
Shale floor.	
Strike N. 85° W., dip 28° NE.	

Section at creek level below No. 33 (34).

	Ft.	in.
Shale	4	
Coal [c]	6	6
Sandstone	5	
Strike N. 70° E., dip 38° NW.		

Section in long tunnel one-fourth mile below house on Trout Creek (36).

	Ft.	in.
Coal	4	6

[a] Included in sample No. 29, pp. 84–87. [b] Included in sample No. 33, pp. 84–87.
[c] Included in sample No. 34, p. 84.

Section in long tunnel one-fourth mile below house on Trout Creek (136).

	Feet.
Shale roof.	
Coal [a]	33
Shale floor.	

Strike N. 65° E., dip 38° NW.

Section in tunnel 1,500 feet below house on Trout Creek (37)

	Ft.	in.
Arkose roof.		
Coal	7	7
Arkose floor.		

Section on small drain into Trout Creek from the west, near mouth of Bear Creek; elevation 395 feet (38).

	Feet.
Shale roof.	
Coal	6
Shale floor.	

Strike N. 2° W., dip 24° SW.

Section on same drain as No. 38; elevation 375 feet (39).

	Ft.	in.
Coal	3	6

Strike N. 25° E., dip 39° NW.

Section on same drain as Nos. 38 and 39; elevation 360 feet (40).

	Feet.
Shale roof.	
Coal	12+
Shale floor.	

Strike N. 15° E., dip 27° NW.

The following sections are all on the east slope of Kushtaka Ridge:

Section on east side of Kushtaka Ridge, one-fourth mile east of U. S. L. M. Kayak No. 4 (41).

	Feet.
Shale	30
Coal	5
Coal and shale	5
Shale	10
Coal	3
Shale floor.	

Strike N. 38° E., dip 70° NW.

Section on east side of Kushtaka Ridge, elevation 1,630 feet (42).

	Ft.	in.
Shale roof.		
Bone		8
Coal	3	8
Shale		1
Coal	3	4
Bone		3
Coal	1	8

[a] Included in sample No. 36, pp. 84–87.

	Ft.	in.
Bone		5
Coal	1	
Shale		4
Coal		11
Bone		2
Dark shale floor.	12	6

Strike N. 45° E., dip 68° NW.

Section on Kushtaka Ridge, east side, 1½ miles north-northwest of cabin; elevation 1,600 feet (43).

	Feet.
Shale roof.	
Coal [a]	14
Shale floor.	

Section on Kushtaka Ridge, east side, 1 mile north northwest of cabin; elevation, 850 feet (44).

	Feet.
Soft shale roof.	
Coal [b]	3
Soft shale floor.	

Strike N. 77° E., dip 40° NW.

Section on east side of Kushtaka Ridge; elevation, 1,335 feet (45).

	Ft.	in.
Coal	12–15	
Shale	1	
Coal	2	6
Shale	2	6
Bone	2	4
Coal	2	6
Bone		6
Coal	1	
Bone		4
Coal	2	6
	27–30	2

Strike N. 22° E., dip 58° NW.

Section in tunnel on trail 2,200 feet north of Kushtaka cabin (46).

	Feet.
Shale roof.	
Coal (pinching out)	10

Strike N. 25° E., dip 42° NW.

Section in tunnel on east face of Kushtaka Ridge; elevation, 790 feet (48).

	Ft.	in.
Firm shale roof.		
Coal [c] somewhat bony and with pyrite nodules	14	6
Hard shale floor.		

Strike N. 65° E., dip 45° NW.

[a] Included in sample No. 43, pp. 84–87.

[b] Included in sample No. 44, pp. 84–87.

[c] Included in samples Nos. 48a and 48b, pp. 84–87.

The following sections are exposed on the crest of Kushtaka Ridge, beginning near United States locating monument Kayak No. 4 and extending for about one-half mile southeast. The stratigraphic position of the beds is given in the section on pages 32–34.

Section on Kushtaka Ridge just below U. S. L. M. Kayak No. 4; elevation, 2,400 feet (49).

	Ft.	in.
Shale.		
Coal	2	2
Coal, shaly	1	
Shale	9	
Coal	4	8
Shale.		

Strike N. 45° E., dip 64° NW.

Section on Kushtaka Ridge 500 feet southeast of U. S. L. M. Kayak No. 4; elevation, 2,340 feet (50).

	Ft.	in.
Shale, carbonaceous	2	
Coal	2	3
Shale, carbonaceous		5

Strike N. 45° E., dip 65° NW.

Section on Kushtaka Ridge 1,300 feet southeast of U. S. L. M. Kayak No. 4; elevation, 2,180 feet (51).

	Ft.	in.
Shale	7	
Coal	3	
Shale		6
Coal		6
Shale		6
Coal	1	
Shale	2	

Strike N. 45° E., dip 45° NW.

Section on crest of Kushtaka Ridge, 1,400 feet southeast of U. S. L. M. Kayak No. 4; elevation, 2,150 feet (52.)

	Ft.	in.
Sandy shale	2	
Shale with coal streaks	2	8
Coal	8	8
Soft shale floor	1	

Strike N. 40° E., dip 40° NW.

Section on Kushtaka Ridge, 1,700 feet southeast of U. S. L. M. Kayak, No. 4; elevation, 2,100 feet (53).

	Feet.
Shale with coal streaks	5
Coal	1
Shale	2
Coal	5
Shale.	

Strike N. 40° E., dip 45° NW.

The following sections are on the west slope of Kushtaka Ridge, in the valley of Carbon Creek:

Section on north bank of Carbon Creek, near headwaters; elevation 1,350 feet (54).

	Ft.	in.
Shale	1	
Coal	2	8
Shale		4
Coal	1	11
Shale	1	

Strike N. 18° E., dip 30° NW.

Section of coal on northwest bank of Queen Creek (55).

	Feet.
Shale roof.	
Coal[a]	27
Shale (pocket?)	7
Coal	2
Shale	10
Coal[b]	31
Shale floor.	77

Strike N. 64° E., dip 42° NW.

Section of coal on southeast bank of Queen Creek (56).

	Ft.	in.
Coal	14	
Shale	4	
Coal	7	
Shale		3
Coal	2	
Shale		2
Coal	10	

Strike N. 66° E., dip 58° SE.

Section on small creek southwest of Queen Creek (57).

	Ft.	in.
Shale roof.		
Coal	1	1
Shale	3	6
Coal	2	2
Shale with coal streaks	1	6
Coal	3	6
Shale		8
Coal	6	8
Shale	3	6
Coal	11	
	33	7

[a] Included in samples Nos. 55a and 55b, pp. 84–87.
[b] Included in samples Nos. 55c and 55d, pp. 84–87.

Section on small creek southwest of Queen Creek (58).

	Ft.	in.
Shale roof.		
Coal[a]	17	
Shale	41	
Coal	4	
Shale	5	
Coal	3	
Shale	2	6
Coal	26	
Carbonaceous shale.		
	98	6

Section on small creek southwest of Queen Creek (59).

	Feet.
Coal	14
Shale	2
Coal	16
	32

Section on Leeper Creek, one-third mile above its mouth (60).

	Feet
Coal[b]	8–11

Strike N. 40° E., dip 75° NW.

Section in stripping on north side of Carbon Creek above the tunnel and at an elevation of 830 feet (61).

	Feet.
Shale roof.	
Coal	8
Shale floor.	

Strike N. 50° E., dip 45° NW.

Section in tunnel on south bank of Carbon Creek (62).

	Feet.
Arkose roof.	
Coal[c]	8–11
Shale floor.	

Section in tunnel near mouth of Nevada Creek (64).

	Ft.	in.
Dark shale	2	
Coal[d]	19	7
Arkose		10

Strike N. 90° E., dip 78° N.

The following sections are in the upper part of the valley of Shepherd Creek, above the mouth of Carbon Creek:

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[a] Included in sample No. 58, pp. 84.
[b] Included in sample No. 60, pp. 84–87.
[c] Included in samples Nos. 62a and 62b, pp. 84–87.
[d] Included in samples Nos. 64a and 64b, pp. 84–87.

Section at north end of upper trail on east side of Lake Charlotte; elevation 810 feet (65).

	Ft.	In.
Shale roof	10	
Coal		2
Shale		5
Coal [a] with many thin partings of bone	9	6
Shale and coal	6	

Strike N. 12° E., dip 72° SE.

At this opening the coal is firm and should stand shipment with less crushing than many of the others in this field, but the amount of ash is excessive. The same seam has been opened again about half a mile south of this point.

Section of prospect opening near Grade Trail cabin ("Doyle camp") on east side of Shepherd Creek, 1.4 miles below Lake Charlotte (66).

	Ft.	in.
Shale roof.		
Coal	20	6
Shale floor.		

Strike N. 40° E., 75°-85° NW.

This bed, which appeared very promising when first opened, showing a great thickness of beautiful, clean coal, has been found to be cut off entirely within a few feet by a fault.

The following section is the only one measured in the lower part of the Shepherd Creek valley, although a considerable area of coal is known:

Section 1 mile northwest of Canoe Landing on Shepherd Creek; elevation 200 feet (67).

	Ft.	in.
Coal [b]	3	
Shale		2
Coal [b]	4	4

Strike N. 50° E., dip 65° NW.

The opening is on the west side of the valley of Shepherd Creek, at an elevation of about 200 feet above Bering Lake.

The following sections are in the valley of Lake Tokun:

Section in prospect opening on west bank of Tokun Creek, 1.4 miles above Lake Tokun (68).

	Feet.
Arkose roof.	
Coal	2
Shale floor.	

Strike N. 65° E., dip 33° NW.

Section in prospect opening a short distance above No. 68 (69).

	Feet.
Arkose roof.	
Coal	3
Shale floor.	

Strike N. 65°, dip 33° NW.

[a] Included in sample No. 65, p. 84.

[b] Included in sample No. 67, p. 84.

Section in lower tunnel on Tokun Creek, about 100 yards above No. 69 (70).

	Ft.	in.
Arkose roof.		
Coal [a]	6	8
Shale floor.		

Section in upper tunnel on Tokun Creek (71).

	Feet.
Sandstone, shaly.	
Coal	6
Strike N. 78° W., dip 40° NE.	

Section at head of gorge on Trail Creek (72).

	Ft.	in.
Sandstone roof.		
Coal	2	6
Sandstone floor.		
Strike N. 15° W., dip 55° NE.		

The coal in the valley of Dick Creek is represented in the following sections:

Section in tunnel on tributary to Dick Creek from the east 1½ miles above mouth of Dick Creek (73).

	Feet.
Coal	6
Sandstone floor.	
Strike N. 15 W., dip 60° NE.	

Section in tunnel on Powers Creek, 1 mile north of Bering Lake (74).

	Ft.	in.
Coal (top concealed)	2	
Shale	1	6
Coal [b]	8	6
Sandstone floor.		
Strike N. 70° E., dip 35° NW.		

Section on tributary to Falls Creek, ½ mile northeast of Christopher's cabin; elevation, 200 feet (75).

	Ft.	in.
Soft shale with probably a little overlying coal.		
Coal [c]	2	7
Shale		7
Coal		9
Shale	1	10
Coal		5
Coaly shale		6
Arkose.		
Strike N. 25° E., dip 60° SE.		

Section in opening in cliffs of Falls Creek, 1 mile north of Bering Lake; elevation, 110 feet (76).

	Feet.
Arkose.	
Coal [d]	3
Coal and shale	3
Coal [d]	4
Sandy shale floor.	
Strike N. 20° W., dip 25° NE.	

[a] Included in sample No. 70, p. 84.
[b] Included in sample No. 74, p. 84.
[c] Included in sample No. 75, pp. 84–87.
[d] Included in sample No. 76, pp. 84–87.

Up the creek from this point are numerous small surface openings, each showing from 2 to 3 feet of irregular coal:

Section on Falls Creek 1 mile above its mouth; elevation, 800 feet (77).

	Feet.
Massive arkose.	
Coal	6
Shale	4
Coal	2+
Strike N. 46° E., dip 35° NW.	

Section on ridge south of Mount Hamilton; elevation, 1,625 feet (78).

	Feet.
Coal	1
Shale	1
Coal	12½
Shale	1
Coal	2
Strike N. 80° W., dip 85° NE.	

Section on ridge south of Mount Hamilton; elevation, 1,550 feet (79).

	Ft.	in.
Arkose.		
Shale	3	
Coal	7	
Shale		9
Coal	2	
Shale	3	
Strike N. 89° E., dip 40° NW.		

Section in gulch two-fifths of a mile southwest of Mount Hamilton; elevation, 1,100 feet (80).

	Ft.	in.
Shale roof.		
Coal [a]	5	
Shale at top and bottom, concealed between	30	
Coaly shale	2	
Coal [b] (somewhat impure)	1	5
Shale		2
Coal [b] with shale streaks	1	4
Shale		4
Coal [b] with little shale	1	
Shaly coal		6
Coal [b]		9
Shale	1	
Coal, impure		4
Coal [c]	1	8
Shale		2
Coal [c]	4	6
Shaly sandstone floor.		
Strike N. 40° E., dip 52° NW.		

[a] Included in sample No. 80a, pp. 84–87. [b] Included in sample No. 80b, pp. 84–87.
[c] Included in sample No. 80c. pp. 84–87.

Section in tunnel on shore of Bering Lake halfway between Poul Point and mouth of Dick Creek (81).

	Ft.	in.
Shale roof.		
Coal		8
Sandstone	1	
Coaly shale		10
Coal [a]	4	
Soft shale		6
Possibly some coal beyond.		
Strike N. 76° E., dip. 72° NW.		

CHARACTER OF THE COAL.

PHYSICAL PROPERTIES.

Numerous specimens of hard, firm, bright, and apparently pure coal, possessing all the physical characteristics of the best anthracite, have been seen in the upper part of the valley east of Carbon Mountain.

These properties are not evident in most of the surface exposures of the coal beds and in the shallow openings, such exposures usually showing only a soft, weathered mass of coal which gives little indication of anthracite character. However, in all parts of the region indicated on the map (Pl. VIII) as containing anthracite float specimens of good anthracite, such as those described above, are found, and the best of the natural and artificial exposures of the coal beds contain some fragments which indicate that the unweathered coal would be of the anthracite character of the hard float specimens. The classification of all the coal of this part of the field as anthracite is furthermore confirmed (see pp. 90–91) by the other properties of the coal.

It is, however, not certain that this coal, though anthracite, will have the value to be expected from its composition. It is impossible to tell, from the present surface exposures, whether beds exposing a soft friable mass of weathered coal will be found hard and unbroken below the zone of surface disintegration, or whether this coal is all badly crushed and shattered. The value of this end of the field, as determined by the possibility of profitable mining, depends largely on this question, for when an anthracite is badly crushed its market value is far more seriously impaired than that of a bituminous coal would be.

The coal of the rest of the region, classed below as semianthracite and semibituminous coal, is all of a friable nature, the least crushed of it somewhat resembling part of the softer bituminous coals of the Eastern States. Many of the beds have been severely crushed and sheared, and the coal is certain to be badly broken up in mining and

[a] Included in sample No. 81, pp. 84–87.

shipping, thus yielding a large proportion of slack. This is not such a great detriment in the case of the semibituminous coking coal as it is with the anthracite and semianthracite, for, as will be shown below some of it will probably be made into coke, while that which is used as steam coal will fuse and cake as soon as it is put into the furnace, thus preventing the loss of slack through the grates.

COMBUSTION.

The coal from all parts of the field burns with short flame and little or no smoke, the length of flame and amount of smoke being least in the coal from the eastern part of the field and increasing gradually westward. The coal from the west end of the field fuses and cakes somewhat on beginning to burn, but that from the eastern part burns without caking. Considerable fine coal or coke usually goes through the grate without burning, but this could be remedied by the use of finer grates than are customarily used in this region. The ashes are soft and fine and little or no clinker is formed.

COKING TESTS.

The coking qualities of the coal from the 33-foot bed on Trout Creek (see tunnel No. 36 on Pl. VIII, pocket, and on p. 73) were tested by the writer in the summer of 1905 in the following manner: A hot wood fire was built in a pit dug for the purpose, and lump coal gradually added until about 600 pounds of coal was burning. Then about a ton of slack and lump coal was added. The sides of the pile were banked with stones and dirt, the top and ends being left open for draft. After several hours the ends were banked and only a small opening at the top was left uncovered to let the smoke escape. Four days later, when the smoke ceased to come off, the pile was opened and the fire extinguished. The resulting coke was firm, strong, porous, and had a good ring and luster. The test showed conclusively that an excellent coke can be made from this coal by proper treatment.

The coal from the 8-foot bed on Carbon Creek (see tunnel No. 62 on Pl. VIII, pocket, and on p. 77) was tested in 1906 in the same manner. Heavy rains, during the early part of the test, made it impossible to get as hot a fire as should have been used, and the test was consequently not as great a success as was hoped for. A small quantity of fair quality of coke was obtained from the center of the pit, which seems to indicate that, under more favorable conditions, good coke could be produced.

Coal from many of the other seams was tested more crudely, and it was found that practically all of the coal here classed as semibituminous possesses such coking qualities that probably by proper treatment a good coke can be made from almost any of it.

CHEMICAL AND CALORIMETRIC PROPERTIES.

ANALYSES AND CALORIMETER TESTS.

Methods of sampling.—The analyses and calorimeter tests recorded in the tables on pp. 84–87 were made upon samples collected by the writer. These samples were all collected in the following manner: A position was selected where a complete and characteristic section of the bed was exposed, and where the effects of weathering were absent or as slight as possible. A fresh cut was then made across the bed from roof to floor, cleaning off all dirt and weathered coal as far as possible. A waterproof cloth was spread to catch the coal, and a sample was cut from the roof to the floor, taking all parts of the bed alike, except such shale and other bedded impurities as could readily be separated in the ordinary practices of actual mining. The parts of each bed which went into the sample are indicated in the local sections. The sample was then pulverized and carefully quartered. A 3-pound sample prepared in this way was sealed immediately in an air-tight can[a] which was not opened until the coal was analyzed.

Methods of analysis.—The samples collected in 1905 and 1906 were analyzed by F. M. Stanton of the United States Geological Survey fuel-testing plant at St. Louis, Mo., using the standard methods[b] adopted in that work. The samples collected in 1904 were analyzed by E. C. Sullivan of the United States Geological Survey. The samples collected in 1903 were analyzed and the calorific value determined by Penniman & Browne, of Baltimore, Md. The methods were the same as those used[c] for the Maryland Geological Survey.

It will be noticed that most of these samples contained a large proportion of total moisture, the greater part of which was driven off by air drying.[d] Under most circumstances this proportion would be regarded as excessive and not characteristic of fair samples. But in view of the large amount of underground water which the rocks of this region contain, and the heavy rainfall, it seems probable that the total moisture of these analyses will represent approximately the proportion which the coal will contain in uncovered cars when it reaches tide water.

