DEPARTMENT OF THE INTERIOR
Roy O. West, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 797—F

GEOLOGY AND MINERAL RESOURCES OF THE ANIAKCHAK DISTRICT, ALASKA

BY

RUSSELL S. KNAPPEN

Mineral resources of Alaska, 1926—F

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CONTENTS

ILLUSTRATION

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By Russell S. Knappen

PREFACE [1]

The possibility that oil may be found in commercial quantities in certain of the geologic formations of the Alaska Peninsula has been recognized for several years. In order that late authoritative information might be available to guide prospectors in their search for oil in this region, the Geological Survey, beginning with the field season of 1920, has sent geologists and engineers to study and map the peninsula. As a result of this work a number of recent reports have been published covering much of the country from Tuxedni Bay southward nearly to Chignik. To continue these studies still farther southward was the object of the party that was sent into the Aniakchak district in 1925, and the results of that work are set forth in this report.

Before the results of this field study had been worked up in the laboratory and office and before the manuscript was completed Mr. Knappen resigned from the Geological Survey and was so occupied with his new duties that he completed only those parts of the report bearing on the principal objects of the inquiry. Many new facts of general geologic and geographic interest relating to other problems, such as information regarding the volcanism and glaciation of the district, had been gathered and were more or less thoroughly analyzed. If the report were delayed until all phases could be comprehensively described and coordinated, its publication might be long put off or indefinitely suspended. To avoid this delay it was decided to send forward the manuscript without further recourse to the author. Care has been taken, however, not to change any of Mr. Knappen's mapping or direct statements. In general, therefore, the report as printed stands essentially as submitted by Mr. Knappen, except for editing. A few of his suggestions or conclusions which appeared extremely debatable or opposed to observations from other sources and which would require further field work for corroboration have been omitted rather than cause that delay.

[1] By Philip S. Smith.

The greatest modification that has been made of Mr. Knappen's manuscript as submitted is the inclusion on the map accompanying this report of a considerable additional tract in the northeastern part of the district, embracing practically all of the area east of longitude 157° 55′. The manuscript contained no specific description of this additional area, and none has been added, as it is covered by the earlier report of Smith and Baker.[2] The geologic mapping of this additional area has, however, been completed by the transfer to the map prepared by Knappen of supplementary data from the published map by Smith and Baker. The combination of these two different pieces of work by a third person obviously introduces uncertainties that would have been avoided had the connection between the two been prepared by either of the geologists personally familiar with all the field evidence. Furthermore, the earlier subdivisions made by Smith and Baker require reconsideration in the light of the later studies by Knappen, especially as he appears to have differentiated in the region to the west certain units that to the east were mapped together.

The conclusions reached regarding the occurrence of oil in the region form obviously the most important part of the report. These may be summarized as follows: Probably none of the rocks that are exposed in the region are such as to indicate a source for any considerable supply of oil, though in places their structure and texture are entirely suitable for retaining oil that may have migrated into them. The uncertainty as to the character of the formations that underlie the exposed rocks and as to their depth below the surface leads the author to conclude that any prediction as to the probability of their containing oil is at best only a hazardous surmise and that drilling to test these beds would be wildcatting of an extremely speculative type. However, Mr. Knappen points out that there are no geologic conditions which prove that such wildcatting is entirely unwarranted, and he discusses those places where conditions for such tests, in case they should be undertaken, appear to have the best chances of success.

INTRODUCTION

LOCATION AND AREA

The following report describes the results of a reconnaissance examination of an area including about 2,750 square miles, lying adjacent to and including Chignik, Alaska. Chignik is on the southeast coast of the Alaska Peninsula 275 miles east of Unimak Pass, which

[2] Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district, Alaska: U. S. Geol. Survey Bull. 755, pp. 151–218, 1924.

separates the peninsula, as usually defined, from the Aleutian Islands. Unimak Pass actually lies southwest of Unimak Island, but the passageway between that island and the peninsula on the east is so narrow that the island is usually regarded as forming essentially part of the peninsula. Chignik is about 2,200 miles distant by the usual steamer routes from Seattle and is 450 miles southwest of Seward, which is the nearest important town on the mainland. Kodiak, the nearest trading point, is a town of about 450 inhabitants and lies 270 miles northeast of Chignik.

The Alaska Peninsula extends southwestward from the mainland of Alaska for 550 miles and separates the Pacific Ocean on the southeast from Bristol Bay and Bering Sea on the northwest. In this distance the peninsula narrows from a width of 110 miles at its base to about 20 miles at the southwest end. In the Aniakchak area the average width of the peninsula is about 45 miles.

The northeastern boundary of the area studied is the southwestern limit of the area earlier surveyed by Smith and Baker [3] and described by them as the Cold Bay-Chignik district. The northwestern and southeastern boundaries of the Aniakchak district are formed by the shore lines, and the southwest side was determined by the ending of the field season. The topographic map of the area, which forms the base for the geologic map, was prepared by R. H. Sargent. Much of the area had never been surveyed before, and large tracts had apparently never even been visited by white men.

The survey herein described was undertaken primarily to determine the oil and gas possibilities of the area, and specifically to learn whether the possible oil and gas bearing formation of the Portage Bay district extended southwestward along the peninsula. In addition the general geology of the region, the extent of its coal deposits, and its volcanic history were investigated and are briefly described.

EARLIER SURVEYS

Although the Alaska Peninsula was discovered and visited by early Russian and English explorers [4] before 1780, the first close examination of part of this region was made in 1827 by the Russian-American Co. In that year Luetke mapped the northern coast of the peninsula, and in 1836 Woronkowsky [5] surveyed the Pacific shore line. In part, their charts have not yet been superseded by later

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[3] Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 151–217, 1924.

[4] Brooks, A. H., The geography and geology of Alaska; U. S. Geol. Survey Prof. Paper 45, pp. 108–109, 1906.

[5] Grewingk, C., Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der nord-west Kueste Amerikas, mit den anliegenden Inseln: Min. Gesell. St. Petersburg Verh., 1848–49, p. 43, 1850.

work. For instance, the position of a portion of the Bristol Bay coast was correctly determined by R. H. Sargent only during the course of the present work. In 1848 Grewingk[6] summarized the previous knowledge about Alaska and published much new geologic information based on a study of miscellaneous collections that had been brought to Europe by the Russians. After the purchase of Alaska by the United States in 1867 the first geologic work in this area was done in 1870 by Dall,[7] then of the United States Coast Survey. Fossil plants were collected from the bluff in a bay called by Dall "Doris Cove," which is probably Anchorage Bay, on whose shores Chignik post office was later established. Returning to the same region in 1895, Dall[8] studied the coal beds on the northwest shore of Chignik Lagoon. Stanton and Martin[9] found Cretaceous marine and continental fossils on the shores of Chignik Lagoon in 1904. They correlated these beds with the Upper Cretaceous Chico formation of California and, by showing the presence of both Cretaceous and Tertiary strata in this region, explained the discrepancy in earlier correlations which perplexed Dall and Harris.[10] Brooks[11] summarized the results of American and Russian explorations of Alaska in a paper which is even to-day the best general statement of the geography and geology of the Territory. Atwood[12] in 1908 made extended surveys in the Alaska Peninsula as a whole and prepared a report on that work, including in it summaries of previous work, as well as descriptions in special detail of its coal resources. He mapped and discussed the geology of the Chignik and Hook Bay areas. Although the present author modifies some of Atwood's boundaries and conclusions, it must be remembered that the earlier party did not have time to make a thorough investigation far from shore and that no map was available until several months after the field work was completed. In general Atwood's work is correct, and the modifications here noted are only such as are to be expected from more detailed study of an area which had been covered only by hurried reconnaissance.