Analyses.—The table on page 84 contains proximate analyses of all the samples collected by the writer, and also calorimeter tests where such were made. Averages of all the analyses of each kind of coal are also given.

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[a] Samples No. 55b, 55d, 62b, and 65 were shipped in canvas sacks, and consequently had a chance to dry in shipment. They were otherwise treated as described above.

[b] Bull. U. S. Geol. Survey No. 261, 1905, pp. 19–20; Prof. Paper U. S. Geol. Survey No. 48, 1906, pt. 1, 177–193; Bull. U. S. Geol. Survey No. 290, 1906, pp. 29–30.

[c] Penniman, W. B. D., and Browne, Arthur L., The chemical and heat-producing qualities of Maryland coals: Maryland Geol. Survey, vol. 5, 1905, pp. 620–625.

[d] Bull. U. S. Geol. Survey No. 261, 1905, pp. 19–20; Bull. U. S. Geol. Survey No. 290, 1906, pp. 29–30.

Analyses and tests of Bering River coals.—I.

Sample No.[a]	Laboratory No.	Thickness of coal, in feet.	Proximate analysis.						Calorific value.		Fuel ratio.
			Loss on air drying.	Total moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Calories.	British thermal units.	
[b]2	2478	2.63	4.70	7.67	5.78	66.03	20.52	2.90	....	....	11.42
[b]3	2485	2.17	1.90	3.74	5.41	85.92	4.93	1.10	....	....	15.88
[b]5	2480	15+	6.10	8.33	6.36	82.00	3.31	1.11	....	....	12.89
[b]6	2483	10.5	13.20	13.89	5.01	73.87	7.23	.82	6,743	12,137	14.75
[b]7	2487	4.7	6.20	7.26	6.64	75.89	10.21	1.27	....	....	11.43
[b]8	2496	15	5.20	5.93	6.76	81.47	5.84	.82	....	....	12.05
[b]9	2882	10	7.00	8.31	7.12	82.43	2.14	1.05	....	....	11.58
([c])	....	....	....	7.88	6.15	78.23	7.74	1.30	....	....	12.86
[b]10	2481	5.25	5.00	7.94	9.20	78.53	4.33	.79	....	....	8.54
[b]11	2479	2.85	1.50	4.43	10.14	80.78	4.65	.51	7,578	....	7.97
[d]14	4461	6.75	6.00	7.77	7.40	75.59	9.24	.66	6,983	12,569	10.21
[d]16	4433	2.58	6.20	7.43	6.86	71.35	14.36	.57	6,606	11,891	10.40
[e]17	....	4.17	....	3.24	9.79	62.97	24.00	1.94	6,502	....	6.43
[d]19	4462	2.67	5.30	7.64	9.82	76.31	6.23	.57	7,255	13,059	7.77
[d]20	4459	1.67	1.80	2.95	6.81	75.74	14.50	1.08	7,104	12,787	11.12
[e]21	....	5	....	1.34	6.30	84.57	7.79	.77	....	....	13.43
[d]23	4431	18	5.00	5.71	8.75	80.89	4.65	1.22	7,881	14,186	9.24
[d]26	4435	5	3.30	4.19	8.71	84.60	2.50	1.42	8,091	14,564	9.71
[d]27	4460	3	5.50	6.59	9.21	71.53	12.67	.60	6,860	12,348	7.77
[d]28	4430	7.42	4.80	5.89	10.86	78.41	4.84	2.50	7,539	13,570	7.22
([f])	....	....	....	5.80	8.87	76.06	9.27	1.08	....	....	8.77
[d]29	4451	4	2.40	3.69	13.17	77.10	6.04	3.08	7,751	13,952	5.85
[b]33	2489	8	1.30	2.11	16.58	79.68	1.63	.78	....	....	4.81
[e]34	....	6.17	....	2.36	18.12	71.87	7.65	.73	7,819	....	3.97
[b]36	2484	33	5.40	6.34	14.29	69.55	9.82	.64	....	....	4.87
[d]43	4428	14	8.00	9.37	12.99	74.02	3.62	.63	7,424	13,363	5.70
[d]44	4455	3	3.80	5.43	13.12	79.65	1.80	.67	8,025	14,445	6.07
[b]48a	2497	14.5	1.90	2.68	11.06	73.31	12.95	5.27	....	....	6.63
[d]48b	4463	14.5	1.30	2.92	10.74	71.32	15.02	4.14	6,859	12,346	6.64
[b]55a	2486	27	3.00	4.23	14.03	79.75	1.99	.96	....	....	5.68
[g]55b	....	27	....	.56	16.61	78.71	4.12	1.25	....	....	4.74
[b]55c	2495	31	4.60	5.66	13.65	76.81	3.88	.77	....	....	5.63
[g]55d	....	31	....	1.20	17.28	77.69	3.83	.78	....	....	4.49
[b]58	2494	17	3.90	4.94	13.34	77.29	4.43	.83	....	....	5.79
[d]60	4453	8	3.20	4.01	12.46	77.47	6.06	1.11	7,873	14,171	6.22
[b]62a	2492	11	3.70	4.22	13.37	78.80	3.61	1.56	....	....	5.89
[g]62b	....	11	....	.38	16.97	77.48	5.17	1.02	....	....	4.57
[b]64a	2491	19.6	5.40	5.95	13.01	76.12	4.92	.61	....	....	5.85
[e]64b	....	19.6	....	2.41	15.03	79.24	3.32	.51	8,345	....	5.27
[g]65	....	9.5	....	.68	17.87	60.73	20.72	.55	....	....	3.40
[e]67	....	7.5	....	1.54	14.58	72.99	10.89	.69	7,664	....	5.01
[b]70	2490	6.67	3.70	4.35	11.97	73.34	10.34	1.13	....	....	6.13
[b]74	2493	8.5	5.10	5.84	11.74	60.21	22.21	3.36	....	....	5.13
[d]75	4454	2.58	3.90	5.51	12.85	64.34	17.30	2.83	6,513	11,723	5.01
[b]76	2488	7	5.20	6.03	12.98	78.40	2.59	.70	....	....	6.04
[d]80a	4437	5	5.20	7.74	15.57	67.83	8.86	.84	6,969	13,544	4.36
[d]80b	4452	5.5	2.70	5.71	13.04	47.10	34.15	6.47	4,659	8,386	3.61
[d]80c	4436	6.3	4.20	6.12	11.72	51.11	31.05	5.25	5,038	9,068	4.36
[d]81	4427	4	4.60	5.14	13.90	75.96	5.00	1.16	7,814	14,065	5.46
([h])	....	....	....	4.18	14.00	72.42	9.39	1.73	....	....	5.28

[a] These numbers agree with the section numbers given on Pl. VIII and in the sections of coal beds. The arrangement is geographic from northeast to southwest.
[b] Sample collected by G. C. Martin, 1905; analysis by U. S. Geological Survey fuel-testing plant.
[c] Average of analyses 2–9 (anthracite).
[d] Sample collected by G. C. Martin, 1906; analysis by U. S. Geological Survey fuel-testing plant.
[e] Sample collected by G. C. Martin, 1903; analysis by Penniman & Browne, of Baltimore, Md.
[f] Average of analyses 10–28, exclusive of No. 21 (semianthracite).
[g] Sample collected by G. C. Martin, 1904; analysis by E. C. Sullivan, U. S. Geological Survey.
[h] Average of analyses 29–81 (semibituminous).

LOCALITIES.

[b] 2. 1⅜ miles above Fourth Berg Lake.
[b] 3. Gulch at head of Second Berg Lake.
[b] 5. Carbon Mountain, east side, second opening from west on hillside trail.
[b] 6. Carbon Mountain, east side, first opening from west on hillside trail.
[b] 7. Carbon Mountain, east side, 200 feet below hillside trail.
[b] 8. Carbon Mountain, west side, north end of hillside trail.
[b] 9. Carbon Mountain, west side, south end of hillside trail.
[b] 10. Carbon. Mountain, west side, near crest at trail.
[b] 11. Carbon Mountain, west side, 50 feet below the last.
[d] 14. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 630 feet.
[d] 16. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 520 feet.
[c] 17. Tunnel on east bank of Canyon Creek, 2⅜ miles above mouth of creek, near Hunt's cabin.
[d] 19. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 950 feet.
[d] 20. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 900 feet.
[e] 21. Carbon Mountain, south end (natural coke).
[d] 23. Tunnel on north bank of Clear Creek above the falls.
[d] 26. Tunnel at base of Clear Creek Falls.
[d] 27. Opening on tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,450 feet.
[d] 28. Opening on tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,200 feet.
[d] 29. Opening on east bank of Clear Creek, 2.9 miles above the mouth of the creek.
[b] 33. Trout Creek, tunnel opposite house.
[e] 34. Trout Creek, opening at creek level below the last.
[b] 36. Trout Creek, tunnel one-fourth mile below house.
[d] 43. Opening on Kushtaka Ridge, east side, 1½ miles north-northwest of cabin, elevation 1,600 feet.
[d] 44. Opening on Kushtaka Ridge, east side, 1 mile north-northwest of cabin, elevation 850 feet.
[b] 48a. Tunnel on east face of Kushtaka Ridge, elevation 790 feet.
[d] 48b. Tunnel on east face of Kushtaka Ridge, elevation 790 feet (same tunnel and seam as last).
[b] 55a. Opening on northwest bank of Queen Creek, upper bed.
[g] 55b. Opening on northwest bank of Queen Creek, upper bed (same as the last).
[b] 55c. Opening on northwest bank of Queen Creek, lower bed.
[g] 55d. Opening on northwest bank of Queen Creek, lower bed (same as the last).
[b] 58. Opening on small creek southwest of Queen Creek.
[d] 60. Tunnel on Leeper Creek, one-third mile above its mouth.
[b] 62a. Tunnel on south bank of Carbon Creek.
[g] 62b. Tunnel on south bank of Carbon Creek (same as the last).
[b] 64a. Tunnel near mouth of Nevada Creek.
[e] 64b. Tunnel near mouth of Nevada Creek (same as the last).
[g] 65. Opening at north end of upper trail on east side of Lake Charlotte, elevation 810 feet.
[e] 67. Tunnel 1 mile northwest of Canoe Landing on Shepherd Creek, elevation 200 feet.
[b] 70. Lower tunnel on Tokun Creek.
[b] 74. Tunnel on Powers Creek, 1 mile north of Bering Lake.
[d] 75. Tributary to Falls Creek, one-half mile northeast of Christopher's cabin, elevation 200 feet.
[b] 76. Cliffs on Falls Creek, 1 mile north of Bering Lake, elevation 110 feet.
[d] 80a. Gulch two-fifths of a mile southwest of Mount Hamilton, elevation 1,100 feet, upper bed.
[d] 80b. Gulch two-fifths of a mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, upper bench.
[d] 80c. Gulch two-fifths of a mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, lower bench.
[d] 81. Tunnel on shore of Bering Lake, halfway between Poul Point and Dick Creek.

Analyses and tests of Bering River coals.—II.

SAMPLES AS RECEIVED.

Sample No.[a]	Laboratory number.	Thickness of coal in feet.	Proximate analysis.				Ultimate analysis.						Calorific value.	
			Loss on air drying.	Total moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
b3	2485	2.17	1.90	8.97	4.41	86.54	5.08	1.10	3.54	81.60	1.36	7.32	7,590	13,662
b5	2480	15+	6.10	8.01	6.01	82.47	3.51	1.11	4.18	80.47	1.48	9.25	7,500	13,500
b6	2483	10.5	13.20	14.30	4.50	73.74	7.46	.82	4.33	71.26	1.30	14.83	6,651	11,972
b8	2496	15	5.20	6.89	6.42	80.97	5.72	.82	4.08	79.80	1.37	8.21	7,463	13,433
b9	2882	10	7.00	8.52	5.76	83.20	2.52	1.05	4.02	81.46	1.45	9.50	7,619	13,714
(c)	......	......	......	8.34	5.42	81.38	4.86	.98	4.03	78.92	1.39	9.82	7,365	13,258
b10	2481	5.25	5.00	7.55	9.28	78.44	4.73	.79	4.19	76.51	1.41	12.37	7,309	13,156
b11	2479	2.85	1.50	4.34	9.19	81.61	4.86	.51	4.04	80.90	1.28	8.41	7,538	13,568
d14	4461	6.75	6.00	7.77	7.40	75.59	9.24	.66	4.07	73.99	1.41	10.63	6,983	12,569
d16	4433	2.58	6.20	7.43	6.86	71.35	14.36	.57	3.71	70.10	1.50	9.76	6,606	11,891
d19	4462	2.67	5.30	7.64	9.82	76.31	6.23	.57	4.43	77.30	1.45	10.02	7,255	13,059
d20	4459	1.67	1.80	2.95	6.81	75.74	14.50	1.08	3.69	74.09	1.18	5.46	7,104	12,787
d23	4431	18	5.00	5.71	8.75	80.89	4.65	1.22	4.28	81.55	1.26	7.04	7,881	14,186
d26	4435	5	3.30	4.19	8.71	84.60	2.50	1.42	4.35	84.01	1.45	6.27	8,091	14,564
d27	4460	3	5.50	6.59	9.21	71.53	12.67	.60	4.30	72.45	1.30	8.68	6,860	12,348
d28	4430	7.42	4.80	5.89	10.86	78.41	4.84	2.50	4.31	78.19	1.33	8.83	7,539	13,570
(e)	......	......	......	6.01	8.69	77.45	7.86	.99	4.14	76.91	1.36	8.75	7,317	13,170
d29	4451	4	2.40	3.69	13.17	77.10	6.04	3.08	4.20	79.99	1.44	5.25	7,751	13,952
b33	2489	8	1.30	1.96	15.95	80.13	1.96	.78	5.04	86.68	1.57	3.97	8,652	15,574
b36	2484	33	5.40	6.26	13.28	69.74	10.72	.64	4.22	74.51	1.47	8.44	7,223	13,001
d43	4428	14	8.00	9.37	12.99	74.02	3.62	.63	4.87	77.19	1.22	12.47	7,424	13,363
d44	4455	3	3.80	5.43	13.12	79.65	1.80	.67	4.55	83.26	1.42	8.30	8,025	14,445
d48b	4463	14.5	1.30	2.92	10.74	71.32	15.02	4.14	3.68	70.10	1.09	5.97	6,859	12,346
b55a	2486	27	3.00	4.32	11.55	81.70	2.43	.96	4.07	83.55	1.56	7.43	8,088	14,558
b55c	2495	31	4.60	5.91	11.95	78.09	4.05	.77	4.35	79.68	1.46	9.69	7,626	13,727
d60	4453	8	3.20	4.01	12.46	77.47	6.06	1.11	4.35	79.87	1.34	7.27	7,873	14,171
b62a	2492	11	3.70	4.40	13.00	78.77	3.83	1.56	4.61	83.82	1.35	4.83	7,999	14,398
b64a	2491	19.6	5.40	6.10	12.26	76.20	5.44	.61	4.58	80.79	1.35	7.23	7,743	13,937
d75	4454	2.58	3.90	5.51	12.85	64.34	17.30	2.83	4.00	66.05	.96	8.86	6,513	11,723
b76	2488	7	5.20	6.16	12.65	77.87	3.32	.70	4.70	82.63	1.28	7.37	7,962	14,332
d80a	4437	5	5.20	7.74	15.57	67.83	8.86	.84	4.55	70.86	1.19	13.70	6,969	12,544
d80b	4452	5.5	2.70	5.71	13.04	47.10	34.15	6.47	3.34	46.97	.81	8.26	4,659	8,386
d80c	4436	6.3	4.20	6.12	11.72	51.11	31.05	5.25	3.62	51.23	.96	7.89	5,038	9,068
d81	4427	4	4.60	5.14	13.90	75.96	5.00	1.16	4.50	80.68	1.38	7.28	7,814	14,065
(f)	......	......	......	5.34	12.95	72.26	9.45	1.89	4.31	75.17	1.29	7.89	7,307	13,152

[a] These numbers agree with the section numbers as given on Pl. VIII and in the sections of coal beds (pp. 67–81). The arrangement is geographic from northeast to southwest.

[b] Sample collected by G. C. Martin, 1905; analysis by F. M. Stanton, U. S. Geol. Survey fuel-testing plant.

[c] Average of analyses 3–9 (anthracite).

[d] Sample collected by G. C. Martin, 1906; analysis by F. M. Stanton, U. S. Geol. Survey fuel-testing plant.

[e] Average of analyses 10–28 (semianthracite).

[f] Average of analyses 29–81 (semibituminous.)

LOCALITIES.

[b] 3. Gulch at head of Second Berg Lake.

[b] 5. Carbon Mountain, east side, second opening from west on hillside trail.

[b] 6. Carbon Mountain, east side, first opening from west on hillside trail.

[b] 8. Carbon Mountain, west side, north end of hillside trail.

[b] 9. Carbon Mountain, west side, south end of hillside trail.

[b] 10. Carbon Mountain, west side, near crest at trail.

[b] 11. Carbon Mountain, west side, 50 feet below the last.

[d] 14. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 630 feet.

[d] 16. Tributary to Canyon Creek on east side and next below Hunt's cabin, elevation 520 feet.

[d] 19. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 950 feet.

[d] 20. Carbon Mountain, west side, creek opposite mouth of Canyon Creek, elevation 900 feet.

[d] 23. Tunnel on north bank of Clear Creek, above the falls.

Analyses and tests of Bering River coals.—II—Continued.

AIR-DRIED SAMPLES (calculated from table on p. 86.)

Sample No. [a]	Proximate analysis.			Ultimate analysis.						Calorific value.		Indices of classification.		
	Moisture.	Volatile combustible.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.	Fuel ratio.	Carbon-hydrogen ratio.	Carbon-oxygen ratio.
[b]3	2.11	4.49	88.22	5.18	1.12	3.39	83.18	1.39	5.74	7,737	13,927	19.62	24.54	14.49
[b]5	2.03	6.40	87.83	3.74	1.18	3.73	85.70	1.57	4.08	7,987	14,377	13.72	22.98	21.00
[b]6	1.27	5.18	84.96	8.59	.94	3.30	82.10	1.50	3.57	7,662	13,793	16.39	24.85	23.00
[b]8	1.78	6.77	85.41	6.04	.86	3.69	84.18	1.45	3.78	7,872	14,170	12.61	22.81	22.27
[b]9	1.64	6.19	89.46	2.71	1.13	3.49	87.59	1.56	3.52	8,192	14,742	14.44	25.10	24.88
(c)	1.77	5.81	87.18	5.25	1.05	3.52	84.55	1.49	4.14	7,890	14,202	15.36	24.06	21.13
[b]10	2.68	9.77	82.57	4.98	.83	3.83	80.54	1.48	8.34	7,694	13,804	8.45	21.03	9.66
[b]11	2.89	9.33	82.85	4.93	.52	3.93	82.13	1.30	7.19	7,652	13,774	8.88	20.90	11.42
[d]14	1.88	7.87	80.42	9.83	.70	3.62	78.71	1.50	5.64	7,429	13,371	10.21	21.74	13.96
[d]16	1.31	7.31	76.07	15.31	.61	3.22	74.73	1.60	4.53	7,043	12,677	10.40	23.21	16.50
[d]19	2.47	10.37	80.58	6.58	.60	4.05	81.63	1.53	5.61	7,661	13,790	7.77	20.16	14.55
[d]20	1.17	6.93	77.13	14.77	1.10	3.55	75.45	1.20	3.93	7,234	13,021	11.12	21.25	19.20
[d]23	.75	9.21	85.15	4.89	1.28	3.93	85.84	1.33	2.73	8,296	14,933	9.24	21.84	31.44
[d]26	.92	9.01	87.49	2.58	1.47	4.12	86.88	1.50	3.45	8,367	15,061	9.71	21.09	25.18
[d]27	1.15	9.75	75.69	13.41	.63	3.90	76.67	1.38	4.01	7,259	13,067	7.77	19.66	19.12
[d]28	1.15	11.41	82.36	5.08	2.63	3.97	82.13	1.40	4.79	7,919	14,254	7.22	20.69	17.15
(e)	1.64	9.10	81.03	8.24	1.04	3.81	80.47	1.42	5.02	7,655	13,775	9.08	21.16	17.82
[d]29	1.32	13.49	79.00	6.19	3.16	4.03	81.96	1.47	3.19	7,942	14,295	5.85	20.34	25.69
[b]33	.67	16.16	81.18	1.99	.79	4.96	87.82	1.59	2.85	8,776	15,779	5.02	17.71	30.81
[b]36	.91	14.04	73.72	11.33	.68	3.83	78.76	1.55	3.85	7,635	13,743	5.25	20.56	20.46
[d]43	1.49	14.12	80.46	3.93	.68	4.33	83.90	1.33	5.83	8,070	14,525	5.70	19.38	14.39
[d]44	1.69	13.64	82.80	1.87	.70	4.29	86.55	1.47	5.12	8,342	15,016	6.07	20.17	16.90
[d]48b	1.64	10.88	72.26	15.22	4.20	3.58	71.02	1.10	4.88	6,949	12,509	6.64	16.91	14.55
[b]55a	1.36	11.91	84.22	2.51	.99	3.85	86.13	1.61	4.91	8,338	15,008	7.07	22.89	17.54
[b]55c	1.37	12.53	81.85	4.25	.81	4.02	83.52	1.53	5.87	7,994	14,389	6.53	20.78	14.23
[d]60	.84	12.87	80.03	6.26	1.15	4.12	82.51	1.38	4.58	8,133	14,639	6.22	20.03	18.02
[b]62a	.72	13.50	81.80	3.98	1.62	4.36	87.04	1.40	1.60	8,306	14,950	6.06	19.96	54.40
[b]64a	.74	12.96	80.55	5.75	.64	4.21	85.40	1.43	2.57	8,185	14,733	6.22	20.29	33.23
[d]75	1.68	13.37	66.95	18.00	2.95	3.71	68.73	1.00	5.61	6,777	12,199	5.01	18.53	12.25
[b]76	1.01	13.35	82.14	3.50	.74	4.35	87.16	1.35	2.90	8,398	15,108	6.15	20.04	30.06
[d]80a	2.68	16.42	71.55	9.35	.89	4.20	74.75	1.25	9.56	7,351	13,232	4.36	17.80	7.82
[d]80b	3.09	13.40	48.41	35.10	6.65	3.13	48.27	.83	6.02	4,788	8,619	3.61	15.42	8.01
[d]80c	2.01	12.23	58.35	32.41	5.48	3.29	53.48	1.00	4.34	5,259	9,466	4.36	16.26	12.32
[d]81	.57	14.57	79.62	5.24	1.22	4.18	84.57	1.45	3.34	8,191	14,744	5.46	20.23	25.32
(f)	1.40	13.50	75.29	9.82	1.96	4.03	78.33	1.34	4.53	7,614	13,703	5.62	19.19	20.94

LOCALITIES—Continued.

[d] 26. Tunnel at base of Clear Creek falls.
[d] 27. Tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,450 feet.
[d] 28. Tributary to Clear Creek heading southeast of Monument Mountain, elevation 1,200 feet.
[d] 29. East bank of Clear Creek, 2.9 miles above its mouth.
[b] 33. Trout Creek, tunnel opposite house.
[b] 36. Trout Creek, tunnel one-fourth mile below house.
[d] 43. Kushtaka Ridge, east side, 1½ miles north northwest of cabin, elevation 1,600 feet.
[d] 44. Kushtaka Ridge, east side, 1 mile north northwest of cabin, elevation 850 feet.
[d] 48b. Tunnel on east face of Kushtaka Ridge, elevation 790 feet.
[b] 55a. Northwest bank of Queen Creek, upper bed.
[b] 55c. Northwest bank of Queen Creek, lower bed.
[d] 60. Tunnel on Leeper Creek, one-third mile above its mouth.
[b] 62a. Tunnel on south bank of Carbon Creek.
[b] 64a. Tunnel near mouth of Nevada Creek.
[d] 75. Tributary to Falls Creek, one-half mile northeast of Christopher's cabin, elevation 200 feet.
[b] 76. Cliffs on Falls Creek, 1 mile north of Bering Lake, elevation 110 feet.
[d] 80a. Gulch two-fifths mile southwest of Mount Hamilton, elevation 1,100 feet, upper bed.
[d] 80b. Gulch two-fifths mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, upper bench.
[d] 80c. Gulch two-fifths mile southwest of Mount Hamilton, elevation 1,100 feet, lower bed, lower bench.
[d] 81. Tunnel on shore of Bering Lake, halfway between Poul Point and Dick Creek.

The tables on pages 84–87 contain proximate and ultimate analyses and calorimeter tests of the samples collected in 1905 and 1906. These analyses and tests were all made at the United States Geological Survey fuel-testing plant, under uniform methods and conditions, and are hence better adapted for comparison with one another than the other analyses. These proximate analyses (p. 84) of the samples collected in 1905 are not the same as the analyses of the same samples given in the other table (p. 86). No ultimate analyses were made until after the 1906 samples were collected, when ultimate analyses were made on both the 1905 and 1906 samples, and the proximate analyses on the former were repeated. The differences between the two sets of proximate analyses on the same samples represent the alteration in the coal samples which took place during the fifteen months that elapsed between the dates of the two analyses.

Phosphorus was not determined in any of the samples collected by the writer, but a group of 17 analyses made under private auspices show phosphorus[a] ranging from 0.003 to 0.070 and averaging 0.017. The exact localities of these samples, as well as the methods of sampling and analyses, are not known.

CLASSIFICATION OF THE COAL.

Schemes of classification.—Coal is classified according to its physical properties, behavior on burning, products of distillation, and chemical composition, into the main classes of anthracite, bituminous, and lignite. Further divisions include semianthracite and semibituminous, which are intermediate between anthracite and ordinary bituminous coal; coking coal, splint, block, and cannel, which represent special phases of bituminous coal; and subbituminous, which is intermediate between bituminous coal and lignite. The Bering River coal is all either anthracite, semianthracite, or semibituminous, so the basis of classification of only these will be considered here.

No one of the characteristics enumerated above forms a sufficient basis for the classification of coal, and since each class of coal probably grades completely across into other classes, it follows that if a large enough number and variety of coals are under consideration, no sharp divisions can be recognized even if all the properties are known. Yet, as a general thing, since some of these properties follow from certain others, a given coal can usually be referred to its approximate position without knowledge of all its properties. For example, anthracite can be recognized and distinguished from all the other classes by its physical appearance, by the way in which it burns, by the relative amounts of volatile hydrocarbons and nonvolatile carbon which it yields on distillation, and by its chemical composition. Semianthracite and semibituminous can not as a general thing be distinguished from each other by their physical appearance, but they

[a] Compare with phosphorus in Fairmont, West Virginia, coking coal, p. 111.

can be distinguished by the amount of flame and smoke, by the fact that semianthracite will not coke while semibituminous will coke, by the relative proportions of the products of distillation, and by chemical composition. Similarly semibituminous and bituminous coal can not usually be distinguished by physical appearance or by coking properties, but can be distinguished by the length of flame, by the amount of smoke, by the relative proportions of the products of distillation, and by the chemical composition.

It can be seen from the preceding paragraph that either the products of distillation or the chemical composition suffices for the recognition and separation of the classes of coal here represented.

The products of distillation are usually determined as moisture, volatile matter or "volatile hydrocarbons," fixed carbon, and ash; and the determination of them is called a "proximate analysis."[a] The relative proportion of the products of distillation is usually represented by the quotient of the fixed carbon divided by the volatile matter, or, as it is usually called, the fuel ratio, which is a convenient index of the classification of the coal. Fuel ratios which have been in use for the last sixty-five years or more were made the basis of a coal classification which was proposed by Frazer[b] in his work for the Second Pennsylvania Survey and which has come into quite general use, though with some modification of the limits of the various classes.

As originally stated by Frazer the fuel ratios of anthracite ranged from 100 to 12, of semianthracite from 12 to 8, of semibituminous form 8 to 5, and of bituminous from 5 to 0. The terms semianthracite and semibituminous, as used in the trade, are applied to coals with somewhat different ranges of fuel ratio than those used by Frazer. Consequently a somewhat different grouping has come into use, in which anthracite is recognized as having a fuel ratio above 10, semianthracite from 10 to 7, semibituminous from 7 to 3, and bituminous of various kinds, subbituminous and lignite below 3.

The chemical composition of coal is determined in the form of an "ultimate" or elementary analysis. The relative proportions of these elements, or of some of them, can then be used to determine the relations of the various coals. These proportions are usually used in the form of a ratio, or index of classification, such as the ratio of carbon to hydrogen,[c] carbon to oxygen, or some other ratio[d] or

[a] This term, although well enough understood for practical purposes, is somewhat misleading, for analysis implies a separation into constituents, yet the volatile matter as obtained in a "proximate analysis" is not a constituent of the coal, but a product of destructive distillation.

[b] Trans. Am. Inst. Min. Eng., vol. 6, 1877, p. 430; Geol. Survey Pennsylvania, Vol. MM, 1879, pp. 128–144.

[c] Campbell, Marius R., Trans. Am. Inst. Min. Eng., vol. 36, 1906, pp. 324–340; Prof. Paper U. S. Geol. Survey No. 48, pt. 1, 1906, pp 156–173.

[d] Parr, S. W., Illinois Geol. Survey, Bull. 3, 1906, pp. 27–78. Grout, Frank F., Economic Geology, vol. 2, 1907, pp. 225–241.

proportion, involving in some cases more than the elementary composition of the coal. None of these schemes have been elaborated and the exact boundaries defined for the classes of coal here under consideration, nor has it yet been shown that for these kinds of coal they are any improvement over the old fuel ratios. The fact is that any ratio or index of classification is of value only as a convenient index, and that a satisfactory classification must be based upon all the properties of coal and on a knowledge of its genesis.

Variation in character.—The table of analyses on page 84 shows that there is considerable difference in the relative proportion of fixed carbon and volatile matter in coals from the eastern and the western ends of the field; in that from the eastern end the amount of fixed carbon is greater and the volatile matter is less, and hence the fuel ratio is greater. East of Carbon Mountain, and in the northern end of the valley of Canyon Creek, the fuel ratios exceed 11, ranging from 11.42 to 15.88. In the lower end of the valley of Canyon Creek and in the upper end of the valley of Clear Creek, the fuel ratios range from 6.43[a] to 11.12. In the lower part of the valley of Clear Creek, and everywhere west of it, the fuel ratios range from 6.64 to 3.97 or 3.40.[b]

The tables of analyses on pp. 86–87 show somewhat different fuel ratios, ranging in the eastern district from 12.61 to 19.62, in the middle district from 7.22 to 11.12, and in the western district from 3.61 to 7.07. The fuel ratios of both tables thus show that the coal is anthracite in the eastern district, semianthracite in the middle district, and semibituminous in the western district.

The carbon-hydrogen ratios also show quite plainly the differences in the character of the coal of the three districts. These ratios range in the eastern district from 22.81 to 25.10, in the middle district from 19.66 to 23.21, and in the western district from 15.42 to 22.89. There is some overlapping of values, but in general the differences between the three districts are quite plainly shown. These limits do not agree very well with the provisional limits suggested by Campbell[c] of 26 (?) to (?) for anthracite, 23 (?) to 26 (?) for semianthracite, and 20 to 23 (?) for semibituminous. Campbell's grouping of these classes of coal was, however, not based upon a sufficient number of analyses, and he suggested that the limits would probably be changed when more analyses were available.

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[a] This sample contains 24 per cent of ash. Consequently, since excessive ash usually appears to lower the fuel ratio, possibly because of the affinity of clay for oily substances, the next lower fuel ratio (7.22) should perhaps be regarded as near the typical lower range of this group of coals.

[b] This sample (No. 65) also contains an excessive amount of ash and consequently has an abnormal fuel ratio.

[c] Campbell, Marius R., The classification of coals. Trans. Am. Inst. Min. Eng., vol. 36, 1906, p. 340.

Carbon-oxygen ratios fail utterly to show any unity of character of coal in either district, or any marked difference between the several districts. The highest ratios (54.40 and 33.23) are from coking coals of the western district, and some of the lower ones (9.66 and 14.49) are from coals whose other characters are anthracitic.

The carbon-oxygen ratio is theoretically a good index of classification, but it fails practically for these classes of coals, because incomplete removal of moisture in air drying has an inordinate effect upon the ratio, since moisture is eight-ninths oxygen, and consequently a very little residual moisture can contain more oxygen than the dry coal should. When we have an accurate and standardized method of removing extraneous moisture (and nothing else), then the carbon-oxygen ratio should furnish an excellent index of classification of coal, but at present its use is impractical.

The separation of the coals into three groups (p. 90) on the basis of their fuel ratios is confirmed by the fact that the coals of the eastern group show some of the physical properties (p. 81) and the behavior on burning (p. 82) characteristic of anthracite, while the coals of the western group have the physical properties, flame, and coking properties of semibituminous coal. The coals of the intermediate group are soft, burn with a short smokeless flame, and do not coke, thus agreeing in all their properties with the semianthracites. The limits of these groups, as far as could be determined from the present investigations, are shown on Pl. VIII (pocket), which gives the area and distribution of the anthracite, semianthracite, and semibituminous. Those limits are subject to revision in the light of further knowledge, especially where the lines are drawn through regions from which no samples have been tested. It will doubtless be found that such lines, as far as definite lines of separation exist, are sinuous, and that the area of each group contains outlying areas of the other groups. Within each of the groups as outlined above no regular variation has been noted.

The explanation of this geographic variation is to be found in the relation to the structure. The anthracite occurs in a region of great structural complexity (p. 42), the rocks being very closely folded and much faulted. The coking coal occurs in a region of simpler structure in which the folds are open. The semianthracite occupies a region of intermediate structural type. Distance from the Chugach Mountains also doubtless has played a part in the distribution of the various kinds of coal, especially if there have been intrusions of large and numerous igneous masses subsequent to the deposition of the coal. Local intrusions are more abundant in the anthracite region, but appear not to be either numerous enough or large enough to have been primarily responsible for the regional variation in the coal. Where such dikes or sills (pp. 70, 71, 72) have come into direct contact with the coal they have driven off the volatile constituents and transformed part of it into a dense natural coke, as shown on Pl. IX, *B*. The effect of such intrusion, as far as could be judged from the instances noted, was extremely local, the coal being altered for only a few inches from the contact.

COMPARISON WITH OTHER COAL.

It was stated above (p. 81) that coal having all the physical characteristics of the best anthracite is known in this region only from float specimens and from outcrops which have not been sampled. The physical properties of these leads to favorable comparison with the best Pennsylvania anthracite. Workable beds of such character have, however, not been opened or sampled, and it is not known whether they exist.

The samples of anthracite, of which analyses and tests are given on pages 84–87, came from beds which do not show all the physical properties of the best anthracite. The analyses and tests also show that this coal is of somewhat lower degree of carbonization than the best Pennsylvania coal. It is, however, as far as chemical and combustion properties are concerned, an excellent fuel.

The semianthracite is of about the same character as the Loyalsock or Bernice basin coal of Pennsylvania.

The semibituminous coal is very close in composition, heating power, and in most of its other properties to the Pocahontas (West Virginia) and Georges Creek (Maryland) coal and to other coals of the Appalachian coal fields.

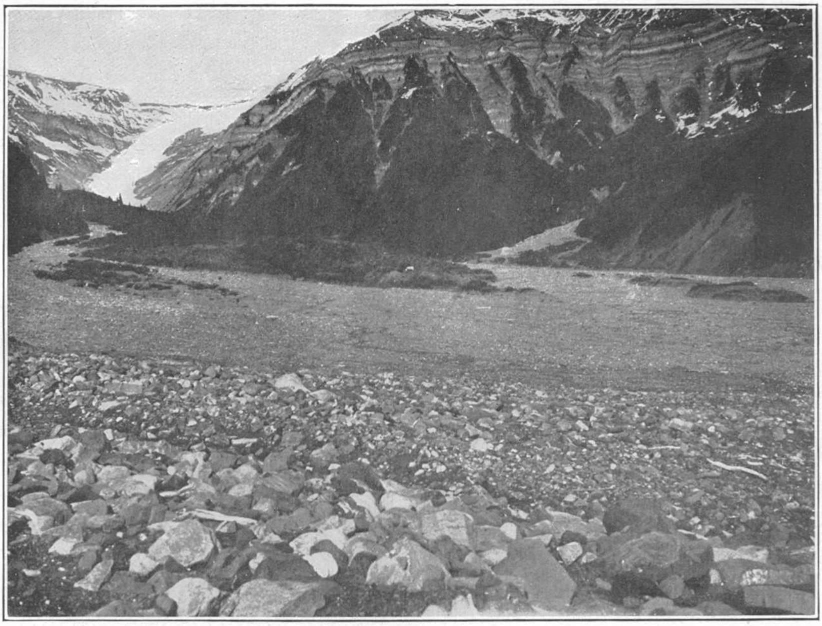
The fuel and commercial value of these coals as compared with other coals with which they may come in competition are discussed under the heading of markets (pp. 111–112).

PROSPECTIVE MINING CONDITIONS.