After the passage of the leasing act in 1920 interest in the oil possibilities of the Alaska Peninsula developed rapidly, and numer-

[6] Grewingk, C., op. cit.

[7] Dall, W. H., and Harris, G. D., Correlation papers—Neocene: U. S. Geol. Survey Bull. 84, p. 239, 1892. Lesquereux, Leo, Contributions to the Miocene flora of Alaska; U. S. Nat. Mus. Proc., vol. 5, pp. 443–449, 1883.

[8] Dall, W. H., Report on coal and lignite in Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 801–804, 1906.

[9] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Geol. Soc. America Bull., vol. 16, pp. 408–409, 1905.

[10] Dall, W. H., and Harris, G. D., op. cit., p. 234.

[11] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, 308 pp., 1906.

[12] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, 137 pp., 1911.

ous expeditions were sent into the peninsula by different companies and individuals. Several parties from the Geological Survey have studied the petroleum possibilities of a number of localities southward from Tuxedni Bay, with especial attention to those areas near Cold and Portage Bays,[13] where active drilling was in progress and where the stratigraphy and structure are similar to those in the Aniakchak area. As already noted, Smith and Baker studied the region immediately northeast of the Anikchak area and utilized all available information in the maps and statements published in their report. Martin has summarized the petroleum possibilities of Alaska [14] and later made a brief survey of the petroleum possibilities around Chignik Lake [15] and reported unfavorably.

FIELD WORK

The party, in charge of R. H. Sargent, topographic engineer, and including four assistants and camp helpers, with the writer as geologist, spent the field season of 1925 in the Aniakchak district. Leaving Seattle June 2, by special arrangement the steamship *Admiral Evans* landed the party, 18 horses, and field supplies, at Chignik on June 13. This special arrangement obviated the customary transfer of passengers and freight at Kodiak to the steamship *Starr*, which furnishes the only regular transportation to Chignik and other ports in southwestern Alaska. Supplies for the entire season were purchased in Seattle and taken with the party, as the only trading points in the area are the stores in Chignik Bay that are operated by the salmon canneries primarily for the company employees and can not be relied upon by others as sources of supply. In 1925 the season was backward, and as the grass had not grown sufficiently for pasturage, hay and grain for the first 10 days were carried from Seward.

Geologic field work consisted in traverses on foot or horseback up all the principal streams to their heads and along many spurs and divides. No map was available as a base in the field, and approximate locations for geologic notes were obtained by sighting prominent points, where were later coordinated with the topographic map as it was completed by the topographer. Where bearings could not be taken to readily distinguishable points, pace traverses were carried to tie observations to the general survey network. Over most of the area exposures are good on the spurs and ridges and along the sides

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[13] Capps, S. R., The Cold Bay district: U. S. Geol. Survey Bull. 739, pp. 77–116, 1923. Smith, W. R., and Baker, A. A., The Cold Bay-Chignik district: U. S. Geol. Survey Bull. 755, pp. 151–218, 1924. Smith, W. R., The Cold Bay-Katmai district: U. S. Geol. Survey Bull. 773, pp. 183–213, 1925.

[14] Martin, G. C., Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, 80 pp., 1921.

[15] Martin, G. C., The outlook for petroleum near Chignik: U. S. Geol. Survey Bull. 773, pp. 209–213, 1925.

of many valley floors. Most of the lower slopes of the hills are covered with a dense growth of long grass or alders, but above an altitude of 1,000 feet exposures are normally good and vegetation is scanty. Glacial drift covers the hard rock in only a few places, so that opportunities for observation are in general fairly good.

The party moved with pack train, establishing camps primarily with reference to shelter from the extremely severe winds and at points where good water was available. Water is abundant throughout the area, except on the flanks of the two large volcanoes, but from July 15 to the end of the season the waters of the larger streams were nonpotable because of the large numbers of decaying salmon which lined the banks. Alders, although scarcely more than large bushes, furnish shelter from wind and storm and provide the only fuel available for campers. As a rule, a space was cleared for each tent in the midst of a clump of these tangled bushes, and the protection they afforded was so good that only one tent was seriously damaged by wind during the season. With the pack train it was possible to establish camp in almost any place desired, and saddle horses could be used along most of the streams and over many of the lower hills. The slopes are generally easy to climb, but a few cliffs along some of the streams and the walls of the cirques and the craters are steep and in many places unscalable. Water transportation was used by the party only at the beginning and end of the season, when the boats were used to transfer the personnel, horses, and equipment from the sand spit at the head of Chignik Bay to Chignik. A boat must be used in surveying the Bristol Bay shore line, and one was needed to cover the cliffed coast around Hook Head, between Hook and Chignik Bays. The use of boats will also be essential for exploration of the coastal region southwest of Chignik post office.

The party reached Chignik at the end of the season, September 13, sailed for Kodiak on the Coast and Geodetic Survey steamer *Discoverer* September 15, and arrived at Seattle on the *Admiral Watson* September 29.

ACKNOWLEDGMENTS

Transportation in both directions between Chignik post office and the sand spit in Chignik Bay was furnished for the entire party and its equipment through the courtesy of Mr. Rogge, superintendent of the Northwestern Fisheries Co.'s cannery; Captain Halvorson, superintendent of the Alaska Packers' Association's cannery; and Captain Osmund, superintendent of the Columbia River Packers' Association's cannery. Each of these gentlemen further assisted by giving much information, providing storage for supplies, and in

many other ways facilitating the work of the party at different times during the season. The Coast and Geodetic Survey steamship *Discoverer* provided transportation to Kodiak at the end of the season, and Captain Garner, the officers, and the crew provided every possible facility for the convenience of the party.

GEOGRAPHY

POPULATION

Except for the settlement around Chignik Bay and the village of Meshik, on Bristol Bay, the region is entirely uninhabited. Chignik post office, which is on Anchorage Bay, is located at the cannery of the Northwestern Fisheries Co. At the head of Anchorage Bay there is a native village of perhaps 100 people that is also called Chignik. At the base of the sand spit on Chignik Bay is another village of 30 or 40 people. Some 25 or 30 natives live the year round on the southeast side of Chignik Lagoon, near the Alaska Packers' Association's cannery. Four native families live at Meshik, northeast of the mouth of Meshik River, on the Bering Sea coast. Each of the three canneries already noted has one or two watchmen to protect the plants in winter. No other permanent residents of the area are known. During the summer about 600 men are brought from Puget Sound, Portland, and San Francisco to work at the canneries and fish traps. Several trappers gather furs in the vicinity of Black Lake and Meshik River during the winter.

INDUSTRIES

The principal industry of the region is salmon canning, and three large canneries have been established, one on Chignik Lagoon and two on Anchorage Bay, with fish traps at several points between Anchorage and Aniakchak Bays. These canneries together pack from 90,000 to 200,000 cases of salmon during the short season from June 15 to September 10. In addition to the men who are brought from the States to work in the canneries, many of the natives find employment in them during the summer. During the winter a few white men and a number of natives make a living by trapping along the valley bottoms and on the Meshik River flats. A few natives catch and dry or smoke fish for the winter. One man has a small herd of reindeer on the Bering Sea side of the peninsula. No crops of any sort are raised or harvested, no minerals are produced, and industry is accordingly limited to exploitation of the animal life.