The geologic factors which will affect the cost of mining in this region include the topographic position of the outcrops, the steep dips and complicated structure, the variability in thickness and the possible lack of persistence of the beds, the friable character of the coal, and the occurrence of explosive gases and of large amounts of underground water. These, with the additional questions of title to the land, of cost of labor and supplies, of transportation, and of markets, determine the possibility of profitable mining.

POSITION OF THE COAL.

The coal-bearing rocks occur in regions of considerable relief, and consequently a large amount of the coal is above drainage level. A large number of the coal beds are known to outcrop in the bottoms of



A. VALLEY OF SHEEP CREEK, SHOWING COAL OUTCROPS ON THE MOUNTAIN FACE.

B. NATURAL COKE AND DIABASE SILLS AT THE SOUTH END OF CARBON MOUNTAIN.

the valleys, and the dip is such that all (if persistent for that distance) can be reached by tunnels at the level of the valley floors. There is no doubt that enough coal can be thus reached to support a large mining industry for a long time. Shafting or slope mining will not be necessary for many years, although the later development of the region will doubtless depend on the coal which is below the general drainage level.

ATTITUDE OF THE COAL.[a]

The effect of dip, in addition to that discussed above in regard to the position of the coal beds, is chiefly to determine the method of mining. Steep dips do not make mining impossible or even excessively costly. They introduce no problems which have not already been successfully met in other fields.

The possible overturned folds and the faults introduce problems the scope of which can perhaps be determined only by exploration of the seams in depth. It seems probable that there are areas within the field in which, because of these difficulties, the coal can not be successfully mined. (See fig. 1, p. 42.) These must be determined by careful surface prospecting, followed by either boring or tunneling at critical points. The anthracite field is especially liable to be affected by these difficulties, which, on the one hand, will be compensated for, in part at least, by the greater value of the coal.

PERSISTENCE OF THE COAL.

Variability in thickness of the seams, especially of the thicker ones, may be considered an ever-present problem, the exact magnitude of which can be determined only by underground exploration. It is the current belief in the region that the seams will assume constant thickness and attitudes as soon as they are followed under a heavy cover of overlying rock. Such is not necessarily the case. The swellings and pinchings of the coal do not depend on the nature of the surface of the ground, but on the mode of formation of the coal bed and on the structure of the rocks. Faults or breaks in the coal, pockets, and squeezes are just as liable to be found under the center of a uniform plateau as on the edges of canyons, and must be determined by the position of the rocks in solid outcrop or by boring or tunneling, and not by the character of the surface of the ground. It is certain that these variations will always be a serious problem in mining in this region; but on the other hand, it is likely that they will in large degree be balanced by numerous areas of excessively thick beds and by the high fuel value of the coal.

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[a] See description of the structure, pp. 42–43.

PHYSICAL CONDITION OF THE COAL.

The friability of the coal, if it persists beyond the zone of surface weathering, will very seriously affect the market value of the anthracite. If the anthracite yields a large proportion of slack, and especially if it crushes during transportation, it will be at a decided disadvantage in the market. No openings on the anthracite have as yet been driven beyond the zone of surface disintegration, so it is impossible to tell whether or not the coal below the surface is sufficiently firm to stand handling. In some of the stream beds are numerous pieces of anthracite which are firm and hard, indicating either that these pieces came from fresh exposures, where the coal was not softened and broken up by frost and other weathering, or that there are beds which are better than those which have been prospected. An opening driven to a sufficient depth on one of the beds would settle this question.

The semibituminous coking coals, although equally friable, are not so seriously affected by this condition, for, as has already been pointed out, such coals will probably be used in part for the manufacture of coke, and when used as steam or other heating coal they will fuse and form a solid mass as soon as put in the furnace.

PRESENCE OF WATER AND GAS.

It is probable that underground water will be encountered in large amounts, owing to the abundance of surface water and the deep fracturing of the rocks. Fortunately, there is a large amount of coal above the general drainage level, so it will not be necessary to resort to shafting for a long time. Consequently the water, although it may be very annoying, will not add materially to the expense of mining.

Gases have been encountered in several of the longer tunnels and will have to be considered as a factor in the cost of mining. It will probably be necessary to resort both to very careful ventilation and to the use of safety lamps. Some legislative provision should be made for this before mining begins.

SHIPMENT.

There is now no available market for Bering River coal and there will be none, except in a limited way for fuel at the local settlements and oil wells, until shipping facilities are provided.

The question of transportation to the several harbors under consideration has already been discussed under railway routes (pp. 23–24). A modification of these proposed methods of shipment has been suggested, which involves transportation of the coal by shallow-draft barges from shoal water to wharves or anchorage on deep, sheltered water. This plan is possible, although it has the disadvantage of interference by the ice during part of the winter.

The cost of shipping coal from whatever harbor is chosen to the places where the coal will be used depends on a readjustment of existing facilities and rates. The existing steamers, although they carry little southbound freight except canned salmon and copper ore, will furnish no adequate facilities for the shipment of the output of a coal mine. When this region produces coal on a commercial scale it must depend for shipment on special coal-carrying vessels. The ocean rates under such conditions will bear no relation to the rates on such commodities as the steamers now carry. Comparison should rather be made with rates on ore and coal on the Great Lakes and on coal on the regular ocean routes.

MARKETS.

The question of markets for Alaska coal is a vital one in connection with the present activity in the developments of coal lands, both in the Bering River field and elsewhere in Alaska. The problem has already been discussed by Brooks [a] and by the writer.[b] The following discussion follows very closely that in the latter paper, but the statistics are brought up to date and the estimates revised.

CONSUMPTION OF FUEL IN ALASKA.

AMOUNT AND SOURCES.

The coal consumption of Alaska from June, 1904, to June, 1905, is estimated at 110,000 tons, derived from the following sources:

Consumption of coal in Alaska, June, 1904, to June, 1905.

	Long tons.
Local supply	[c] 2,440
Imported from United States	[d] 42,728
Imported from foreign countries, chiefly British Columbia	[d] 64,832
	110,000

It is estimated that an additional amount of at least 137,000 tons is consumed by steamers plying between United States or foreign ports

[a] Brooks, Alfred H., The outlook for coal mining in Alaska: Trans. Am. Inst. Min. Eng., vol. 36, 1905, pp. 683–702.

[b] Martin, G. C., Markets for Alaska coal: Bull. U. S. Geol. Survey No. 284, 1906, pp. 18–29.

[c] Estimated (the available statistics being for the calendar year).

[d] From table on p. 97.

and Alaska. This fuel comes largely from the home ports of the steamers or chiefly from Puget Sound. The fuel of local coastwise and river boats is, however, included in the total of 110,000 tons. The total coal consumed in Alaska and on voyages thereto is at least 247,000 long tons.

This is not the entire amount of fuel used, for there is a large but unknown amount of wood burned and over 2,700,000 gallons of crude petroleum and 700,000 gallons of naphtha were shipped to Alaska during 1905.

DISPOSAL.

This coal is consumed approximately as follows:

Distribution of coal consumed in Alaska, June, 1904, to June, 1905.

	Long tons.
Towns and mines:	
Southeastern Alaska	[a] 42,000
Pacific coast from Yakutat to Dutch Harbor	[a] 10,000
Bering Sea and Arctic coast	[a] 26,000
Canneries and cannery boats:	
Southeastern Alaska	[a] 5,000
Pacific coast from Yakutat to Chignik	[a] 5,000
Bristol Bay	[a] 12,000
Steamers:	
Local coastwise and river steamers (excluding cannery boats)	[a] 10,000
Puget Sound to southeastern Alaska	[b] 45,000
Puget Sound to Prince William Sound and Cook Inlet	[b] 23,000
Puget Sound to Nome	[b] 32,000
San Francisco to Alaska	[c] 7,000
British Columbia to southeastern Alaska	[c] 25,000
Foreign ports to Nome	[c] 5,000
	247,000

The bulk of the crude petroleum was used in Seward Peninsula and on the Yukon, while the larger part of the naphtha went to the same regions, the remainder being used on the Pacific Coast. Almost all of the crude petroleum and of the naphtha was used for heat and power, the petroleum under boilers and the naphtha in engines.

[a] Estimated from customs reports. The individual items may not be exact, but the total of these items (110;000 tons), as given in the preceding table, is fairly accurate.
[b] From data furnished chiefly by the steamship companies.
[c] Computed from tonnage and horsepower of boats.

PROSPECTIVE INCREASE IN USE OF COAL.

The shipments of coal to Alaska during the last four years are shown in the following table:

Shipments of coal to Alaska, July 1, 1902, to June 30, 1906.[a]

	Twelve months ending June 30—							
	1903.		1904.		1905.		1906.	
	Long tons.	Value.[b]	Long tons.	Value.[b]	Long tons.	Value.[b]	Long tons.	Value.[b]
Domestic anthracite	20	$276	....	....	5	$85	....	....
Domestic bituminous	56,120	255,841	41,704	$193,740	42,245	187,352	67,293	$265,047
Domestic coke	65	288	392	2,251	478	4,281	346	3,676
Foreign anthracite	....	....	....	....	10	148	304	1,836
Canadian bituminous	54,072	216,089	63,652	261,987	59,272	260,110	41,481	187,312
Other foreign bituminous	....	....	1,909	7,303	....	....	....	....
Foreign bituminous, shipped via United States	40	350	3,324	23,904	5,550	29,673	706	4,838
Total	110,317	472,844	110,981	489,185	107,580	481,657	110,130	462,709

[a] Commerce of the noncontiguous territory of the United States, Bureau of Statistics, 1903, 1904, 1905, 1906.
[b] At port of shipment.

An increase in the consumption of coal is to be expected from the present rate of development of the region and from the initiation of new enterprises, such as the building of railroads and smelters. These factors of increase will act directly, in the fuel actually consumed by such enterprises, and indirectly in the stimulus to trade and the increase in population which will result. Neither of these direct factors will be large at first. A few small mines along the railroads will supply all the fuel which they will consume, while all the copper ore produced in Alaska in 1906 could be smelted with less than 6,000 tons of coke. These items will, however, probably both increase very rapidly and must be considered very important factors in the development of local industries. Mines situated on the coast or having tide-water connections will probably be able to supply a large part of the bunker coal consumed on both local steamers and those from the United States and foreign ports. This now amounts to 147,000 tons, divided as is shown in the table on page 96.

Mines shipping first-class coal from ports on Controller Bay or Prince William Sound should be able to secure immediately half or possibly all of the patronage of steamers running to Prince William Sound and Cook Inlet, provided the prices are right. A large proportion of the patronage of the other Alaska steamers can probably be secured by shipping the coal either to the Alaska termini of these lines or to Puget Sound or San Francisco. The aggregate tonnage of Alaska steamers which, according to the reports of the Bureau of Statistics, was increasing at the rate of 6 per cent per annum from 1903 to 1905, increased 17 per cent from 1905 to 1906. A rapid rate of increase may be expected in the future.

COMPETITION WITH PETROLEUM.

The question of the competition between coal and petroleum very seriously affects the possibility of developing an important coal-mining industry in Alaska. The use of petroleum has already, to a large degree, stopped the mining of coal on the Yukon for the river steamers and has driven out part of the imported coal used both there and in other parts of Alaska. It has also, to a large extent, driven the Washington, Oregon, and British Columbia coals from the San Francisco market, thus spoiling what might otherwise be a very important market for Alaska coal.

USE OF PETROLEUM IN ALASKA.

The importation of petroleum and its fuel products into Alaska is shown in the following table:

Shipments of petroleum to Alaska.[a]

Period.	Crude petroleum.			Naphthas.	
	Gallons.	Barrels.	Value.	Gallons.	Value.
Six months ending—					
December, 1902	21,000	500	$390	60,358	$12,186
June, 1903	840,000	20,000	28,000	210,147	33,831
December, 1903	1,008,000	24,000	36,000	84,776	18,054
June, 1904	1,008,400	24,010	35,823	231,658	43,814
December, 1904	1,008,030	24,001	33,603	106,623	23,904
June, 1905	1,780,326	42,389	59,204	499,196	75,187
December, 1905	935,060	22,263	31,864	214,300	34,734
June, 1906	1,428,000	34,002	20,400	361,681	60,214
December, 1906	1,260,100	30,000	18,009	219,297	40,480

[a] Monthly summary of commerce and finance, Bureau of Statistics, 1902–1906.

EFFECT OF CALIFORNIA PETROLEUM ON PACIFIC COAST COAL TRADE.

It is believed by many that the coal industry on the Pacific coast will not be able to survive this competition, but that California petroleum, because of its lower cost, will ultimately displace coal in all uses to which petroleum is applicable. The statistics contained in the following table will shed some light on this subject:

Relation of production of petroleum to output and price of coal on the Pacific coast.

Year.	Production of petroleum in California (barrels).[a]	Production of coal on the Pacific coast (short tons.)							
		California.[b]		Oregon.[c]		Washington.[d]		Vancouver Island.[e]	Total Pacific coast production.[f]
		Amount.	Price per ton.	Amount.	Price per ton.	Amount.	Price per ton.	Amount.	Amount.
1895	1,208,482	75,453	$2.33	73,685	$3.36	1,191,410	$2.16	1,058,045	2,398,595
1896	1,252,777	78,544	2.12	101,721	2.90	1,195,504	2.00	1,003,769	2,379,538
1897	1,903,411	85,992	2.34	107,289	2.72	1,434,112	1.94	1,019,390	2,646,693
1898	2,257,207	144,288	2.43	58,184	3.65	1,884,517	1.78	1,263,154	3,350,142
1899	2,642,095	160,615	2.67	86,888	3.00	2,029,881	1.78	1,347,583	3,625,059
1900	4,324,484	171,708	3.05	58,864	3.74	2,474,093	1.90	1,549,379	4,254,044
1901	8,786,330	151,079	2.60	69,011	2.51	2,578,217	1.62	1,469,666	4,267,973
1902	13,984,268	84,984	2.99	65,648	2.44	2,681,214	1.72	1,397,385	4,229,231
1903	24,382,472	104,673	2.82	91,144	2.42	3,193,273	1.69	964,068	4,353,158
1904	29,649,434	78,888	4.76	111,540	2.18	3,137,681	1.63	1,145,887	4,473,996
1905	33,427,473	77,050	4.97	109,641	2.58	1,864,926	1.79	1,113,519	4,165,136
1906	33,098,598	25,290	2.40	79,731	2.66	3,276,184	1.80	1,339,383	4,720,588

[a] Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 831.
[b] Idem for 1905 (1906), pp. 554–556; for 1906 (1907), pp. 653–654.
[c] Idem for 1905 (1906), pp. 651–652; for 1906 (1907), pp. 707–708.
[d] Idem for 1905 (1906), pp. 689–691; for 1906 (1907), pp. 733–736.
[e] Ann. Repts. Minister of Mines, British Columbia.
[f] Computed from the other items in this table.

NOTE.—The price of coal per ton as given above represents "spot value" at the mines.

Variation in amount of coal produced and used on the Pacific coast (short tons).

Year.	Total Pacific coast production.[a]	Shipments of coal to the Pacific coast.[b]	Coal consumed on Pacific coast.[a]	Coal consumed in California.[b]	Coal consumed on Pacific coast outside California.[a]
1895	2,398,595	510,120	2,908,715	1,653,520	1,255,195
1896	2,379,538	458,727	2,838,267	1,505,660	1,332,607
1897	2,646,693	421,638	3,068,331	1,601,540	1,466,791
1898	3,350,142	346,222	3,696,364	1,802,373	1,893,991
1899	3,625,059	299,947	3,925,006	1,740,027	2,184,979
1900	4,254,044	292,654	4,546,698	1,889,128	2,657,570
1901	4,267,973	306,746	4,574,719	1,834,785	2,739,934
1902	4,229,231	368,062	4,597,293	1,445,598	3,151,695
1903	4,353,158	456,742	4,809,900	1,215,554	3,594,346
1904	4,473,996	298,039	4,772,035	1,051,072	3,720,963

[a] Computed from the other items in these tables.
[b] The production of coal in 1904 (advance chapter from Mineral Resources U. S. for 1904), U. S. Geol. Survey, 1905, p. 102.

During the ten years (1895 to 1904) completely covered by these tables there has been an extraordinary increase in the output of California petroleum. The production in 1904 (29,649,434 barrels) is 24½ times the amount produced in 1895 (1,208,482 barrels). As this was nearly all fuel oil it might be expected that it would displace a large amount of coal and that we would find, throughout the same period, a corresponding decrease in coal mining and coal trade not only in California but in the other regions which supply California with coal. The statistics, however, show that the production of coal in California increased from 1895 to 1900 and has fluctuated, but on the whole fallen off, since that time. The production in Oregon has shown an irregular but quite general increase during this ten-year period. The Washington mines have increased their product to almost triple. Vancouver Island mines had a not much greater output at the end of the period than at its beginning, but showed a rise and subsequent fall during the interval. Shipments from Atlantic and oriental ports have decreased somewhat irregularly but very decidedly during these ten years. The amount of coal consumed in California has varied irregularly, but has on the whole shown a decided decrease. The amount of coal consumed on the whole Pacific coast (north of Mexico) has increased from 2,908,715 tons in 1895 to 4,681,012 tons in 1904. The increase on the Pacific coast outside of California is even more striking, the amount having risen from 1,255,195 tons in 1895 to 3,629,940 tons in 1904.

The price of coal mined in California increased during the period under discussion, but subsequently fell (1906). Oregon and Washington coals decreased in value, although the price has been rising from 1904 to 1906. No figures are at hand regarding the prices of Vancouver Island or other imported coals.

The general effect of the increase in petroleum has been to demoralize the San Francisco coal market. The gradual increase in oil output from 1895 to 1900 was accompanied by a very prosperous condition of the coal trade not only in California but throughout the country. After this the output of oil became so great as to preclude all possibility of competition by coal in the oil territory except for those special uses to which oil can not be applied. That is, coal was forced to seek markets of its own, which include, in addition to the special ones mentioned above, those districts in which the relative freight charges on coal and oil make competition possible. In the former the price of coal rose and the demand increased. This result may be attributed to the very factor which in other respects demoralized coal trade. The increase in petroleum output, furnishing a cheap and abundant fuel, stimulated general industrial conditions and thus increased the demand for coal in its special markets.

The cutting down of shipments from the other Pacific coast fields to San Francisco has resulted in a reduction in prices, caused by the attempt to compete with the cheaper petroleum and by the lively competition of the coal mines among themselves in attempting to develop and control new markets nearer home. They have been successful in their home markets, as may be seen by the great increase (289 per cent) in consumption of coal on the northern Pacific coast during the ten years from 1895 to 1904. This means a large increase in manufacturing and other business interests, and indicates that there is a substantial permanent increase in the demand for coal, which helped cause the lately increased price and production and which, barring overproduction or an unlooked-for invasion of petroleum, should lead to a continuation of the upward tendency in prices.