ANIMAL LIFE

Every year humpback, silver, and chum salmon come in from the Pacific Ocean and the Bering Sea in great numbers to spawn in the numerous streams and lakes of the region. In the season of 1925 the run of salmon was said to have been smaller than usual, but over a million fish passed the Bureau of Fisheries weir and entered Chignik Lake at the head of Chignik Lagoon. A smaller number were caught and packed by the canneries. While the run of fish in other streams on the Pacific Ocean side is said to be large, the number in any one stream is much smaller than the number entering Chignik Lake, because the spawning areas are smaller. On the Bering Sea coast great numbers of fish enter Port Heiden and make their way up Meshik River and its tributaries, as well as into the numerous other streams that empty into the bay. Dolly Varden trout are the most common fish in the streams aside from the salmon. Along the coast hair seals are not uncommon and are used by the natives for food and leather, the skins being chiefly utilized in making footgear and the covering of the peculiar native canoe, which is called a "kayak." Sea otters are very rare but are occasionally reported. They have been almost exterminated by hunters who sought their valuable skins in earlier years. As they are now rigidly protected, their numbers will probably increase.

Land animals are not numerous but because of the small human population are not very timid. The most prominent animal of the region is the great brown Kadiak bear. Fifty-four bears were seen by the party during the season. Fortunately the bears seen were very timid and ran at the sight of man or horse, and the people of the area say that they have little fear of them. Next to the bears in size are the caribou, which show little fear of man, some of them approaching within 50 feet of members of the party. They customarily frequent the high areas and were found in largest numbers on the north side of Mount Veniaminof, where probably 125 caribou range. Except on the extreme peaks of Aniakchak Volcano and Mount Veniaminof, the caribou range over the entire area, their tracks being frequently found 800 feet above any vegetation along the ridge crests, where well-worn trails indicate their customary routes of travel. Smaller predatory animals are wolverine, red fox, mink, and marten. Wolves are very rare in the region. Trappers said that they did not range southwest of the timbered area around the Katmai National Monument, but one was encountered, and in three places in the Aniakchak district their footprints were recognized during the season. Wolverine is also not a common animal. Red foxes were very common, and almost any pleasant day one or more of these animals could be seen on the tops of some of the small hills or roaming the

more open lower hill slopes. They frequently followed members of the party for several hours, approaching within a few feet and showing great curiosity. The great Arctic hare is rather common but is shy and was not often seen. Ground squirrels, locally known as "parky" squirrels, are abundant on dry, open hillsides, and many broad excavations 2 or 3 feet deep on the hillsides bore witness to the eagerness with which the bears dig out these little animals.

Birds are numerous and range from great bald eagles to tiny wrens and finches. Ducks of various species breed on the marshes of the low plain that borders the Bering Sea. Sea gulls appear with the coming of the salmon and are a noisy addition to the fauna of the area. Ptarmigan breed in large numbers in the grass and mossy slopes, and their meat forms a welcome addition to the usual fare of the explorer. Unlike most other parts of Alaska, the Aniakchak district does not abound in insect life. Mosquitoes and gnats were troublesome during only a few days in late July and early August. The coastal marshes furnish ideal breeding grounds for mosquitoes, but at no time was a mosquito veil essential, and veils were worn on very few days by members of the party. Bees and a few flies were also found throughout the season. It seems probable that insect life is greatly reduced by the long-continued winds.

VEGETATION

The plants of the region consist chiefly of grasses, flowering plants, and mosses. Trees are missing from the entire region, except for a small clump of about 60 poplars which grow between Landlocked and Braided Creeks on the Bering Sea side of the mountain range. Alders are abundant along the streams and on the lower slopes of the hills. This bushlike tree is crushed nearly flat by the wind and by the weight of winter snows, and groups of it form a tangled maze of trunks and branches. Here and there the thickets are so impenetrable that it is necessary to chop the brush in order to pass with the pack train or saddle horse, but in most places the thickets may be avoided by a little selection of route. A man on foot moves with great difficulty through these thickets, continually thrusting branches aside or crawling over trunks that are too large to be readily moved. A few of the larger trunks reach 6 inches in diameter, but as a rule they range from 1 to 3 inches. The limbs and trunk may have a total length above the ground of 15 to 20 feet, but they rarely stand more than 10 feet high. The alders are the chief sources of shelter and of fuel. Coal is available at many points but is not of high grade and is not used in the area at present. The dry alder burns readily, and both dry and green wood form an excellent charcoal, which holds fire for a long time and is readily

ignited. Once a fire has been started, it may be fed with green wood and will give a pleasant, steady heat. The wood is too small, crooked, and soft to be used for timber of any sort. The alders are usually limited to a height of 600 or 800 feet above sea level. Willows are found along the streams and here and there to an altitude of 500 feet. Over the marshy lowlands they appear as stunted bushlike forms, rarely exceeding 3 feet in height or an inch in diameter of the trunk. In some sandy but well-watered locations they attain a diameter of 5 inches and a height of 15 feet. In no place were the willows of sufficient size to provide any timber. On the borders of the alder clumps and on drier portions of the lowlands grow salmonberries and a few dwarf raspberries. Devil's club was found only on the point east of Anchorage Bay. Other bushes are rare.

The absence of trees from the southwestern portion of the peninsula and the west half of Kodiak Island has puzzled many observers and is still a problem. The climate is favorable, being milder than that of great areas farther north and northeast, which are heavily timbered, and the soils seem fertile. Confinement of the outposts of the forests to sheltered valleys suggests that exposure to severe winter winds is probably one of the controlling features in their distribution.

Grass is the most abundant and most luxuriant plant in the region. The long period of daylight during the growing season and the numerous heavy rains combine to produce a growth 3 to 6 feet high and so dense that in places a man on foot can see only a little distance ahead as he forces his way through it. These grasses are primarily redtop and beach rye. On the shores of Chignik Bay a little timothy was noted, but probably the seed had been dropped accidentally by a General Land Office party which traversed that portion of the region in 1922. The luxuriant grass furnishes excellent feed for stock, and after June 20, when the grass began to grow freely, the horses had abundant forage throughout the season. The possibilities of summer feeding of cattle on this grass are very great, for it covers the land portions of the broad plain northwest of the mountains for a distance of 10 to 15 miles to the Bering Sea. A great difficulty with stock raising in this area is that the frequent rains throughout the summer probably make it impracticable to cut the grass and cure it as hay. Grass that is not cut does not cure naturally and on freezing becomes unpalatable, so that horses will literally die of starvation rather than eat it. Accordingly the grazing season is limited to three or four months, except on the sandy areas where the beach rye flourishes. If this grass is ever to be utilized, then, it will probably be necessary either to remove the livestock in the fall and return them in the spring, or else provide

artificial heat or other satisfactory means of curing hay under cover to subsist the animals for the seven or eight months when they can not provide for themselves in the open. Except for reindeer and a few horses, no livestock is kept in this portion of the peninsula.

The grass becomes less luxuriant as altitude increases, and above 800 feet it is rarely much of an obstacle to walking. On the drier hill sides and above the terrain on which grass and alder flourish moss and heather grow abundantly, forming in many places a cushion a foot or more thick over the underlying rock. This type of vegetation extends up to an altitude of 2,500 or 3,000 feet. Above this tract there is practically no vegetation except in protected coves with a southerly exposure.

Flowering plants are abundant throughout the district and are especially numerous on the drier portions of hillsides. White and yellow blooms are most common, but brilliant reds and blues are also abundant. During the short growing season the blossoms develop in great luxuriance, and at many places one may collect 75 different species in half an hour.