CAPABILITY OF COAL TO COMPETE WITH PETROLEUM.

The following factors determine the possibility and result of competition between coal and oil:

1. Relative adaptability of coal and oil to the special use under consideration.
2. Relative efficiency of oil and coal.
3. Relative prices as determined by cost of production and freight.
4. Supply available.

Relative adaptability.—The factor of relative adaptability determines the special markets for coal and for oil. In each of these markets the other fuel can not compete at any price. The Bering River coal, like some of the other Alaska coal, is of such quality that it is especially suitable for use as a domestic fuel. As such it should find a widespread market along the Pacific coast, selling at a high price in San Francisco and the California oil fields. Competition with oil will be slight, at least until improvements are made in the methods of burning oil. Competition with other coals will be considered in another place (pp. 106–112).

The coal from the western end of the Bering River field will produce a good quality of coke and, for this purpose, the coal will not come into competition with petroleum, but should sell independent of the presence and cost of oil, the price being determined solely by competition with other coking coals. The present increase in steel and smelter industries will make great demand for such coals.

The Bering River field will also furnish a high-grade blacksmith coal. Petroleum will not compete for this purpose. In fact, the oil fields of the Pacific coast will themselves constitute one of the most attractive markets, and any extension of the oil fields will create new demand for blacksmith coal. The present supply of such coal on the Pacific coast is practically all brought from the east at great cost.

It does not seem practicable at present to adapt petroleum to general naval use. Petroleum will consequently not compete with Alaska coal in this market. Much of the Bering River coal is of such quality as to make it especially suitable for use on warships or wherever a high-grade smokeless steaming coal is required. The only effect which petroleum has at present in this market is to render other coal available for competition and thus indirectly to reduce the selling price. If naval architects succeed in solving the structural and storage problems which at present keep petroleum from being used in this way, present conditions will be changed, for petroleum has many advantages over coal for this use.

Relative efficiency of coal and oil.—The factor of relative efficiency is determined primarily by the quality of the coal, the fuel value of petroleum being more nearly constant.

The United States Naval "Liquid Fuel" Board has obtained the following results from tests with the Hohenstein marine water-tube boiler:

Equivalent evaporation from and at 212° F. per pound of oil.[a]

	Pounds.
Beaumont petroleum (average of 47 tests)	12.51
California petroleum (average of 20 tests)	11.57
Mixture (dregs) of Beaumont and California petroleum (average of 2 tests)	11.52

Equivalent evaporation from and at 212° F. per pound of coal as fired.[b]

	Pounds.
Pocahontas coal, run of mine (average of tests 1 to 3)	8.65
Pocahontas coal, run of mine (average of tests 4 to 6)	9.40
New River coal, run of mine (average of tests 7 to 9)	9.37
Pocahontas coal, hand picked and screened (average of tests 10 to 17)	9.30

From each can or bag of coal that was brought into the fireroom a specimen was taken and collected in a box, so that there could be forwarded for analysis a fair sample of the fuel used.

The following table gives the result of the analyses of samples of each lot of coal. The analyses were made by the chemist at the New York Navy-Yard:[c]

Analyses of coal used in comparative fuel tests.

	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
Pocahontas coal, run of mine, used in tests 1 to 3	0.49	17.61	73.30	8.60	0.48	4.16
Pocahontas coal, run of mine, used in tests 4 to 6	.79	19.53	75.78	3.90	.71	3.88
New River coal, run of mine, used in tests 7 to 9	.49	21.79	72.99	4.73	.46	3.35
Pocahontas coal, hand picked and screened, used in tests 10 to 17	.73	19.62	76.81	2.84	.73	3.91

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	B. t. u.
Pocahontas coal, run of mine, used in tests 1 to 3	28.26	3.89	4.12	0.64	0.49	8.60	14,067
Pocahontas coal, run of mine, used in tests 4 to 6	84.96	4.07	5.46	.90	.71	3.90	14,534
New River coal, run of mine, used in tests 7 to 9	83.60	4.85	4.87	1.41	.46	4.81	14,841
Pocahontas coal, hand picked and screened, used in tests 10 to 17	85.94	4.45	4.50	1.14	.82	3.15	14,992

[a] Rept. U. S. Naval "Liquid Fuel" Board, 1904, pp. 250–252.

[b] Op. cit., p. 52.

[c] Op. cit., p. 10.

The following conclusions are stated in the report:[a]

The relative evaporative efficiency of oil and coal as a fuel, as determined by this extended series of comparative experiments, is practically in the proportion of 15 to 10. The actual superiority of oil will be considerably greater, for in the coal experiments unusual skill was exercised in the management of the fires. Lump coal of superior quality was used; and as the tests with coal were of comparatively short duration, the resulting loss from cleaning fires was much less than would occur in actual service. The oil experiments, however, were carried on under conditions that more closely approximated those that could be secured on board the sea-going vessel. The actual evaporative efficiency of a pound of oil as compared with a pound of coal will therefore be in the ratio of 17 to 10, and these figures can be regarded as substantially correct.

* * * * * * *

In noting the comparative economical efficiency, for naval purposes, of oil and coal, there must also be taken into consideration the fact that a ton of oil can be stowed in somewhat less space than a ton of bituminous coal. Then, again, it must be considered that in the carrying of the oil the compartments can be more completely filled. The relative efficiency of oil and good steaming coal from the naval standpoint of fuel supply in war ships may thus be regarded as in the ratio of 18 to 10.

It was found by comparative tests of coal and oil on the steamship *Alameda* between San Francisco and Honolulu that the efficiency of equal weights of oil fuel and a mixture of British Columbia and Australia coal was in the ratio of 1.42 to 1, or that 1 ton of coal equaled 4.10 barrels of oil.

The following quotations will show the relative values of various coals in comparison with petroleum:

Tests have proved that 1 pound of California petroleum used on a passenger locomotive evaporated 10.96 pounds of water from and at 212° F., as compared with 7.14 pounds of water under like conditions evaporated by 1 pound of Comox bituminous coal, or 4 barrels of oil did the work of 1 ton of coal. This is rather below the results attained by other tests, which in many cases showed that from 3¼ to 3½ barrels of petroleum did the work of 1 ton of coal.[b]

Comparison of petroleum with various coals.[c]

Combustible.	Pounds of water evaporated at 212° F. per pound of combustible.	Barrels of petroleum required to do the same amount of evaporation as 1 ton of coal.	Cost of coal per ton to equal petroleum at $1 per barrel.	Less 10 per cent, owing to the greater economy in handling petroleum.
Petroleum, 15° to 18° Baumé	16.0			
Cardiff lump, Wales	10.0	4.0	$4.00	$3.60
Cape Breton, Canada	9.2	3.7	3.70	3.33
Nanaimo, British Columbia	7.3	2.9	2.90	2.61
Cooperative, British Columbia	8.9	3.6	3.60	3.24
Greta, Washington	7.6	3.0	3.00	2.70
Carbon Hill, Washington	7.6	3.0	3.00	2.70

[a] Op. cit., pp. 417–418.

[b] Oliphant, F. H., The production of petroleum in 1901: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, p. 583.

[c] Oliphant, F. H., The production of petroleum in 1903 (separate from Mineral Resources U. S. for 1903), U. S. Geol. Survey, 1904, p. 170.

The following estimates have been gathered from various sources:

Equivalent in petroleum of 1 ton of various coals.

	Barrels of petroleum.
Pocahontas coal	4.5
Georges Creek coal	4.3
Pittsburg coal	4.3
Nanaimo coal	3.2
Carbon Hill coal	2.7

There is some variation in the values given. This may be ascribed in part to differences in quality between different parts of the same field, in part to differences in the efficiency of the boilers, in part to differences in value of various petroleums, and in part to errors.

There is, however, no doubt that a large part of the Bering River coal is of such high grade that a ton of it will equal at least 4 barrels and probably 4.5 or more barrels of California oil.

These figures are all based on the relative efficiency of coal and petroleum when used with a steam engine. The values representing the relative efficiency of these fuels when used with a gas engine,[a] or for direct heat (as in roasting or smelting, or in a stove), might be very different.

Relative prices.—It is impossible to here make any definite estimate of the cost of producing and shipping Alaska coal. It would seem, however, that it should not be much in excess of the cost in many other western mining districts. It is reasonable to assume that with proper management it could be reduced below the present selling price on Vancouver Island.

Freight rates from Bering River mines to tide water ought not to be excessive, and ocean rates from Alaska to Puget Sound or San Francisco should be very low.

The price of California crude petroleum at the wells ranged in 1904 from 17½ cents to $2 per barrel, depending both on local and temporary differences in supply and demand and on differences in quality. The average price was about 28 cents per barrel, as compared with 30 cents in 1903. The cost per barrel, delivered at San Francisco, was from $1.40 to $1.50 in 1904.

These prices in equivalents of Puget Sound coal, estimating 1 ton of coal as equal to 3 barrels of oil, are as follows:

Petroleum at $0.125 per barrel = coal at $0.375 per ton.
Petroleum at $0.28 per barrel = coal at $0.84 per ton.
Petroleum at $1.40 per barrel = coal at $4.20 per ton.
Petroleum at $1.50 per barrel = coal at $4.50 per ton.

The coal values will be about 25 to 33 per cent greater for the best Bering River coal. They show that it is impossible for any coal to

[a] See preliminary report on the operations of the coal-testing plant, etc.: Bull. U. S. Geol. Survey No. 261, 1905, pp. 16, 17, 85–120.

compete with fuel oil in those districts where oil has the advantage of transportation rates. It is possible, however, that rates to San Francisco might be made such that coal and oil can compete. There ought to be lively competition north of San Francisco if the cost of mining and shipment of coal is reduced to a minimum.

Available supply.—It is not likely that either petroleum or coal could be produced on the Pacific coast in sufficient amount to supplant the other without soon proving inadequate to the demand, in which case there would be an advance in price and consequent reopening of competition.

The following conclusions [a] are of interest on this point:

Careful consideration has been given the question as to the supply of crude petroleum in the United States available for fuel purposes. This matter has been specially investigated by Prof. Arthur L. Williston, of the Pratt Institute, Brooklyn, N. Y., who reports as follows:

"The supply of oil which is available for fuel in the United States, therefore, is, first, the small percentage (probably not over 2 or 3 per cent) of the total production of the Pennsylvania and Ohio oil—the residuum from the process of refining; second, crude oil from the Ohio and Indiana fields, wherever the price of coal makes the burning of oil at 95 cents or $1 per barrel (plus freight) profitable; third, those portions of the California oil which are not best suited for refining; fourth, practically the entire output of the Texas field."

The demands for the better grades of oil for refining purposes will probably keep pace with its production; consequently we can never expect to see such grades of oil compete with coal to any large extent.

On the other hand, the refining value of the Texas oil and much of the California oil is so low that its value will probably always be largely controlled by the demand for it for fuel purposes. It is inconceivable that a fuel which has so many distinct advantages, and which is not unlimited in its supply, should sell in all markets at a price which would make it cheaper to burn than coal. Any great demand for such a fuel would bring its price up at once.

On the other hand, so long as there is an assured supply of Texas and California fuel oil, the price of such oil that has little intrinsic value for refining, will probably remain low enough to enable it to compete successfully with coal in those regions where coal is scarce in quantity and poor in quality. And the area in which this condition exists is sufficiently wide to create a demand for the fuel oil that will soon equal the supply, unless further stores of oil are found as the demand for it increases.

The fact should be remembered that in every region there is with each succeeding year a progressive proportionate increase in the percentage of the yield consumed for illuminating purposes.

The petroleum output of California in 1904, which was more than one-fourth (25.33 per cent) of the production of the United States and over 12 per cent of the entire production of the world, is the

[a] Rept. U. S. Naval "Liquid Fuel" Board, 1904, p. 416.

equivalent of only 1.7 or 1.8 times the coal then burned on the Pacific coast of North America alone. In 1906 the consumption of fuel oil in California exceeded the production in that State.[a] It would appear from this that the supply of fuel petroleum must increase very much before it will be possible for petroleum to make much greater inroads into the coal market without ultimately causing a reactionary advance in prices. Such an increase from the present producing oil fields is not probable.

COMPETITION WITH OTHER COAL.

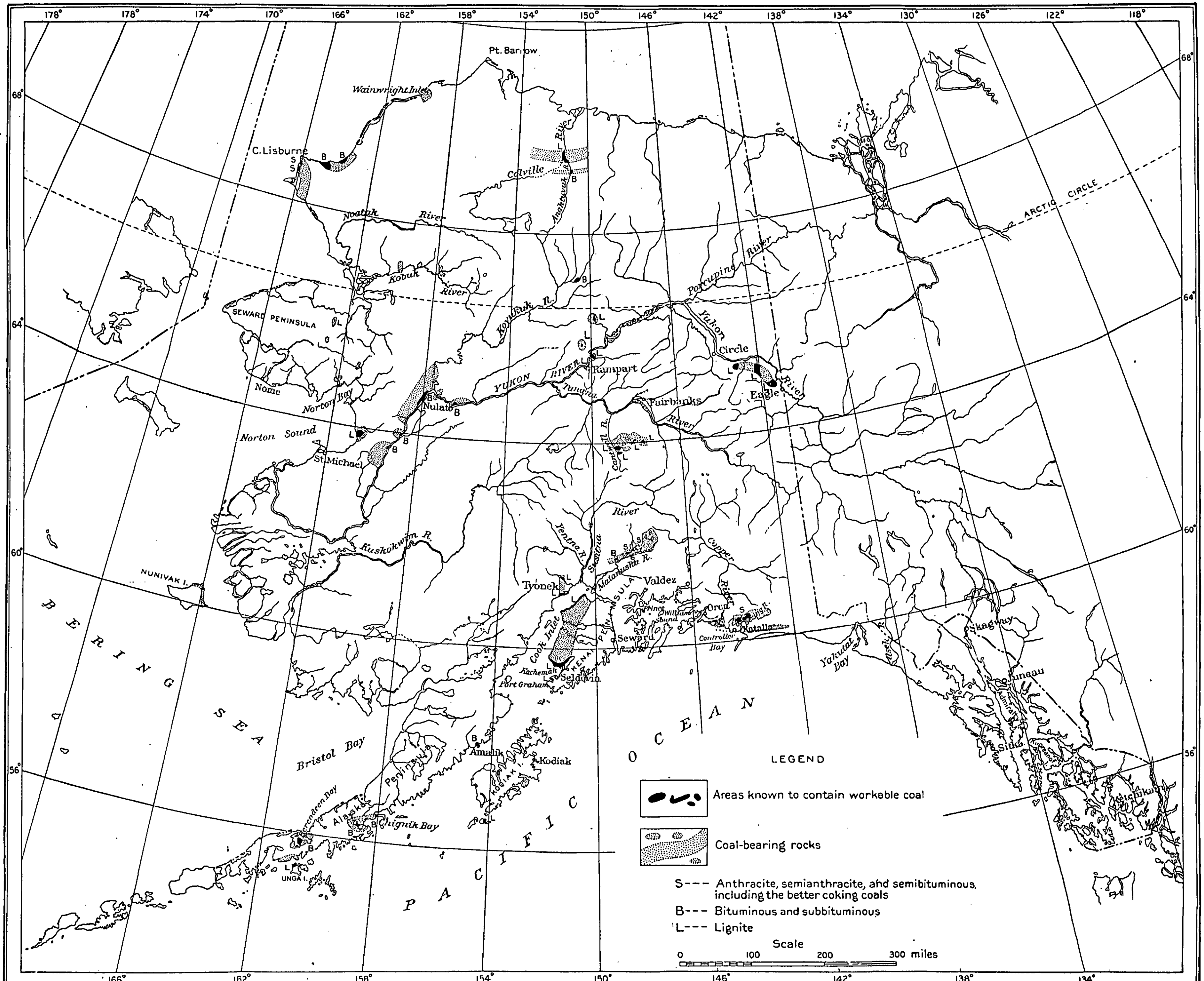
ALASKA COAL.

There are many districts in various parts of Alaska which may produce coal either for local use or for shipment. It is important to consider all of these because, while only those which possess coal of the best quality could compete with Bering River coal in outside markets, most of them must be regarded as possible sources of local supply, and may thus restrict the market which the better coal can reach.

The writer has recently published a brief summary[b] of existing knowledge of Alaska coal, which has been extensively drawn upon in the preparation of the following pages.

Distribution and area.—The distribution of the coal fields of Alaska is indicated on the map (Pl. X), which shows (1) known areas of workable thickness of high-grade coal (anthracite and semi-bituminous); (2) known areas of workable thicknesses of lower-grade coal (bituminous and subbituminous); (3) known areas of workable lignites, and (4) areas of coal-bearing rocks. The last includes those areas which are known to contain some coal but in which beds thick enough to be mined have not yet been discovered, areas in which coal has been authentically reported, but concerning which detailed information is lacking, and areas in which the character of the rocks is similar to that in neighboring coal fields and where, consequently, the occurrence of coal is to be expected. These statements apply also to the table of areas given on p. 107. The areas mapped as "coal-bearing rocks" are consequently not well defined and must be regarded as subject to considerable changes by subsequent exploration. They are intended to indicate the regions in which new discoveries of coal seem, in the light of our present knowledge, to be most probable. The extent of the various areas noted above, as well as the area of each individual coal field, is shown in the following table, which gives a total of at least 1,238 square miles,

[a] Griswold, W. T., Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907, p. 827.
[b] Martin, G. C., The Alaska coal fields: Bull. U. S. Geol. Survey No. 314, 1907, pp. 40–46.



MAP OF ALASKA, SHOWING DISTRIBUTION OF COAL AND COAL-BEARING ROCKS, SO FAR AS KNOWN.

or 792,320 acres, of known workable coal, and 12,576 square miles, or 8,048,640 acres, of "coal-bearing rocks:"

Areas [a] of Alaska coal fields.

[Square miles.]

	Coal areas.	Areas [b] of coal-bearing rocks.
Anthracite:		
Bering River	26.4	
Matanuska River	4.2	
	30.6	
Semibituminous:		
Bering River	20.2	620
Matanuska River	20.3	
Cape Lisburne	14.2	
	54.7	
Bituminous:		
Matanuska River	22.0	900
Alaska Peninsula	69.0	657
Yukon Basin	167.0	2,490
Cape Lisburne	205.0	1,255
Anaktuvuk River	9.0	68
	472.0	5,370
Total anthracite and bituminous	557.3	5,990
Lignite:		
Southeastern Alaska	10.0	50
Cook Inlet region	304.0	2,565
Southwestern Alaska	16.0	300
Copper River	....	20
Yukon Basin	216.0	1,557
Bering Sea	52.0	426
Northern Alaska	83.0	1,736
	681.0	6,654
Grand total	1,238.0	12,576

[a] The difference between the areas given here and those which have been published elsewhere is due chiefly to the recognition of four classes of coal instead of three, and the consequent division of the Lisburne areas into semibituminous and bituminous and of the Yukon areas into bituminous and lignite, and of similar changes in other smaller areas.
[b] See explanation on p. 106.