CULTURE AND TRANSPORTATION

There are few man-made features in the region except the settlements and canneries already mentioned or the few scattered houses and other features, all of which are indicated on the accompanying topographic map. Except for a short road to an old coal mine and the trails made by the Land Office and Geological Survey parties, the only trails marked on the ground are those made by the bear and caribou. These caribou and bear trails are usually beaten hard and have been selected to follow dry ground, so that they furnish the best routes through the district. The principal means of travel used by the natives are the waterways, the light native canoes being adapted to movement along shore during calm weather and to journeys up some of the larger streams. All summer travel across the peninsula, within the area described, follows the canoe route that goes from Chignik Bay through the lagoon, up Chignik Lake and Chignik River to Black Lake, over a portage, through two small unnamed lakes, and finally down a small stream which empties into Bering Sea about 20 miles southwest of Port Heiden. During the winter travel is relatively easy in any direction on the lowlands, because the swamps are frozen and the heavy blanket of hard snow furnishes good footing for snowshoes. In the summer much of the lowland area north of the mountains is an almost impassable marsh in which horses become mired and over which a man can pick a way only with great difficulty. It is necessary to follow the lower slopes of the mountains, where they are free from alders, and to search for

high places such as raised spits and sand bars in the flat, or else to travel above the line of the alders on the mountain slope.

In a district with so scanty a population as that of the Aniakchak district there is little demand for intercommunication, and accordingly no telegraph lines exist within the area, and except along the coast there are no post offices. The steamer *Starr* carries mail from Seward to points along the Pacific coast of the peninsula once a month throughout the year. During the summer it passes into Bering Sea and serves post offices on the north side of the peninsula and at Nushagak. The only post office within the area here discussed is at Chignik. A wireless station operated by and located at one of the canneries at Chignik during the summer handles commercial messages to and from the Government station at Kodiak and so provides good communication with the rest of the world.

The best harbor in the area is Anchorage Bay, where steamers can lie at the cannery docks. Shelter and anchorage for smaller vessels are available in Mud Bay, Chignik Lagoon, and Hook Bay, although a broad bar at the mouth of Chignik Lagoon can be crossed only at high tide. Sitkum Bay is said to offer good anchorage, and a good harbor for small boats is reported in the lagoon at the head of Aniakchak Bay. On the northwest coast only Port Heiden interrupts the smooth curve of the sandy beach. It is reported to be shallow at low tide, and broad areas of exposed mud flats lend confirmation to the report.

CLIMATE

As the Alaska Peninsula is a comparatively small body of land between two large bodies of water, its climate is much more equable than that of most of the rest of Alaska. From whatever direction the wind may blow it comes from salt water—the ocean or Bering Sea. The summers are short and moderately warm. In the field season of 1925 the temperature rarely exceeded 80°, and only at high altitudes was frost noted. Snow lay on the hills within 400 feet of sea level in the middle of June, but it had largely disappeared from southern slopes by the middle of July, and at the end of the field season in September only the glaciers on the volcanoes and gulches in the mountains southeast of Chignik Lagoon retained large amounts of the previous winter's snow. Until late August, however, snowbanks lay in ravines in the mountains and furnished distinctive landmarks. At times during the summer the winds are violent and during severe blows are estimated by navigators to have a velocity of 80 to 100 miles an hour along the seacoast. In several places it was necessary for men moving along exposed ridges to

crawl on hands and knees because of the impossibility of standing upright in the terrific wind.

From whatever direction the wind blows, the air rising over the mountains has its moisture quickly condensed, and clouds and rain form almost continuously around the peaks. Because of this condition the crests of the high volcanoes were invisible for days at a time.

The rainfall is variable, being high on the mountains and low in the adjacent plains. The actual amount of rain is less than would be inferred, because most of the moisture comes as a fine mist rather than large drops, and although there may be many consecutive days of wet weather the rainfall seldom exceeds 2 inches in any one day. The climate in this area is reported to be more pleasant than that of the Cold Bay region, to the northeast. During the field season of 91 days in 1925, there were 33 days of rain, 16 days partly stormy, and 42 days that were fair.

The winters are marked by heavy snowstorms and the drifting of the fine granular snow before high winds that sweep the region. It is reported that storms of three to five days' duration are common. During these storms it is unsafe for people to leave their homes because of the swirling and drifting snow, although the temperature is said rarely to go much below zero. Throughout the field season each member of the party wore heavy wool clothing and habitually carried special rubber-cloth coat and trousers, which afforded excellent protection against wind and weather.

PHYSIOGRAPHIC UNITS

The Aniakchak district may conveniently be divided into three physiographic subdivisions—two major ones that are well marked and a third that is less extensive and less pronounced—extending along the peninsula. The major divisions are the Aleutian mountain range and the Bering Sea coastal plain. The lowlands adjacent to parts of the Pacific Ocean constitute the minor division. Each of the two major provinces is the southwestern extension of well-defined topographic and structural features which continue far into other parts of Alaska.

The lowland near the Pacific coast is a narrow strip of land, ranging in width from 4 miles to the vanishing point. At Hook Head, Nigger Head, and the promontories on each side of Anchorage and Mud Bays the mountains rise directly from the ocean. Elsewhere inland from the shore line is a gently rolling erosional plain, which in turn rises slowly toward and merges with the mountain slopes. In a few places this plain is covered with glacial till, and near the shore line its surface is formed by marine sand and gravel deposits

which have been recently uplifted. Stratigraphically and structurally this lowland region is similar to and in most parts not clearly separated from the mountain range that lies behind it.

The Aleutian mountain province embraces the range of mountains which extends the length of the peninsula. This range lies closer to the Pacific Ocean than to Bering Sea all the way from the northeast end of the peninsula, at Kamishak Bay, down to the southwest end, where the province is cut off by the waters of the Pacific Ocean and Bering Sea, though the mountain chain is continued farther west by the Aleutian Islands. Throughout its extent the range slopes down toward the southeast, either directly into the ocean or to the lowland which has just been described. Within the Aniakchak district the Aleutian Range consists chiefly of a long, roughly anticlinal uplift which has been deeply and maturely incised by the consequent streams that flow away to the Pacific and Bering Sea. Several spurs branch off toward the west from this range and are arranged en échelon along its north side. The ends of these spurs are characteristically marked by volcanoes. Thus Mount Veniaminof, Purple Crater, and Aniakchak Volcano are so situated that they appear to dominate the main range from westward-trending ridges. The spurs are composed largely of volcanic rock. It therefore seems possible that they represent large gash fractures in the crust of the earth formed during the folding that produced the Aleutian Range. Probably relief of pressure due to the tension fracturing here permitted the extrusion of igneous rock, which formed the volcanoes and so made the spurs that extend from the main range. On the south side of the range is the high mass of Hook Head, which is also volcanic but which, so far as known, has no significant relation to the main structure of the mountains. Southeast of Chignik Lagoon faulting has raised masses of lava and Cretaceous and Tertiary sediments to the altitude of the general mountain system, and between Chignik Lagoon and Kuiukta Bay the lowland adjacent to the Pacific Ocean is reduced to a strip of alluvium half a mile wide.

The mountain peaks rise rather consistently to a general altitude ranging from 2,500 feet in the northeast to 3,000 feet at the southwest. Aniakchak Volcano and Mount Veniaminof tower high above the general summits of the range, as they rise to altitudes of 4,200 and 8,400 feet respectively. No marine plain or other surface of erosion beveling the tops of the mountains was identified. Field conditions did not permit the gathering of sufficient evidence to determine whether the general accordance of level is due to uniformity of original uplift, to the presence of a maturely eroded, upwarped, and folded erosion surface, or to isostatic adjustment on a minute scale of a series of sedimentary blocks floated on an underlying magma which has, in part, escaped to the surface through numerous

vents. The absence of evidence of a high-level surface of erosion, the presence of a large number of faults, the varied tilting of the fault blocks, and the abundant volcanic phenomena strongly suggest that the third hypothesis is the correct explanation but by no means prove it.