Pacific coast region.—The Pacific coast coal fields (which include the Bering River field) are of moderate area but of wide distribution. They include both Mesozoic and Tertiary coals, having a complete range in composition from a good quality of anthracite, through high-grade semibituminous steam and coking coals and ordinary bituminous coal, to lignites of various character. The coal beds are frequently of great thickness, especially where the coal is of high carbonization, but unfortunately there usually goes with the high grade of coal and great thickness of bed an irregularity of geologic structure unfavorable to mining conditions. The Pacific coast coals are in general favorably situated for shipment, and in this respect, as in their character, offer possibilities for a larger, more regular, and wider market than any of the other Alaska coals.

Interior region.—The interior region, which is here defined to include the valleys of Copper and Yukon rivers and their tributaries, contains Cretaceous bituminous coal on the lower Yukon and Tertiary lignite and subbituminous coal on the upper Yukon and in the Tanana, Koyukuk, and Copper river basins. None of this coal is suitable for export, but it may be of considerable importance as local fuel.

Bering Sea and Arctic slope.—The coal of this region has great range in geologic age and great variety in character. Coal is present in the Carboniferous, Jurassic, Cretaceous, and Tertiary. In the Cape Lisburne region Carboniferous semibituminous and Jurassic bituminous coals occur, and in the Colville basin Cretaceous bituminous coal and Tertiary lignite are present. In other regions (except at Wainwright Inlet, where the coal is Jurassic), the coal, so far as is now known, is of Tertiary age and is lignite.

It is not likely that any of this coal is of immediate value for other than local use. The high-grade coal at Cape Lisburne may find an extensive market at Nome, but the shipping problems are serious. The other coal is of such character that its market must be restricted to local regions, in which the cost of better imported coal is high. It may be of extreme importance and of great value in local operations, but it is not good enough to ship very far from the mines.

Developments and production.—The coal-mining industry of Alaska is still in a practically undeveloped condition. Coal has been mined intermittently and on a small scale at several places for many years, but the industry has never been of much importance, the maximum total production of all Alaska in any one year being less than 7,000 tons. This has been because the better coal has not been well known until recently and can not be shipped without railway connections from the mines to tide water, and also because no adequate provision has been made for granting title to sufficient tracts to assure profits on the large investments which are required.

The most active mining operations have been on Cook Inlet, on the Alaska Peninsula, on the Yukon, in Seward Peninsula, and at Cape Lisburne. All of these were carried on to obtain local fuel on small coastwise or river steamers, at mining camps, and at canneries.

The most important developments which are now going on outside the Bering River region are preparatory to mining the high-grade Matanuska coal on a large scale for shipment away from the coal fields. This coal, much of which rivals the Bering River coal in amount and quality, is adapted to use[a] on ocean steamers and rail-

[a] Martin, G. C., A reconnaissance of the Matanuska coal field, Alaska, in 1905: Bull. U. S. Geol. Survey No. 289, 1906, 36 pp.

ways and for the manufacture of coke, and for other purposes for which high-grade coal is required. Before this coal can be mined it will be necessary to build about 150 miles of railroad.[a] It is believed that this project is legitimate and that if favorable title can be obtained the field will be producing on a large scale within a few years. A railroad is now under construction.

The coal of the interior and northern parts of Alaska will probably be dependent for its market on local demand as long as better coal is being mined in other regions—that is, it can now be sold only where excessive freight rates on outside coals give it the advantage. This local demand will depend chiefly on mining camps and will be transient or permanent, according to whether the mining camps are placer or lode. Such coal fields of the interior as may be on the line of railroads or near lode mines, especially if the ores are smelting ores and the coal capable of coking, will attain considerable importance, but these conditions are contingent on future discoveries and developments, which can not be foretold.

Character of Alaska coal.—The character of the coal in the Alaska coal fields has been stated in the previously published descriptions of the various fields and has been referred to in the preceding pages. A detailed discussion of this subject is consequently not necessary here. The following table is a summary of all the analyses of Alaska coal which have been made for the United States Geological Survey, and will show approximately the character and comparative value of the coal from the various known areas.

Analyses of Alaska coals.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
ANTHRACITE.						
1. Bering River, average of 7 analyses	7.88	6.15	78.23	7.74	1.30	12.86
2. Matanuska River, 1 sample	2.55	7.08	84.32	6.05	.57	11.90
SEMIANTHRACITE.						
3. Bering River, average of 11 analyses	5.80	8.87	76.06	9.27	1.08	8.77
SEMIBITUMINOUS.						
4. Bering River, coking coal, average of 28 analyses	4.18	14.00	72.42	9.39	1.73	5.28
5. Cape Lisburne, average of 3 analyses	3.66	17.47	75.95	2.92	.96	4.46
6. Matanuska River, coking coal, average of 16 analyses	2.71	20.23	65.39	11.60	.57	3.23
BITUMINOUS.						
7. Lower Yukon, average of 11 analyses	4.68	31.14	56.62	7.56	.48	1.90
SUBBITUMINOUS.						
8. Matanuska River, average of 4 analyses	6.56	35.43	49.44	8.57	.37	1.40
9. Koyukuk River, 1 sample	4.47	34.32	48.26	12.95	....	1.40
10. Nation River, 1 sample	1.39	40.02	55.55	3.04	2.98	1.39
11. Alaska Peninsula, average of 5 analyses	2.34	38.68	49.75	9.22	1.07	1.30
12. Cape Lisburne, average of 11 analyses	9.35	38.01	47.19	5.46	.35	1.24
13. Anaktuvuk River, 1 sample	6.85	36.39	43.38	13.38	.54	1.20

[a] Brooks, Alfred H., Railway routes, Bull. U. S. Geol. Survey No. 284, 1906, pp. 10–17; Railway routes in Alaska, Nat. Geog. Mag., 1907, pp. 165–190.

Analyses of Alaska coals—Continued.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
LIGNITE.						
14. Port Graham, 1 sample	16.87	37.48	39.12	6.53	.39	1.04
15. Southeastern Alaska, average of 5 samples	1.97	37.84	35.18	24.23	.57	1.02
16. Wainwright Inlet, 1 sample	10.65	42.99	42.94	3.42	.62	1.00
17. Colville River, 1 sample	11.50	30.33	30.27	27.90	.50	1.00
18. Upper Yukon, Canadian, average of 13 analyses.	13.08	39.88	39.28	7.72	1.26	.99
19. Upper Yukon, Circle province, average of 3 analyses	10.45	41.81	40.49	7.27	1.30	.97
20. Upper Yukon, Rampart province, average of 6 analyses	11.42	41.15	36.95	10.48	.33	.91
21. Seward Peninsula, 1 sample	24.92	38.15	33.58	3.35	.68	.88
22. Chitistone River, 1 sample	1.65	51.50	40.75	6.10	....	.79
23. Kachemak Bay, average of 6 analyses	19.85	40.48	30.99	8.68	.35	.77
24. Nenana[a] River, 1 sample	13.02	48.81	32.40	5.77	.16	.66
25. Kodiak Island, 1 sample	12.31	51.48	33.80	2.41	.17	.66
26. Unga Island, average of 2 analyses	10.92	53.36	28.25	7.47	1.36	.62
27. Tyonek, average of 4 analyses	8.35	54.20	30.92	6.53	.38	.58
28. Chistochina River, 1 sample	15.91	60.35	19.46	4.28	....	.32

[a] Formerly Cantwell River.

1. This report, p. 84.
2. Bull. U. S. Geol. Survey No. 284, 1906, p. 98, analysis 1.
3. This report, p. 84.
4. This report, p. 84.
5. Bull. U. S. Geol. Survey No. 278, 1906, p. 47, analyses 13 to 15.
6. Bull. U. S. Geol. Survey No. 284, 1906, p. 98, analyses 2 to 17.
7. Bull. U. S. Geol. Survey No. 218, 1903, pp. 62, 63, analyses 26, 28 to 38.
8. Bull. U. S. Geol. Survey No. 284, 1906, p. 98, analyses 18 to 21.
9. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analysis 28.
10. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analysis 17.
11. Bull. U. S. Geol. Survey No. 284, 1906, p. 27.
12. Bull. U. S. Geol. Survey No. 278, 1906, p. 47, analyses 1 to 7, 9 to 12.
13. Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 114, analysis 607.
14. Bull. U. S. Geol. Survey No. 259, 1905, p. 170.
15. Bull. U. S. Geol. Survey No. 284, 1906, p. 27.
16. Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 114, analysis 653.
17. Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 114, analysis 620.
18. Bull. U. S. Geol. Survey No. 218, 1903, pp. 61, 62, analyses 3 to 15.
19. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analyses 16, 18, 19.
20. Bull. U. S. Geol. Survey No. 218, 1903, p. 62, analyses 20 to 25.
21. Bull. U. S. Geol. Survey No. 247, 1905, p. 67.
22. Prof. Paper U. S. Geol. Survey No. 41, 1906, p. 125.
23. Bull. U. S. Geol. Survey No. 259, 1905, p. 170, analyses 3, 4, 7 to 10.
24. Bull. U. S. Geol. Survey No. 218, 1903, p. 62.
25. Bull. U. S. Geol. Survey No. 259, 1905, p. 170.
26. Bull. U. S. Geol. Survey No. 259, 1905, p. 170.
27. Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 23, analyses 1 to 4.
28. Prof. Paper U. S. Geol. Survey No. 41, 1906, p. 124.

IMPORTED COAL.

The coal which is now being shipped to Alaska is derived from the following sources: Vancouver Island, Puget Sound, Australia, the Appalachian region, and Wales. Alaska coal will not only have to compete with these at home, but if it seeks a more extended market will also meet these coals on Puget Sound, at San Francisco, and in the navy-yards and coaling stations of the Pacific, and will also compete to some extent with the coal now being mined in California and Oregon. It is consequently important to compare the character of the Alaska coals with that of all those with which they may come into competition. This may be done by inspecting the following tables of analyses, which are the best available substitutes for actual practical tests and which may be relied on to give a close approximation to the quality and value of the coal:

Average composition of Pacific coals.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.
British Columbia, Crows Nest Pass, average of 10 analyses [a] [b]	1.09	21.07	70.54	7.29	0.37	3.35
British Columbia, Comox, average of 9 analyses [b] [c] [d]	1.18	28.41	62.91	7.49	1.54	2.21
British Columbia, Nanaimo, average of 6 analyses [b] [c] [e]	2.12	34.07	55.94	7.93	.64	1.64
Washington, Wilkeson, average of 7 analyses [f] [g] [h]	.92	27.15	61.82	10.11	1.42	2.28
Washington, Cokedale, average of 3 analyses [f] [h]	1.27	28.04	62.30	8.39	.34	2.22
Washington, Blue Canyon, average of 3 analyses [f] [g] [i]	1.62	32.63	60.47	5.28	.53	1.85
Washington, Carbonado, average of 15 analyses [g] [i]	1.67	33.11	56.74	8.48	.94	1.71
Washington, Roslyn, average of 9 analyses [b] [f] [g] [h] [i]	2.68	34.37	52.75	9.87	.24	1.53
Washington, Franklin, average of 5 analyses [f] [g]	3.22	35.40	53.82	7.55	.15	1.52
Washington, Renton, average of 10 analyses [g] [h]	4.48	36.01	51.17	8.23	.61	1.42
Washington, Newcastle, average of 5 analyses [f] [g]	7.51	37.69	48.94	5.86	.48	1.30
Washington, Black Diamond, average of 4 analyses [f] [h]	4.44	40.50	51.73	3.33	.44	1.28
Oregon, Coos Bay, average of 4 analyses [f]	10.41	46.15	36.85	6.59	1.02	.80
California, average of 10 analyses [j]	11.32	45.09	35.91	7.68	....	.80
Japan, average of 8 analyses [k]	2.62	42.49	50.07	4.82	.92	1.18
Philippines (Cebu) average of 9 analyses [l]	14.00	31.08	50.53	4.85	....	1.64
Philippines (Batan), average of 5 analyses [l]	13.57	36.91	44.92	4.60	....	1.22
New South Wales, southern, average of 21 analyses [m]	.97	23.10	56.26	10.67	.46	2.83
New South Wales, western, average of 13 analyses [m]	1.87	31.49	52.61	14.03	.63	1.67
New South Wales, northern, average of 77 analyses [m]	1.92	35.09	54.08	8.91	.54	1.62

[a] Ann. Rept. Geol. Survey Canada, Vol. 3, pt. 2, 1887–8, pp. 12T–15T.
[b] Ann. Rept. Minister of Mines, British Columbia, for 1902, p. 262H.
[c] Ann. Rept. Geol. Survey Canada, 1872–3, pp. 76–78.
[d] Ann. Rept. Geol. Survey Canada, 1876–7, p. 468.
[e] Ann. Rept. Geol. Survey Canada, 1882–1884, p. 37M.
[f] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 490, 501, 510.
[g] Ann. Rept. Washington Geol. Survey, Vol. 2, 1902, p. 270.
[h] Rept. State Inspector of Mines, Washington, 1901–2.
[i] Ann. Rept. Washington Geol. Survey, Vol. 1, 1901, Pls. XXV, XXVII.
[j] Geology of California, Vol. 3, p. 48.
[k] Outlines of the geology of Japan, Imperial Geol. Survey of Japan, 1902, p. 190.
[l] The coal measures of the Philippines (report to the United States military governor in the Philippines), War Department, 1901, pp. 178–181, 256–259.
[m] Mineral resources of New South Wales, 1901, pp. 324–348.

Average composition of eastern coals.

District and kind of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Fuel ratio.	Remarks.
Pennsylvania, anthracite, average of 9 analyses. [a]	3.39	3.81	83.79	8.42	0.59	22.33	Domestic coal.
Loyalsock, Pa., semianthracite, average of 4 analyses. [a]	1.49	11.07	78.88	7.69	.86	7.13	Do.
Pocahontas, W. Va., semibituminous, average of 38 analyses. [b]	.73	17.43	77.71	4.63	.62	4.46	Steam and coking coal.
Georges Creek, Md., semibituminous, average of 53 analyses. [c]	.70	18.81	72.96	7.26	1.01	3.89	Steam coal.
Connellsville, Pa., bituminous, average of 3 analyses. [d]	1.07	32.70	60.28	5.05	.81	1.84	Coking coal.
Fairmont, W. Va., bituminous, average of 63 analyses. [e]	.75	38.16	54.63	6.45	2.30	1.43	Coking [f] and steam coal.

[a] Ann. Rept. Geol. Survey Pennsylvania, 1885, pp. 313, 318.
[b] Rept. Geol. Survey West Virginia, Vol. 2, 1903, pp. 695, 696, 700.
[c] Rept. Maryland Geol. Survey, Vol. 5, 1906, pp. 631–633.
[d] Rept. Geol. Survey Pennsylvania, Vol. MM, 1879, pp. 21–22.
[e] Rept. Geol. Survey West Virginia, Vol. 2, 1903, p. 209.
[f] The phosphorus in these analyses ranges from 0.0019 to 0.037, averaging 0.0117.

It may be seen from these tables that the Bering River anthracite has no equivalent among the coals now being mined on the Pacific coast and that it compares favorably with Pennsylvania anthracite.

It ought to be put into the San Francisco and other Pacific coast markets at a cost far below that of eastern coal, in which case it should have no difficulty in entirely supplanting the latter.

The Bering River semibituminous (like part of the semibituminous coal from Matanuska River) is also better than anything that is being mined in the West. These coals are the equivalent of the Pocahontas, New River, and Georges Creek coals of the East and are eminently adapted for use on warships and for other purposes for which a high-grade, pure, "smokeless" steaming coal is required; and for these purposes will command a considerably higher price than any coal that is now being mined on the Pacific coast, or if offered at equal prices should readily drive the latter from the market.

Part of this coal will produce an excellent quality of coke, better in fact (except possibly regarding content of phosphorus, regarding which few data are available) than coke which can be produced from any of the Washington and Vancouver Island coals and equal to the coke from Crows Nest Pass. If an important smelter industry grows up in Alaska, as now seems possible, the Bering River coking coal should have the advantage, both in quality and in transportation rates, over any coking coal which is now being used on the Pacific coast.

PETROLEUM.

INTRODUCTION.

LOCATION OF THE OIL FIELD.

The Controller Bay petroleum field is located in the southern part of the mainland region discussed in this report. The localities at which there are indications of petroleum are confined to a belt about 25 miles long from east to west and 4 to 8 miles wide from north to south (see fig. 2). This belt is adjoined on the north in part by the Bering River coal field. Its southern border is formed by Controller Bay and the Pacific Ocean and by the alluvial flats on the east shore of Controller Bay. The eastern and western terminations are Bering Glacier and the Copper Delta, respectively.

GEOLOGIC CONDITIONS IN THE OIL BELT.

The rocks which outcrop within the oil belt, as shown on the geologic map (Pl. V, pocket), are chiefly the various members of the Katalla formation represented in the section of rocks south of Bering Lake as given on p. 37. In addition to these some of the metamorphic rocks, the Quaternary deposits, and the dikes described on pages 24–42 are represented. The structure has been described on pages 43–46.

DEVELOPMENTS.

Active attempts to produce petroleum in commercial quantities in this region have been made for the last five years. The first well was begun in the summer of 1901, but no oil was produced and no great depth was reached, as the tools were soon lost and the well abandoned. The next year (1902) the same people drilled another well and obtained some oil. Six wells were being drilled in 1903. The following year (1904) witnessed the greatest activity that the region has seen, eight wells being in progress. In 1905 and 1906 operations were restricted to two wells.

The result of these operations has been to obtain one well which yields a moderate amount of oil, another well which is capped, but in which the oil has at times a considerable pressure, and two more wells in which an unknown amount of oil stands near the top of the casing.

Drilling has proved to be very difficult and expensive and the results not as encouraging as had been hoped. These facts, together

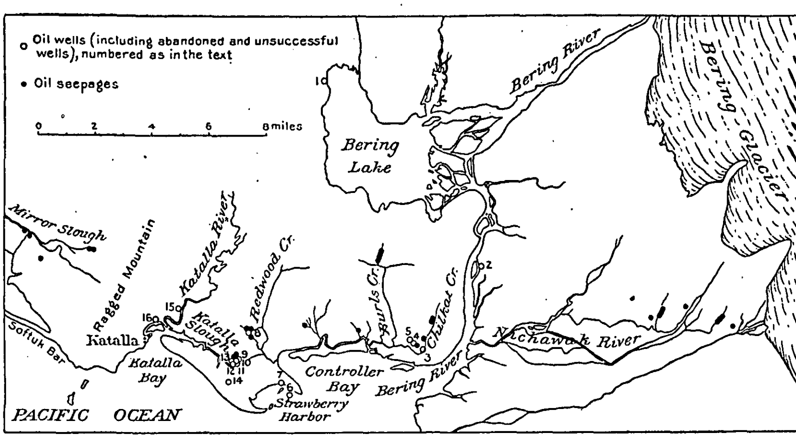


FIG. 2.—Map of Controller Bay oil field, showing position of wells and seepages.

with the uncertainty as to the amount of territory which one concern may legally control and the equally great uncertainty as to the conditions of the market, have led to a suspension of some of the more active operations.

OCCURRENCE OF PETROLEUM.

SEEPAGES.

GEOGRAPHIC DISTRIBUTION.

It may be seen from inspection of the map (fig. 2) that the seepages all occur within a long narrow belt extending from the edge of the Copper Delta to Bering Glacier, a distance of about 28 miles from east to west. The belt is very narrow, not exceeding 4 miles at the widest known point, and is parallel to the north shore of Controller Bay, which has the same east and west direction as the larger aspect of the shore of the Pacific Ocean between Copper River and Yakutat Bay. The seepages at Cape Yaktag[a] are also reported to lie on a line having the same direction as this and practically coinciding with it in extended position. Several of the smaller groups of seepages, such as the group on Redwood Creek and at the head of Katalla Slough, those in the valleys of Burls and Chilkat creeks, and in the Nichawak region, have a distinct linear arrangement each running about N. 15° E. These lines coincide with the directions of the valleys in which they occur, and the relationship suggests that either the position of the valley and that of the line of seepages are due to the same cause or that the one is due to the other.

RELATIONS TO KINDS OF ROCK.

The oil of the seepages reaches the surface through a variety of rocks (see pp. 116–119). The seepages west of Katalla are associated with metamorphic rocks, the oil reaching the surface either through the joints and bedding or cleavage planes of the slate and graywacke or through surficial deposits which probably overlie such rocks. The presence of petroleum in rocks of this character is somewhat unusual and worthy of notice. Similar occurrences of small quantities of oil in metamorphic rocks are known in California and Washington, where the oil is considered to have migrated into the metamorphic rocks subsequent to their alteration. A similar explanation may hold for the Alaska occurrence. The writer would suggest as a possible explanation that the metamorphic rocks, which are known to be separated from the Tertiary shales by a fault (see p. 44), are overthrust upon the shales along a fault plane of low hade, and that the oil at the seepages west of Ragged Mountain is coming through the metamorphic rocks from underlying shales.

The seepages at the head of Katalla Slough and on Redwood, Burls, and Chilkat creeks are all in the soft shales which compose a large part of the Katalla formation (*g* of section on p. 37). Those between Redwood and Burls creeks are associated with conglomerates of presumably higher position (*e* of the section). Such of the seepages of the Nichawak region as have been seen by the writer are in shales which closely resemble those referred to above. The Yaktag seepages are said to be in Miocene sandstone and shales.

RELATION TO STRUCTURE.

The position of the seepages with reference to the structure is somewhat vague and uncertain. Those west of Katalla are on steeply folded and slightly metamorphosed rocks in which the detailed

[a] Locally known as Cape Yakataga.

structural features have not been determined. The group on Redwood Creek and Katalla Slough is apparently in close proximity to a fault. The Burls Creek group and the Redwood Creek group are near the axes of anticlines, the Redwood Creek anticline being probably broken near or west of its axis by a fault. The seepages between Burls and Redwood creeks are on monoclinal conglomerates. The general structure of the Nichawak region has not been determined, but the rocks have steep dips and are probably closely and complexly folded. The Yaktag region, which has not been visited by the writer, is said to have an anticline near and parallel to the coast, north of which the rocks have monoclinal northward dip. The seepages are said to occur on the north flank of the anticline, parallel to and not far from its axis.

It may be seen from the preceding paragraphs that, although small groups of seepages lie on local structure lines, yet the general distribution of all the seepages in a long, narrow, east-west belt diagonal to the structure and to the belts of outcrop of the various kinds of rock is unexplained. The existence and position of this belt, nevertheless, must have been determined by the stratigraphy and structure—if not by that of the surface rocks, then by that of some rocks which do not outcrop at that surface.

The rocks which outcrop within this region have been shown above to be for the most part unaltered Tertiary sediments, with smaller areas of metamorphosed rocks similar to those which probably compose the greater part of the Chugach Mountains and of the shores and islands of Prince William Sound. These older rocks are of undetermined age, but the weight of the evidence from all the wide region through which they extend indicates that they are Paleozoic. In this case there is an hiatus between them and the Tertiary rocks which is represented in neighboring regions by many thousand feet of strata. North of the Chugach Mountains in the valley of the Chitina River this interval is represented by about 4,000 feet of Triassic[a] sediments and 1,600 feet of Jurassic[b] beds. In the Matanuska Valley it is represented[c] by several thousand feet of Jurassic and Cretaceous rocks. On Cook Inlet and the Alaska Peninsula[d] over 2,000 feet of upper Triassic, 8,500 feet of Jurassic, and probably several thousand feet of Cretaceous rocks intervene between the metamorphosed Paleozoic and the slightly consolidated Tertiary beds.

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[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska. A special publication of the U. S. Geol. Survey, 1901, pp. 46–50.

[b] Mendenhall, Walter C., Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 52.

[c] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 16–24.

[d] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 391–410.

The Jurassic rocks on the west shore of Cook Inlet and on the Alaska Peninsula yield petroleum[a] which is of the same character and composition as the Controller Bay oil, and very different from most of the Tertiary oil of California and other Pacific coast fields. The inference naturally follows that the Controller Bay petroleum may be derived from Mesozoic strata which are buried beneath the Tertiary rocks. If such be the case a fault parallel to the coast and to the mountains will account for the position and character of the shore and will offer a zone of movement for the oil from its original source in the Mesozoic rocks below into its present apparent source in the Tertiary rocks at the surface. By such a fault the Tertiary rocks, closely folded when in immediate proximity to the mountains, might have overridden Mesozoic beds which were at a distance from the zone of disturbance, and hence not necessarily folded or disturbed. The oil could then come up along the fault planes and through joints from buried Mesozoic rocks of possibly simple structure into the complexly folded Tertiary rocks. The structure of the underlying rocks and the position of the fault or faults would determine the major east-west seepage belt, while the structure of the more intricately folded rocks at the surface would determine the details of the minor northeast and southwest groups of seepages. This hypothesis removes the difficulty of accounting for light-gravity oils in complexly folded and faulted rocks and explains the occurrence of the seepages in a narrow zone diagonal to the structure, parallel to the mountains along the general east and west shore line, and in line with the belt of seepages at Yakataga. It is a possibility which should be borne in mind in further local geological studies or in interpreting the position of apparent oil-sands in wells or at seepages.

DESCRIPTION OF THE SEEPAGES.

Petroleum seepages and gas springs are very numerous in many parts of the oil belt, and at some of them the flow of oil or of gas is large.

Several large oil seepages were seen by the writer on the banks of Mirror Slough, near the mouth of Martin River. The petroleum reaches the surface from the clay and mud of the valley floor, and a large amount has accumulated in the pools on the swampy surface and in the soil. The nearest outcrops of hard rock are sandstones or graywackes, probably the same as those on Wingham Island and in Ragged Mountain, and if so of pre-Tertiary and probably Pale-

[a] Martin, G. C., The petroleum fields of the Pacific coast of Alaska, with an account of the Bering River coal deposits: Bull. U. S. Geol. Survey No. 250, 1905, pp. 37–59; Notes on the petroleum fields of Alaska: Bull. U. S. Geol. Survey No. 259, 1905, pp. 128–139.

ozoic age. It seems almost certain that oil came from these rocks. Seepages were also seen near the head of Mirror Slough at the base of Ragged Mountain. The oil here reaches the surface through soil immediately underlain by either glacial drift or by talus or landslide débris. The underlying rocks are probably the slate or graywacke referred to above. Another seepage about 1 mile south of this point, in the canyon immediately north of Bald Mountain, was visited by the writer. The oil was here seen oozing in small quantities directly from the joints and bedding planes of the steeply dipping slate, chert, and graywacke.

Oil is reported to have been seen in large amounts at the time of the earthquake, 1899, on the surface of the water of the small ponds and the creek at the south end of the town of Katalla. The surface material consists of rock débris largely from Ragged Mountain, underlain by the soft shales of the Katalla formation.

Numerous and copious seepages are to be seen at the head of Katalla Slough. The oil impregnates the soil very completely at many points and has accumulated in large amounts on the surface. These accumulations are chiefly of oil, and are not residues as at the California brea deposits. No outcrops are near but the underlying rock is almost certainly the soft shale referred to above and probably has a steep dip.

On the west slope of the valley of Redwood Creek about 1½ miles northwest of the mouth of the creek and near a well (No. 8, fig. 2, p. 113), oil can be seen coming directly from soft, fissile, iron-stained shales. The shale has been broken into small angular fragments and recemented by ferruginous material. This condition is frequent at or near seepages in these shales, but it is not known whether it is a surface condition connected with erosion or whether it indicates crushing of the rocks at a depth below the surface during the process of folding or faulting. Here, as at many other seepages, sulphur springs are associated with the oil. Another seepage was seen near the headwaters of Redwood Creek.

It is reported that oil may be seen at low tide in the beach sands on the north shore of Strawberry Harbor. The rocks in the vicinity are sandstone and shale, probably belonging much higher in the stratigraphic column than the soft shale at the seepages previously described.

There are several seepages along the wagon road which leads from the head of Katalla Slough to the mouth of Bering River. Two of these are located about a mile and a half west of Burls Creek and close to the road. The amount of oil at one of these is large. The nearest visible rock is steeply dipping conglomerate which outcrops a few feet away, but the oil can be seen only on the surface of the soil, the direct source not being visible.

The upper part of the valley of Burls Creek contains many seepages at which the oil oozes directly from steeply dipping shales which here contain a large amount of glauconite grains, which gives the rock a bright-green color. Thin sections show abundant casts of Foraminifera and diatoms. Large calcareous concretions are abundant and often take the form of septaria nodules with calcite fillings. Organic remains consisting chiefly of mollusks and crabs are frequently seen in the concretions. The soft shale is also rich in organic material, some beds being so dark as to suggest in appearance impure coal. No coal was seen by the writer in these rocks, either at this locality or elsewhere. The rocks at this point seem to be very strongly impregnated with oil and seepages are numerous, but large surface accumulations are rare. Broken shale recemented by ferruginous material was seen here as on Redwood Creek.

Some seepages with considerable surface accumulation of oil were seen along the edge of the tidal flat, close to the wagon road, half way between Burls Creek and the mouth of Bering River. Outcrops were absent in the immediate vicinity, but fragments of shale indicated the presence of such rock.

Several seepages have been reported from Chilkat Creek. The largest one seen by the writer is in the west bank of the creek, 1½ miles above the forks of the wagon road. The oil reaches the surface through soft brecciated shale with a steep westerly dip. The seepage is associated with a black sulphur spring.

Many seepages have been reported in the group of hills centering around Mount Nichawak. Those seen by the writer were small, but the oil issued directly from the rock, which is shale resembling that at the seepages west of Bering River. Others are reported to be located on the banks of a small lake, which is said to be covered at times with oil.

Other seepages have been reported from various parts of the Controller Bay region, but they have not been seen by the writer.

Reference should be made to the seepages in the vicinity of Cape Yaktag, about 75 miles east of Controller Bay. The amount of oil is said to be very large, there being a continuous flow from several of the seepages, one of which has been estimated to yield several barrels of oil per day. The oil is said to come directly from the rocks, which are shales and sandstones of Miocene age, the seepages being in a line along the crest of an anticline parallel to the coast.

Inflammable gas comes to the surface of the water in large amounts in several places. The largest of the "gas springs" seen by the writer are in Mirror Slough and in Katalla River. The former is sufficient to furnish a large continuous flame. The composition of the gas is not known. It issues from the mud on the bottom of the slough.

WELLS.

The wells in which oil has been obtained in this region are so few that they throw little or no light on the problem of the occurrence of oil. A flow of oil had been obtained in one well (No. 10, fig. 2) and less quantities in three others (Nos. 5, 8, and 13). All of these wells are close to seepages and are on the outcrop of the upper shales of the Katalla formation. They are all on lines of seepages having a north-northeast to south-southwest direction, and are all on the steeply dipping northwest flanks of anticlines and possibly on or near lines of faulting. It is unfortunate that no other wells have been drilled in similar positions on the structural lines alluded to above. Such wells might not be successful, but they would test the possible theory that the above-mentioned lines have something to do with the distribution of the oil.

The net result of the drilling has been to show the existence of moderate amounts of oil in at least part of the territory. The wells are neither numerous enough nor deep enough to determine the outline of the pools and the area of productive territory, or to show whether the oil exists in sufficient quantity to pay for exploitation. They have demonstrated the difficulty and expense of drilling, and the need of ample resources and careful management. The existence of oil in remunerative quantities has neither been proved nor disproved. The evidence from the existing wells, like that of the seepages, is sufficient to warrant further testing, if it be done intelligently and carefully by companies strong enough to exploit large areas on a scale which permits of wholesale economies, and also strong enough to risk their capital on what must certainly be regarded as a speculation rather than an investment.

The following list contains an account of each well that has been drilled in the district. The numbers refer to the geographic location of the wells, as shown on the map (fig. 2, p. 113).

No. 1. West shore of Bering Lake. The surface rocks are sandy shales, presumably underlying the coal-bearing rocks. Dip, 12° to 35° NW. Well begun in 1905, but interrupted by accidents to machinery. Depth, several hundred feet.

No. 2. East shore of Bering River. Begun in 1903. Abandoned without reaching bed rock at depth of 580 feet because of difficulty of sinking casing through the mud.

No. 3. Chilkat Creek. Drilled in 1904 to depth of several hundred feet. No information available.

No. 4. Edge of tidal flats 1 mile west of mouth of Bering River. Drilled in 1904 to depth of several hundred feet.

No. 5. Edge of tidal flats a short distance northwest of No. 4. Drilled in 1904 to depth of several hundred feet. Oil now stands near top of casing. Small but continuous flow of gas. Amount of oil not known.

No. 6. Strawberry Harbor. The derrick was built on piling about 1,000 feet offshore. Casing sunk deep into the mud in 1904 without reaching bed rock.

No. 7. Strawberry Harbor. Drilled several hundred feet in 1904 without obtaining oil.

No. 8. Redwood Creek. Drilled to depth of several hundred feet in 1904. Oil now stands about 20 feet below the top of the casing. Quantity not known.

No. 9. Near head of Katalla Slough. Drilled to unknown depth in 1904. No oil as far as known.

No. 10. Near head of Katalla Slough. Drilled in 1902 to depth of 366 feet, when a flow of oil was obtained. Drilled to 550 feet in 1903 without further results. In 1904 this well was pumped for fuel at the other wells of the same company. It is now capped, the oil oozing from around the casing. The following is a record of this well, as reported by the Alaska Steam Coal and Petroleum Syndicate, and published by F. H. Oliphant:[a]

Record of 550-foot well near head of Katalla Slough.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface drift	6	6
Decomposed shale	10	16
Light-colored shale	140	156
Fine-grained sandstone, containing 6-inch bed of coal	18½	174½
Dark shale, very hard, including 6 inches of quartz containing iron pyrites	190½	365
Oil sand; flow of oil	1	366
Length of 12-inch casing		220
Length of 9⅝-inch casing		340

Numerous small showings of petroleum and natural gas were encountered as the drill proceeded down, and at 366 feet a large quantity of oil was developed, which flowed some petroleum. The well is said to have continued to flow until capped.

No. 11. Near head of Katalla Slough. Drilled in 1901 and abandoned because of loss of tools.

No. 12. Near head of Katalla Slough. Drilled in 1903 to unknown depth.

[a] The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

No. 13. Near head of Katalla Slough. Drilled in 1904 to unknown depth. Now capped, the oil squirting at times in strong jets from the casing.

No. 14. Between head of Katalla Slough and Cave Point. Drilled in 1903 to 1,710 feet and abandoned because limit of outfit was reached.

No. 15. Katalla River. Casing sunk to depth of 280 feet in 1903 without reaching bed rock.

No. 16. Near Katalla. Two holes drilled in 1904 to 1906 to a depth of about 1,500 feet. Work still in progress.

CHARACTER OF THE PETROLEUM.

A sample collected by the writer from a well (No. 10 in list, on p. 120) near the head of Katalla Slough was tested by Penniman & Browne, of Baltimore, with the following results:

Test of petroleum from Katalla Slough.

	Per cent.	Specific gravity at 15.5° C.
Distillation by Engler's method:		
Benzine (80° to 150° C.)	21	0.7573=54.9° Baumé.
Burning oil (150° to 300° C.)	51	.8204=40.6° Baumé.
Residuum (paraffin base)	28	.9096=23.9° Baumé.
Sulphur	Trace.	
Specific gravity of crude oil	....	.828 =39.1° Baumé.

The burning oil was purified by concentrated sulphuric acid and soda, the volume of acid used up being too small to measure. The purified burning oil was put into a small lamp, where it burned dry without incrusting the wick or corroding the burner, and without any marked diminution of flame. The burning oil compares very favorably in these respects with Pennsylvania oil prepared in the same way.

The following analysis of this petroleum was published by Mr. Oliphant:[a]

Analysis of petroleum from Katalla Slough well.

Specific gravity at 60° F. 0.7958, equal to 45.9° Baumé.
Cold test; did not chill at 3° F. below zero.

Distillation:	Per cent.
Below 150° C., naphtha	38.5
150° to 285° C., illuminating petroleum	31
Above 285° C., lubricating petroleum	21.5
Residue, coke and loss	9

The following tests of Controller Bay and Yaktag oil have been published by Redwood[b] from results obtained in his laboratory.

[a] The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

[b] Redwood, Sir Boverton, Petroleum, vol. 1, 2d ed., 1906, p. 198.

Physical properties of crude petroleums.

Locality.	Specific gravity.	Flashing-point (Abel test).	Color.
		°*F.*	
Burls Creek	0.942	234	Dark reddish brown.
Johnstone Creek, 1	.964	200	Dark brown.
Johnstone Creek, 2	.879	178	Do.
Poul Creek (lowest)	.970	250	Do.
Poul Creek (top, west)	.881	67	
Poul Creek (upper)	.914	156	Do.
Katalla Meadow, 1	.929	240	Do.
Katalla Meadow, 2	.901	156	
Katalla Meadow, 3	.874	156	
Katalla Meadow, 4	.869	152	
Katalla Meadow, 5	.961	266	
Bore hole at Katalla, 120 feet (1902)	.802	Below 60	Dark red.
Bore hole at Katalla, 355 feet (1902)	.790	Below 60	Do.
Oil Creek	.855	108	Dark brown.
Morrison Creek	.991	270	Do.
Argyll Creek (Icy Bay)	.962	310	Do.
Yakogelty	.937	246	Do.
Crooked Creek	.921	172	Do.