The mountains have been glaciated submaturely, producing large cirques, which are especially prominent on the north and east slopes. Most of the larger valleys within the Aleutian Range, except those cut in recent volcanic deposits, are distinctly U-shaped, with hanging or poorly developed tributary valleys. The main valleys are cut 500 to 2,000 feet below the adjacent upland and are normally broadly open and either swampy or floored with coarse débris from the higher slopes. Stream meander belts on these flat floors attain half a mile in width. The proof of glaciation rests largely on topographic evidence, for the rapid weathering of the soft rocks and the easy erosion of moraines on valley floors has removed most of the smaller-scale features that might indicate glaciation. Numerous terminal moraines and a few glaciated surfaces, however, are preserved and confirm the conclusions drawn from the topography. Many upland divides are broad and gently rolling, for the severe glaciation and stream erosion have only submaturely dissected the range.

Throughout the mountains weathering proceeds rapidly, owing to the abundance of moisture and repeated freezings and thawings. On the slopes vegetation retards or prevents wash of the soil, but creep steadily removes the soil and broken rock faster than the master streams can transport it. A peculiar type of creep is notable. A combination of frost action, saturation, and gravity breaks the moss cover of the surface and permits the soil and broken rock to slump a foot or two. The semifluid mud shoves the moss into a nearly vertical position, where it holds the soil, while the water drains away through the mat of vegetation. Thus a low step is formed on the mountain side, ranging from 6 inches to 3 feet in height, moss forming the steep slope and bare rock fragments covering the flat part or tread of the step. Many mountain slopes show this feature prominently through a vertical distance of 500 to 1,000 feet. When the frost is coming out of the ground the steps are extremely soft, and a person treading on one may sink in above his knee before he is able to withdraw his foot. In crossing such slopes it is necessary to walk on the tops of the steep mossy surfaces and jump from one such firm place to another. By the middle of July, however, the water has largely drained away, and the entire slope can be traversed without difficulty. Probably this process moves large tracts of the surface of the hillsides down the slope several inches a year and involves the soil to a depth of 1 to 2 feet.

The Bering Sea coastal plain lies northwest of the Aleutian Range. This plain has a low, marshy surface, rising at a rate of 5 to 15 feet a mile from Bering Sea to the foot of the mountains. In places the lowland does not grade into the mountain slope but intersects it sharply, but elsewhere the lowland merges imperceptibly with the mountain slopes. Probably the coastal plain consists chiefly of material washed from the mountains and of volcanic ash and sand blown from the numerous volcanoes. It is so recent in age that it is still in process of formation, for it contains many lakes, ponds, and marshes that are being destroyed by growth of vegetation, wash of streams, and volcanic deposits. Practically the whole of this plain is almost impassable during the summer because of the extremely wet and boggy character of the land and the numerous lakes and marshes. Traverse of this plan is so difficult that only one member of the party crossed the plain to Bering Sea during the field season, although the shore was in sight almost continuously for two months and a half. In going northwestward from Aniakchak Volcano it was possible to take advantage of what are probably glacial moraines that extend far toward the sea from the mountain. Over the last 4 miles it was necessary to follow an extremely circuitous route, the traveler wandering around one marsh after another, seeking good footing. It is probable that one could follow a similar series of low spurs and hills which extend northwestward from Mount Veniaminof and thus reach Bering Sea without difficulty from that mountain. The arrival of the end of the field season, however, prevented an attempt to reach the sea along this route. There is less swamp along this route, and accordingly the passage would be much easier than northwest of Aniakchak Volcano. Northwest of Mount Veniaminof are numerous volcanic necks and several small flows, which have obviously been extruded upon the coastal plain recently. For all practical purposes it may be said that between Aniakchak Volcano and Mount Veniaminof the coastal plain, except when frozen, is impassable.

The Bering Sea coastal plain is characterized by meandering streams, a marshy surface, and a total absence of outcrops of consolidated rock, except northwest of Mount Veniaminof. North and west of Aniakchak Volcano there are many low hills rising 20 to 60 feet above the plain, which from a distance suggest half-buried rock hills. About 26 of these hills were visited, and every one proved to be either a mound of glacial drift or a sand dune. Wherever examined, these low hills were found to consist of volcanic products swept down the slopes of Aniakchak Volcano by ice, streams, or wind and piled above the general swamp level by ice or wind when climatic conditions were different from those of the

present day. The morainic hills show distinct terraces and, in a few places, flat tops, apparently cut by waves. The most marked of these terraces occur at about 160, 290, and 375 feet above sea level. Distinct spits, bars, and crescentic beaches occur intermittently far inland of the present shore line in the tract south of Meshik River between Landlocked and Charles Creeks. These elevated, drier areas were welcome routes of easy travel along the mountain front.

The lowland is a plain of construction, and its deposits are of unknown but probably great thickness. The flanks of the Aleutian Range plunge down at angles of 10° to 25° at the contact with the plain, and presumably bedrock lies at a depth of hundreds if not thousands of feet beneath the surface of the plain. Because of the water and the rank vegetation, exposures of the soil and subsoil are not usually available.

DRAINAGE

Streams.—The drainage of the region is different in each of the physiographic provinces. The plain near the Pacific Ocean is well drained by numerous consequent streams, which enter the ocean at rather short intervals along the shore. Only a few small lakes and marshes are located on this plain. Their origin is not clear, but they appear to be due to drainage derangements caused by recent uplift, for so far as noted they are not connected with glaciation, and in at least one place they clearly occupy an old stream channel.

The mountains are well drained. Only three cirque lakes were found, and in most places the meadows that might be expected in old cirques, if they ever existed, have been entirely drained and dissected. The tributaries tumble swiftly down steep slopes to join the main streams, most of which meander over the broad, glaciated floors of their valleys. Waste from the mountain sides is usually brought in greater quantity than the main streams can transport, and in consequence the valley floors are aggraded by meandering, braided streams whose small tributaries incise their channels in the mountain slopes. Marshy floors have therefore developed in many valleys, particularly upstream from the junction of a vigorous tributary, whose alluvial fan has partly ponded the main stream.

On the coastal plain adjacent to Bering Sea streams meander widely between low banks. Deposition exceeds erosion, and the creeks frequently abandon choked channels for new courses or, branching repeatedly, are finally lost in the maze of ponds and swamps. North of Aniakchak Volcano most of the surface water sinks into the deep ash and the creeks are lost, but on the other sides the flow continues uninterruptedly to Meshik, Aniakchak, and Cinder Rivers. Similarly, many streams disappear on the flanks

of Mount Veniaminof, but from the lower slopes some continue without interruption to Bering Sea or Chignik River.

Chignik, Meshik, and Aniakchak Rivers are the largest streams of the area. The largest tributary of Chignik River rises east of Mount Veniaminof and flows in a northerly direction toward Black Lake but before reaching that lake turns sharply east to join Chignik River, which flows southward and empties into Chignik Lake. A large area between the Purple Crater Volcano and the main range drains through Alec River into Black Lake and thence to Chignik River. The water passes through Chignik Lake and a short river section to Chignik Lagoon and the ocean. Below the junction of the creek which comes from Bearskin Gulch, Chignik River is too deep to be forded. Alec River can not be forded within the first 4 miles east of Black Lake. Similarly the outlet of Black Lake flows through a broad, swampy area, which is almost impassable when not frozen.

Meshik River occupies a position somewhat similar to the eastern part of Alec River, for it drains the region between the Aniakchak Volcano and the main Aleutian Range. In late July, 1925, it was thigh deep on a sand bar above Shoe Creek. Downstream it widens, increases greatly in volume, and is probably too deep to ford, even if it could be approached across the swampy plain. Aniakchak River rises inside the Aniakchak Crater. For about 10 miles from the crater it can be forded only with difficulty at favorable points, but farther southeast it becomes sluggish and more readily forded. Aniakchak and Chignik Rivers are the only streams that cross the mountains in this area. Elsewhere the mountain axis forms approximately the main divide. The other streams of the area are usually less than 4 feet deep and can be crossed without great difficulty.