Commercial products of crude Alaska petroleum.[a]

Specific gravity.	Petroleum spirit (benzine).	Kerosene.	Intermediate and lubricating oils, with solid hydrocarbons.	Coke.
	Per cent.	*Per cent.*	*Per cent.*	*Per ct.*
0.869	....	19.0	78.6	1.7
.914	....	9.0	87.6	2.7
.800	24.8	53.9	16.7	1.2

[a] Redwood, Sir Boverton, op. cit., p. 214.

The analyses given below were published by Stoess:[a]

The following analysis was made in Seattle from a sample of the crude oil taken from the well at Katalla:

Analysis of oil from Katalla well.

Specific gravity, 0.800.

Naphtha	34.4
Illuminating oil	34.4
Lubricating oils	16.5
Coke and residue	14.5

Another analysis [possibly the same as that published by Oliphant and quoted above], made in Los Angeles, Cal., gave—

Analysis of oil from near Katalla.

Specific gravity	0.7957 (45.9° B)
Cold test	Not chilled at 3° below zero
Naphtha	38.5
Illuminating oil	31.0
Lubricating oils	21.5
Coke and loss	9.0

Oil has a flash test of 70° to 80°. Oil is light green in color.

[a] Stoess, P. C., The Kayak coal and oil fields of Alaska: Min. and Sci. Press, vol. 87, 1903, p. 65.

The results of all available analyses and tests on oils from the Controller Bay and Yaktag regions are brought together in the following table:

Summary of analyses and tests of Controller Bay and Yaktag petroleum.

Locality.	Color.	Specific gravity.	Gravity, Baumé.	Flashing-point.	Benzine.	Kerosene.	Lubricating oil.	Residue: Coke and loss.
			°	° F.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Katalla Slough, well No. 10		0.8280	39.1		21.0	51.0	28.0	
		.7958	45.9		38.5	31.0	21.5	9.0
	Light green	.7957	45.9	70-80	38.5	31.0	21.5	9.0
		.800			34.2	34.4	16.5	14.5
	Dark red	.802		Below 60.				
	do	.790		Below 60.				
(?)		.869				19.0	78.6	1.7
(?)		.914				9.0	87.6	2.7
(?)		.800			24.8	53.9	16.7	1.2
Burls Creek	Dark reddish brown.	.942		234				
Johnstone Creek	Dark brown	.964		200				
	do	.879		178				
Poul Creek	do	.970		250				
	do	.881		67				
	do	.914		156				
	do	.929		240				
Katalla Meadow		.901		156				
		.874		156				
		.869		152				
		.961		266				
Oil Creek	Dark brown	.855		108				
Morrison Creek	do	.991		270				
Argyll Creek, Icy Bay	do	.962		310				
Yakogelty	do	.937		246				
Crooked Creek	do	.921		172				

Many of the samples consisted of seepage oil and probably have not yielded as large a proportion of the more volatile constituents as would be obtained from "live" oil from the wells.

The results of the tests may be compared with those of other petroleums in the following table:

Tests of petroleum from Alaska and other fields.

	Alaska.[a]	Alaska.[b]	Pennsylvania.[c]	Ohio.[d]	Colorado.[e]	Mexico.[f]	Beaumont, Tex.[g]
Benzine (80°-150° C.)	21	38.5	16.5	10	16	10	2.5
Burning oil (150°-300° C.)	51	[h] 31	54	50	40	60	40
Residuum	28	[h] 30.5	29	40	44	30	57.5
Sulphur	Trace.						1.7
Gravity	39.1° B.	45.9° B.			43° B.		22° B.

[a] Penniman & Browne for this report.
[b] Oliphant, F. H., The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.
[c] Peckham, S. F., Report on Petroleum, p. 365.
[d] Woodman, Durand, Jour. Am. Chem. Soc., Vol. 13, p. 168.
[e] Oliphant, F. H., Petroleum: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, p. 250.
[f] Stillman, T. B., Engineering Chemistry, p. 364.
[g] Hayes, C. W., and Kennedy, W., Oil fields of Texas-Louisiana coastal plain: Bull. U. S. Geol. Survey No. 212, 1903, pp. 146-151.
[h] See above.

The petroleum is clearly a refining oil of the same general nature as the Pennsylvania petroleum. It resembles the latter in having a high proportion of the more volatile compounds and a paraffin base and in containing almost no sulphur. The proportions of the several constituents given in the tables above do not necessarily represent the full amounts that could be obtained in practice by different treatment.

PRINCIPLES GOVERNING THE OCCURRENCE OF PETROLEUM.

The four great problems of the geologic occurrence of petroleum are the origin of oil, the movements of oil in the rocks, the stratigraphic and structural distribution of the existing accumulations of oil, and the determination of the location and area of valuable accumulations from the known facts of surface geology.

These problems are stated above in order of increasing importance from the point of view of immediate utility. The last problem can be determined by expensive practical testing with drill or by the solution of the first and second problems, together with a complete and accurate knowledge of the areal geology of the region in which the occurrence of oil is suspected. In the present condition of our knowledge drilling is the only certain way of determining this problem. But all knowledge gained in this way, as well as all facts concerning the geology of the oil-bearing rocks, lead us nearer to the solution of the other problems and hence hasten the time when we can determine within reasonable limits the presence of oil from our knowledge of how oil originates and how it accumulates. The first and second problems are consequently the problems of greatest ultimate importance, and should be given at least equal weight in a public geologic investigation with the other or immediate commercial problems.

Petroleum occurs in rocks of practically all ages from the oldest Paleozoic to the Recent. All known productive bodies of oil are in rocks of sedimentary origin, such as sandstones or sands, shales or clays, limestones, and conglomerates. Minute quantities of oil have, however, been seen in volcanic or other crystalline rocks.

The origin of petroleum may be explained according to one of two theories. The oil may be of organic origin, having been derived from animal or vegetable matter which was associated with the mineral constituents of the rocks at the time they were deposited; or it may be of inorganic origin, having been formed by the chemical action of water on the formerly unoxidized mineral constituents of the rocks. The prevalent scientific opinion is in favor of the organic theory for the origin of the larger and more widespread accumulations of petroleum.

The movement of petroleum in the rocks is controlled by the following factors: The direct action of gravity, capillary attraction, the presence of water, gas pressure, and the distribution of channels or zones through which the oil can move.

The effect of the direct action of gravity is to cause oil to go down as far as the rocks are porous, dry, and not too warm for the oil to exist as such. It will sooner or later be stopped in this downward movement by an impervious stratum (either a bed of close-textured rock or a bed filled with water), and will then move laterally along the upper surface of that stratum to its lowest point, where it will accumulate.

The effect of capillary attraction is to cause the oil to be diffused somewhat throughout the rocks in all directions, provided the rock is dry and of the right texture to permit capillary movement. The directions in which it will move will be controlled by the distribution of porous rock and water, and will be modified by gravity and the other factors here discussed.

The presence of water causes an upward movement of the oil. The essential conditions for such movement are a porous rock containing both water and oil and a lower limit[a] beyond which the water can not go. The water, because of its greater density, seeks a lower level than the oil and forces the latter upward until either the demand of all the water for space is satisfied or until the oil is checked in its upward movement by an impervious stratum. In the former case the oil rests on the surface of the water in a state of equilibrium; in the latter case it is confined under pressure with a potential upward force.

Gas pressure tends to drive the oil in any unblocked direction. The requisites for oil movement caused by gas are the presence of gas, either in a contiguous body to the oil or being given off from or within the oil, and an impervious bed above the gas and through which it can not pass. The gas then tends to accumulate on the upper surface of the oil and to force the oil downward in the direction of least resistance, which may be either vertical or have a lateral component. The oil would already have been in the lowest available space,[a] so further downward motion implies the displacement of water. The motion continues until there is equilibrium between the expansive pressure of the gas and the hydrostatic pressure of the water. The oil is then confined between these forces and will escape under pressure at the first opportunity.

The most favorable conditions for the occurrence of petroleum over large and regular areas are the following:

1. A large and widely distributed original source of oil-yielding material.

[a] If the liquids have not already reached this lower limit, the case is considerably modified, and the exact condition can not, in the present state of our knowledge, be positively asserted.

2. Thick, extensive, and regular porous beds in which the oil can move freely and accumulate.
3. Impervious beds above and below the porous beds.
4. Small angles of dip and fairly regular structure.
5. Absence of deep fracturing or of irregularities of structure.
6. Absence of water in the rocks if the oil-bearing beds are synclinal, or presence of a moderate amount of water if they are anticlinal.

Such conditions are favorable to the occurrence of petroleum in large, regular, and easily outlined pools, to moderately large production and long life of the wells, and to a large degree of certainty in oil prospecting.

These conditions probably nowhere exist in their entirety, at least not over any broad area. Some of the Mississippi Valley and Appalachian oil fields come nearer to satisfying these conditions than any others in North America. It is very evident that few of these conditions are met in the Controller Bay region, so nothing will be gained from further comparison with regions in which simple structure predominates.

Some of the California,[a] Wyoming,[b] and Colorado[c] oil fields are characterized by complex and broken structure, in this respect being not unlike the Controller Bay region. These western fields show that it is possible for large accumulations of oil to exist in rocks with steep dips, irregular folds, and large faults. They show that the structure does not make it impossible for oil to exist in quantity in the region under discussion, but they show also the difficulties of drilling and of locating the pools in such a field, and demonstrate very clearly the need of careful operating and the risks which are necessarily involved.

EXPLOITATION.

LOCATING POOLS.

If oil is found in quantity it will almost certainly be in circumscribed areas, and the location and boundaries of these will be of the utmost importance in the development of the field. The position, size, and shape of these productive areas can not be foretold in advance of all drilling or at the present stage of development. The

[a] Eldridge, G. H., and Arnold, Ralph, The Santa Clara, Puente Hills, and Los Angeles oil districts, southern California: Bull. U. S. Geol. Survey No. 309, 1907, 266 pp. Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, California: Bull. U. S. Geol. Survey No. 321, 1907, 91 pp. Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, California: Bull. U. S. Geol. Survey No. 322, 1907, 161 pp.

[b] Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: Prof. Paper U. S. Geol. Survey No. 56, 1907, 178 pp.

[c] Fenneman, N. M., Geology of the Boulder district, Colorado: Bull. U. S. Geol. Survey No. 265, 1905, 101 pp.

wells which have been drilled in this region are so few, most of them are so shallow, and so little oil has been obtained, that they give almost no light on the occurrence of oil in the rocks. But if at least one area were outlined wholly or in part by the known position of productive and nonproductive wells it would then be possible to determine the relation of the occurrence of the oil to the geology, and from the known facts of the geology to outline other possible productive areas in advance of drilling. For this reason it is of the utmost importance to obtain complete and accurate records of all wells and to use the information and experience thus gained in locating subsequent wells.

DIFFICULTIES OF DRILLING.

Crooked holes.—Much difficulty has been encountered in keeping the wells vertical, and delay and expense have resulted from the necessity of frequently reaming out the holes in order to straighten them. The crooked holes are the natural result of the steep inclination of the rocks with frequent alternations from hard to soft beds. Whenever the drill passes from a soft rock to a harder one dipping at a steep angle the drill tends to be deflected and a crooked hole results. This difficulty will always be encountered in this region and will increase the time and cost of drilling. The difficulties should, however, become less in the future, for the tendency of the drill to deflect can be lessened by drilling slower when the deflecting bed is struck and by special shaping of the tool, and the holes can be straightened more quickly when the drillers are better acquainted with local conditions.

Caving.—When a well in soft or fractured rock stands uncased too long, the rock caves in, often burying and frequently causing the loss of the tools, and sometimes making it necessary to abandon the well. Much delay has been caused in this way at most of the local wells, and it has added greatly to the cost of drilling. It has been impossible on this account to drill several of the wells as deep as they would otherwise have gone. The only remedy is to case the well at the proper time, and when the drillers know better the rocks with which they are dealing they will be able to anticipate the caving and introduce casing when it is needed. Conditions may thus be expected to improve in the future, making the cost less and the speed greater, and making it possible to sink wells to greater depths.

Water.—The rocks of this region are full of water and consequently large amounts are encountered in all the wells. This is undesirable for two reasons: The pressure of the column of water in the well keeps the oil back in the rocks and prevents it from coming out into the well, and the water reduces the effective weight of the drill and acts as a cushion between the drill and the rock, in both ways reducing the power of the blow. The only remedy is in casing off the water, which can not be done too often without reducing the size of the hole to undesirable dimensions and finally limiting the depth to which it can be drilled without pulling the casing and going back and reaming out the hole.

Remoteness from supplies.—The remoteness of this region from a base of supplies not only increases the cost of labor and of freight, but also makes it necessary either to carry an exceptionally large equipment of fishing and repairing tools and of general supplies, or to be subject to delays in ordering special tools from a long distance. Conditions will improve in this respect with better facilities for communication and transportation, and can also be bettered if machine shops and supply depots are established, as they will be if the presence of productive oil territory is shown.

Inexperience with local conditions.—The difficulties caused by the lack of experience of the drillers with the rocks of the local section have already been alluded to. They may be summarized as including failure to drill slowly or to dress the tools so as to avoid deflecting the drill on hard, steeply inclined surfaces; failure to note the crookedness of the hole and remedy it promptly; ignorance of local caving strata and consequent failure to case in time to prevent cavings; and failure to secure proper and adequate outfit and supplies.

Cost of labor and transportation.—The cost of drilling has been very largely increased, over what it would be in more favored and better established oil fields, by the high cost of labor and of transportation of men and of freight. Not only are the drillers paid higher wages than they would receive at most localities, but the unskilled labor receives excessive pay. It is highly probable that, when conditions become more settled and work is done on a larger and more permanent scale, wage conditions will become more normal and transportation charges will be reduced.

SHIPMENT AND MARKETS.

If petroleum is produced in commercial quantities a new set of problems concerning its disposal will arise. All the petroleum of the region, so far as known, is a refining oil of high grade, for which there is a good demand on the Pacific coast. The content of extremely volatile constituents, such as gasoline, is so great that it is questionable whether the oil can be safely shipped in bulk without some refining. There are plenty of good sites for refineries in the immediate vicinity of the wells. If a harbor in the vicinity of Katalla or elsewhere in the Controller Bay region, is utilized, it will be a very simple matter to transport the oil from the wells to the wharves by short pipe lines on a practically level grade. If no harbor in the immediate vicinity can be used it will be necessary to ship from Orca Bay or elsewhere on Prince William Sound, a distance of about 80 miles westward and across Copper River. The grades to Orca are almost nothing and there will be no difficulties except crossing Copper River. The distances from Katalla and from Orca to Seattle by the steamer route, "outside way," are about 1,250 and 1,350 statute miles, respectively.

CONCLUSIONS.

Geographic conditions are such as to cause heavy initial expense of prospecting and drilling, but admit of permanent improvements which will make these conditions much better without great engineering difficulties or excessive cost.

The geology is complex and difficult to interpret and does not show definitely the relation of the occurrence of the petroleum to the stratigraphy and structure. The known facts of the local geology are unfavorable to the presence of productive bodies of oil, and indicate that if oil is found in quantity the distribution of the productive areas will be very irregular and difficult to locate. However, if future developments confirm the theory of an overthrust along the coast (pp. 45–46, 115–116), separating the complexly folded rocks at the surface from rocks of simpler structure below, conditions may be found to be much more regular and more favorable for the development of a good oil field than the surface conditions indicate. This theory is, however, not proven, and is suggested merely as a possibility.

The surface oil showings (seepages), though widespread and copious, are not conclusive evidence of the occurrence of productive oil pools. They are apparently more promising than any of the other known geologic features of the region. The only safe conclusion to be drawn from them is that they indicate the possibility of productive oil areas in the vicinity.

Operators and investors who may not be familiar with local conditions will do well to be governed by the following suggestions:

1. They should be certain that legal title can be obtained to a sufficient area to make it possible to sink many test wells under widely differing conditions, and to permit a large enough probable production to pay for heavy initial expenditures and large permanent improvements.

2. They should have enough capital to be able (*a*) to purchase in quantity and at low rates; (*b*) to build good roads and other improvements and thus reduce cost of operating; (*c*) to carry a large stock of tools and supplies, in order to avoid costly delays in drilling and to be able to drill deep; (*d*) to secure the best professional advice and good drillers; (*e*) to drill many test wells without hope of immediate profit; (*f*) to market the product in the face of the existing conditions in the petroleum industry; and (*g*) to afford to lose the investment.

3. The first wells should be located on the strike and at no great distance from producing wells, or down the dip from a good seepage and at such varying distances that the rocks outcropping at the seepage will be encountered at depths of from a few hundred feet to the limit (in depth) of drilling.

4. Subsequent wells should be determined in position by the location of existing wells and by the structure. With respect to productive wells, they should be along the strike and close to[a] the wells; while with respect to nonproductive wells they should be either not along the strike and at a short distance, or along the strike and at a considerable distance, from the wells.

5. Drillers and tool dressers should be obtained from regions where there is difficulty in keeping the holes straight.

6. If oil is obtained, it will probably be down the dip, rather than up the dip from a seepage; in shallow wells near a seepage, in deeper wells farther from a seepage.

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3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost.

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Topographic maps.

The following maps are for sale at *5 cents a copy*, or $3 per hundred:
Casadepaga quadrangle, Seward Peninsula; scale, 1:62500; by T. G. Gerdine.
Grand Central Special, Seward Peninsula; scale, 1:62500; by T. G. Gerdine.

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The following maps are for sale at *25 cents a copy*, or $15 per hundred:

Seward Peninsula, northeastern portion of, topographic reconnaissance of; scale, 1:250000; by T. G. Gerdine.
Seward Peninsula, northwestern portion of, topographic reconnaissance of; scale, 1:250000; by T. G. Gerdine.
Seward Peninsula, southern portion of, topographic reconnaissance of; scale, 1:250000; by T. G. Gerdine.

In preparation.

Water-supply investigations in Alaska, 1906 and 1907, by F. F. Henshaw and C. C. Covert.
Geology of the area represented on the Nome and Grand Central Special maps, by F. H. Moffit, F. L. Hess, and P. S. Smith.
Geology of the area represented on the Solomon and Casadepaga Special maps, by P. S. Smith.
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Koyukuk River to mouth of Colville River, including John River; scale, 1:625000; by W. J. Peters. Contained in Professional Paper No. 20. (Out of stock.) Not published separately.

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