Lakes.—Near the Pacific coast there are no lakes of importance. Within the mountains three distinct types of lakes occur. Chignik Lake is over 8 miles long and half a mile to 1½ miles wide and lies in a valley cutting squarely through the mountain range at right angles to its axis. Glaciation has considerably modified the valley, but there is no apparent structural cause for its origin. Chiaktuak and Bearskin Creeks occupy parallel valleys, but the valley of Chignik Lake became part of a transmountain depression because it headed against another valley that was developed along the fault line of Chignik Lagoon. With the exception of Black Lake, Chignik is the largest lake in the region.

Crater lakes exist in Purple and Aniakchak Craters. In Purple Crater four lakes lie around a large eccentric plug which rises about 500 feet above the surrounding crater rim. The largest lake is about three-quarters of a mile in diameter, has a steeply shelving bottom

near its margin, and is apparently very deep. Its water is deep bluish purple, reflecting the color of the neighboring andesite, is remarkably clear, and is not appreciably mineralized. It drains through a dam of lava fragments and volcanic breccia to a lake 15 feet lower on the west and eventually down Crater Creek. The other lakes in this crater are small. Surprise Lake covers about 1¼ square miles in the northeastern part of Aniakchak Crater. The water is milky green because of muddy streams that enter the lake on the northwest. Apparently the lake is not very deep and owes its existence chiefly to two deltas built by streams flowing from the southeastern part of the crater. The rock floor in The Gates is about 20 feet below the lake level, and removal of the deltas would nearly or completely drain the lake.

The coastal plain near Bering Sea contains one large lake (Black Lake) and innumerable unnamed lakes and ponds a square mile or less in area. Black Lake stands at almost the same altitude as the divide between the Bering and Pacific drainage systems. Its northern shore is, in part, a terminal moraine of a glacier that formerly pushed northward up the present course of the West Fork of Chignik River. On the south the alluvial fan of the West Fork dams the outlet of Black Lake and thus establishes the present level of the lake. Alec River is building a delta in the eastern part of the lake. Probably the lake is shallow, but no soundings are known. During periods of heavy winds the water is muddy, so that it is not very inviting for camp use. All the larger lakes of the coastal plain and the Meshik River Basin are correctly represented on the accompanying map, although there are in addition countless minor ponds which are too small and too numerous to show on the scale adopted. With the adjoining marshes and meandering streams the lakes constitute a great, almost impassable swamp.

Stream flow.—No measurements of stream flow have been made in this area, but available data indicate that the streams have the normal regimen for a humid region with severe winters. During the winter ice forms to a depth of 4 feet or more and probably flow ceases except in a few large streams. Deep snow accumulates in protected places, filling gulches to a depth of 30 feet or more and burying the alders. Melting snows provide great volumes of water until early July, after which the flow decreases and fluctuates with the amount of the rains in the mountains until the freeze up in November.

Sufficient water power to operate a small hydroelectric plant is available during the summer at many places, but no large projects of this sort appear to be practicable, unless the West Fork of Chignik River could be used. It is doubtful whether an effective dam site

could be found in this valley, because of the highly porous character of the volcanic rocks which form the slopes of Mount Veniaminof. Small streams supply steady power and water during the summer to each of the canneries near Chignik.

Springs.—Seepages and small springs are numerous at the bases of many steep slopes both in the mountain valleys and on the flanks of the range. A warm soda and iron bicarbonate spring occurs west of Surprise Lake, and hydrogen sulphide springs issue on the east and west sides of Purple Crater. Several large carbon dioxide springs bubble up in the shallow water on the east side of Purple Lake.

Glaciers.—Several small cliff glaciers lie on the divide near the heads of Braided, Yellow Bluff, and Thompson Creeks and the northern tributaries of Alec Creek. A few small glaciers are also mapped near the summits of the mountain south of Anchorage Bay. They are the last remnants of the great glaciers that formerly occupied the heads of all the large valleys and pushed far down some of them.

The crater of Mount Veniaminof is filled with a great circular glacier, 5 or 6 miles in diameter, which overflows in three directions. To the northeast it flows through small cols, spilling down the mountain and forming Crab Glacier outside the crater; to the south the ice overtops the crater for a length of 2 miles or more, but probably this ice stream is relatively shallow; to the west the ice flows through a canyon estimated as 2,000 feet deep, forming Cone Glacier. The western outlet is fully 1,000 feet lower than either of the others, and a great river of crevassed and shattered ice, perhaps 600 feet wide, grinds through the passageway and greatly depresses the level of the ice on that side of the crater.

Several glaciers, some of which are as much as 6 miles long, originate in the cliffs outside of the crater and flow down the near-by valleys. The largest of these from east to west are Slim, Finger, Harpoon, Island, and Fog Glaciers and an unnamed glacier lying between Crab and Island Glaciers.

Aniakchak Volcano supports a number of cliff glaciers on the nearly vertical southern wall of its crater, and several others lie near the crest, outside the crater, on the high southern slope. A bed of ice, perhaps 1,000 feet in diameter, fills the crater of Vent Mountain, the large cinder cone inside the main crater. There is no outlet for this ice, but as no measurements are available to indicate whether melting balances the annual accumulation it is not known whether the amount of ice remains constant or is decreasing, or whether it is accumulating and will eventually spill over the edge and erode the cone.

COAST LINE

As shown on the map, the coast contiguous to the Pacific Ocean differs strikingly from the coast contiguous to Bering Sea. On the Pacific side of the peninsula exposures of Pleistocene or Recent marine sand at altitudes as great as 100 feet indicate a recent uplift of the region, but no well-marked raised cliffs, beaches, or other shore features are known. Apparently the ocean has not stood long above its present level since the Pleistocene glaciation. Wave erosion is vigorously attacking the present shore line, and nearly vertical cliffs 20 to 350 feet high stand on the exposed faces of headlands. Stacks, caves, and arches are common along the shore, for the sediments are easily eroded. Crescent beaches, bars, or spits have been built in most coves and are being steadily enlarged. Chignik Lagoon and Mud Bay are practically shut off from the ocean at low tide, and long hooks are growing in Anchorage and Hook Bays.

The Bering Sea coast line is much more regular than the Pacific coast. The most recent movement recorded there seems to have been an uplift of about 130 feet, producing a regular shore line through the area, except for the depression of Port Heiden, which is the western extension of the Meshik Valley syncline. Off shore, bars are being piled up by the waves, and breakers half a mile from the beach indicate shallow water and a gently sloping floor. Sand dunes as much as 50 feet high are piled along the beach, but they do not travel far inland, as their movement is soon stopped by the growth of the rank beach rye on them.

STRATIGRAPHY

Sedimentary rocks form most of the area here described. Except for a small mass of quartz diorite on Hook Head, no deep-seated igneous rocks crop out. Mount Veniaminof, Aniakchak Volcano, and Purple Crater are the three prominent volcanoes of the region. Their flanks are composed in large part of volcanic ash and agglomerate with interbedded lava flows. Numerous dikes intersect the walls of the volcanoes and can be traced for short distances on the surface. Associated with or cutting the sedimentary rocks in the vicinity of each of the volcanoes are igneous rocks in the form of flows, dikes, necks, or possible plugs, some of which since their formation have been largely removed by erosion. Examples of these volcanic rocks are the great mass of igneous material on Hook Head, the lavas on the south side of Meshik Valley extending from Purple Crater to the northeastern boundary of this area, and the upper parts of some of the peaks at the head of Birthday Creek. South of the depression extending from Chignik Lagoon to Black Lake dikes

and flows are numerous, and they are particularly abundant near the head of Bearskin Gulch. In most of these areas the precise boundary between igneous and sedimentary rocks can not be indicated in detail on a map of so small a scale as the one used here. The dikes are numerous and short, and they make up from 1 to perhaps 80 per cent of the rock in any particular area. The boundaries shown on the geologic map accompanying this report (pl. 6) therefore only approximately differentiate regions in which igneous rocks predominate from those in which the dike material is a minor constituent, and it should be noted that dikes are not unknown even 3 miles outside the boundaries of igneous rock as they are indicated on the map.

Furthermore, the field work was entirely of reconnaissance character, and no map was available in the field except one of the region along Chignik Bay; therefore boundaries and other geologic data have since been plotted on the map from field notes and sketches. Because of these conditions and because of the small map scale used, the boundaries have been generalized, and their position in places is subject to personal interpretation.

The sedimentary rocks of the region are all of Mesozoic age or younger. Although Middle Jurassic and lower Upper Jurassic formations crop out near Wide Bay, 60 miles northeast of Aniakchak Volcano, they are not known to occur in this area. They may underlie the later strata here exposed, and on this possibility depends the only chance of petroleum production from this region. This possibility is discussed in greater detail in the section on mineral resources.

MESOZOIC ROCKS

JURASSIC SYSTEM

NAKNEK FORMATION

Lithologic character.—Spurr[16] applied the name Naknek to a series of arkoses and conglomerates which occurs in the Katmai region along the route once followed by mail and other traffic across the northeastern part of the peninsula. The formation has since been traced southwestward from the type locality by Smith and Baker,[17] and the outcrop is nearly continuous from the type locality to the Chignik district. In the Aniakchak district mudstone, shale, and fine sandstone constitute most of the formation. Limestone is almost entirely absent. A few layers of argillaceous ferruginous

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[16] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, p. 169, 1900.

[17] Smith, W. R., and Baker, A. A., op. cit. Smith, W. R., The Cold Bay-Katmai district: U. S. Geol. Survey Bull. 773, pp. 183–207, 1925.

limestone 1 to 2 inches thick appear in the upper part of the thick sequence of mudstones which forms the hills northwest of Chignik Bay. Similar beds were noted in the probably equivalent rocks on the divide between Hook Creek and Bluff Creek. The limestones are mud cracked, are nowhere over 2 inches thick, and are separated from one another by 10 to 15 feet of other rocks in the section. Except where exposures are unusually good, the limestone does not crop out and the beds are not sufficiently continuous to serve as horizon markers for detailed mapping. The sandstone grades into shale or light-gray to chalky-white arkose, carrying grains of quartz and feldspar and fragments of granite 1 to 4 millimeters in diameter. The arkose is rare in the southwestern portion of the district but becomes more abundant toward the northeast. Around Aniakchak Volcano fully half of the exposed formation is strongly arkosic and appears greenish tan or buff in the hillside and in specimens. The sandstone and arkose in a few places contain lenses or well-marked beds of conglomerate. Most of the conglomerate lenses are not over 3 feet thick, and rarely can one be traced for more than a few hundred feet horizontally. On the south side of Conglomerate Creek, however, a great bed of coarse conglomerate appears which is more than 300 feet thick and extends 4 miles along the strike. Other outcrops of thick conglomerate in the Naknek formation occur at the heads of Landlocked and Braided Creeks, where the thickness exceeds 100 feet. Similar thick beds are more common in the region east of Aniakchak Crater, and in general the amount of conglomerate increases as the formation is followed toward the north or east. The conglomerate is light green to mottled green and black, consisting of pebbles of quartz, quartzite, granite, diorite, chert, and hornstone, named in the order of abundance, white quartz pebbles being much the most common. The matrix is a fine sand or clay, which is commonly greenish because of secondary chlorite that has developed throughout the rock. In most places the conglomerate is better cemented and more resistant to weathering than any other member of the formation.

Black or dark-gray mudstone and shale constitute fully 65 per cent of the formation. They pass insensibly into fine sandstone which is distinguished with difficulty from the argillaceous rocks. The sandstone, mudstone, and shale together form more than 95 per cent of the formation. Much of the shale is well bedded. Many laminations show a regular gradation from fine sand below to silt or clay above. Clay, on the other hand, was deposited in many places without primary structure or bedding. Such nonlaminated clays or mudstones may have been precipitated colloidally in salt water at a fairly steady rate, the conditions for lamination not being present. In some places the clay has hardened to a dense rock which resembles

the hornstone formed at igneous contacts. The material is so uniform in color and grain that it may be mistaken for limestone until its hardness is tested. It is eroded by waves or running water to the round, smooth forms of a dense limestone, is thoroughly jointed, and, except for its greater hardness and resistance to acid, presents all the characteristics of a normal dense dark-gray limestone. This peculiar argillite is found at several horizons in the formation but is most common toward the southwest, where apparently the water was deeper during the deposition of the Naknek sediments. All the sandstones are fine grained and argillaceous. None of them would be suitable for building stone, and, except on close examination, they are readily mistaken for shale. In these characteristic dark dense rocks few of the sand grains reach a size of 0.2 millimeter. Naknek sedimentation was characterized by repeated deposition of clay and silt, but none of the individual beds can be traced for long distances, and only very general correlations were made between the outcrops in different parts of the Chignik district. Lithologically similar material was repeatedly deposited, and there is so little variation between the beds that except on excellent exposures members can not be correlated at distances exceeding half a mile.

The arkose is olive-drab, yellowish, or light gray and coarse grained, and the beds are separated by fine, clean mudstone or shale. They can not be traced for long distances, because they interfinger, are channeled, and show other evidences of current deposition in shallow water. The presence of numerous marine pelecypods shows clearly that the rocks in which they occur are of marine origin. The primary structural features exhibited by these rocks indicate a rapid variation in location and carrying power of the current that deposited the sediments of which the rocks are composed.

Mather[18] describes boulders in the Chisik conglomerate (basal member of the Naknek formation) with a diameter of 15 feet on Kamishak Bay, at the northeast end of the peninsula, and Smith and Baker[19] found some as large as 6 or 8 feet at Cold Bay; but in the Aniakchak area the largest boulder was not over 2 feet in diameter, and probably less than 25 were seen which exceeded 1 foot. From north to south and from northeast to southwest there is a steady decrease in size of boulders, in percentage of conglomerate, in amount of arkose, and in evidences of contemporaneous erosion. In the same direction there is a steady increase in the percentage of clay, in the amount of mudstone, in the regularity of beds, and in the amount of fossil material. In addition to the lithologic changes, cross-bedding and ripple marks indicate that the material was carried southward

[18] Mather, K. F., Mineral resources of the Kamishak Bay region: U. S. Geol. Survey Bull. 773, p. 169, 1925.
[19] Smith, W. R., and Baker, A. A., op. cit., p. 179.

and southwestward during its accumulation. Spurr reports many plant fossils in the Katmai region, but farther southwest only marine organisms occur. It accordingly follows that the Naknek formation as exposed on the Alaska Peninsula represents a great mass of detritus that was laid down south or southwest of the shore of a land that occupied the position of the present mainland of Alaska approximately in the Lake Iliamna region.

Topographic expression.—Erosion of the Naknek formation produces a topography that varies with the type of rock present. The shale and mudstone are readily removed, and the fine sandstone is almost as easily eroded. These members yield on erosion a series of steep slopes intersected by ravines. The main valleys in these rocks are broadly open at the base and in some places are steep sided where glaciation has recently scoured them, but normally they have smooth slopes covered by creeping material which flows down steadily to the valley floor. The arkose is more resistant to weathering than the shale or mudstone but is readily eroded by running water. The streams in the areas of arkose accordingly cut sharp box canyons with steep sides and flat, gradually widening floors. Where erosion is slow the arkose weathers to rounded hills which support a dense vegetation.

The conglomerate is more resistant than any of the other members of the formation, and where the overlying shale is stripped away it makes sharp hills with steep, bare slopes. Weathering attacks the matrix of the rock slowly, and the removal of loose material occurs quickly after it is loosened by weathering. The conglomerate surfaces are accordingly bare and rough. The limestone makes up so small a part of the formation that it has no effect upon the topography.

Detailed section.—The total thickness of the Naknek in this area is unknown, as the base of the formation is not exposed. Northwest of Portage Bay Smith and Baker [20] found a total thickness of about 5,600 feet in an incomplete section. Farther northeast they measured a section 11,000 feet thick but considered this thickness excessive and probably due to concealed faulting. Calculations from exposures in the Aniakchak district indicate an exposed thickness of over 6,400 feet, but this determination is only approximate, because time did not permit the measurement of detailed sections and close correlations have not been made between the different outcrops. There is no way to estimate from surface observations the thickness of the Naknek beds which are concealed below the lowest exposures. This uncertainty is extremely unfortunate, for the possibility of finding petroleum in this area depends in large part on the content

[20] Smith, W. R., and Baker, A. A., op. cit., p. 180.

of oil in the Shelikof formation, which may underlie the Naknek. The Shelikof is believed to be the oil-bearing formation in the Cold Bay region. This thickness of the Naknek probably decreases toward the southwest as the average size of grain diminishes, but present information is not sufficient to justify an estimate of the rate of thinning or the total thickness of the Naknek in this area.

The following rough section was measured in the course of a pace traverse up Bluff Creek. It includes the lowest Jurassic beds exposed in the Aniakchak district but does not include 2,500 to 3,000 feet of arkosic sands and pebble conglomerates which form the upper part of the Naknek formation on the flanks of Aniakchak Volcano and along Alec River.

Section of Naknek formation along Bluff Creek

Cretaceous system: Chignik formation.	
Unconformity marked by weathering of Jurassic and development of coarse basal conglomerate.	
Jurassic system: Naknek formation:	Feet
Sandstone, dark, very fine grained, chocolate-colored to black	200
Arkose, green-gray, grains as much as 3 millimeters in diameter	600
Arkose and dark sandstone, interbedded	600
Sandstone or siltstone, grains less than 0.2 millimeter in diameter, dense, well cemented, weathering smooth, gray to blue-gray. (This section may be duplicated in part by thrust faulting)	1,200
Sandstone, black to dark brown, with minor amounts of interbedded gray arkose and considerable black shale	800
Mudstone, almost entirely unstratified, indurated to the hardness of an argillite but showing no secondary minerals or cleavage; contains rare zones of thin siderite concretions and very thin argillaceous limestone strata	500+
Covered.	
	3,900+

Areal distribution.—The Naknek formation crops out along the crest of the Aleutian Range through the Aniakchak district as far northeast as Blue Violet Creek. It extends far down on the flanks in most places, and the amount of its exposure depends upon the erosion of the overlying Chignik and Kenai formations. The outcrop is cut off at the northeast, where the volcanic rocks described by Smith and Baker[21] as lying along the Pacific shore extend over the top of the mountains. The outcrop widens toward the southwest and reaches its maximum extent along the Chignik Lagoon and

[21] Smith, W. R., and Baker, A. A., op. cit., p. 194.

Black Lake depression. Beyond this line volcanic rocks from Mount Veniaminof and the unmapped area southwest of Anchorage Bay overlie much of the Naknek, and its outcrop is narrowed. As seen with field glasses it appears to be exposed for about 10 miles southwest of Knife Peak. The flanking volcanic rocks appear to merge over the top of the mountain range south of that point, which lies on the headwaters of Chignik River. There is no information to indicate whether the Naknek is exposed farther southwest.

Isolated outcrops of the Naknek formation occur on the south and east sides of Aniakchak Volcano. The mountain is not purely a volcanic cone, for its southeast side consists of sedimentary rocks capped by about 1,200 feet of volcanic rocks. The north and west flanks are composed entirely of volcanic ash, breccia, and a few flows. No Mesozoic sedimentary rocks were seen in the northwestern crater walls, but the Naknek crops out on the east and south faces of the crater. Fog seriously handicapped field work in the crater, so that a detailed study of the crater walls was impossible, and it may be that a small area of Naknek occurs on the Bering Sea side. No outcrops of the Naknek or of other sedimentary rocks are known in the alluvial plain of Meshik River or the broad coastal plain of Bering Sea, and it seems improbable that the Naknek lies near the surface under any of that area.

Paleontologic character.—Marine forms are abundantly present in the Naknek formation at certain horizons. The laminated shale contains numerous pelecypods and many cephalopods. In some places the shale is so crowded with fossils that every hand specimen contains one or more. They are rare in the dense "hornstone" layers and are almost entirely absent from the arkose, where, however, a few appear, showing that it was deposited in the ocean. A number of paleontologic collections have been made in the past within the Naknek formation at several places in the Aniakchak district. These have all been lately described and summarized by Martin [22] and assigned to the Upper Jurassic. In addition to these earlier collections several new ones were made in the course of the present work. As the identification of these new collections has not been published they are given here in full. The recent collections as well as practically all the older ones have been identified by T. W. Stanton. All these collections are regarded by him as representing the Naknek. This conclusion supports the field determination that the Middle (?) Jurassic Kialagvik and Upper Jurassic Shelikof formations do not crop out in the Aniakchak area.

[22] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, pp. 203–218, 1926.

13463. Nos. 44 and 50. Divide between South Fork of Chignik River and Bearskin Gulch, 24 miles west of Chignik post office:

Pecten? sp.
Eumicrotis sp.
Aucella sp. related to A. pallasi Keyserling.
Turbo? sp.
Jurassic, Naknek formation.

13464. No. 51. Ridge between Bearskin Gulch and northwest end of Chignik Lake:

Aucella sp. related to A. erringtoni (Gabb).
Jurassic, Naknek formation.

13465. No. 70. Northwest side of Chignik Lagoon, 2.6 miles southwest of native village:

Aucella sp. related to A. erringtoni (Gabb).
Jurassic, Naknek formation.

13469. No. 75. Northwest end of sand spit, head of Chignik Bay:

Aucella sp. related to A. bronni Rouillier.
Jurassic, Naknek formation.

13471. Nos. 86, 140, and 142. Rainbow Creek on south slope of Aniakchak Volcano, 40 miles northeast of Chignik post office:

Lima sp.
Pteria sp.
Aucella sp. related to A. pallasi Keyserling.
Aucella sp. related to A. erringtoni (Gabb).
Aucella sp. related to A. bronni Rouillier.
Jurassic, Naknek formation.

13475. No. 116. Hidden Creek, east side of Aniakchak Volcano:

Fragment of cephalopod 15 inches in diameter.
Septate fragment which may belong to Lytoceras, but there is not enough of it to determine either genus or horizon.

13476. No. 122. Six miles northwest of Hook Bay:

Aucella sp. related to A. pallasi Keyserling.
Belemnites sp.
Jurassic, Naknek formation.

13481. No. 191. Northwest side of Chignik Lagoon, 4 miles southwest of native village, at contact of Naknek and Chignik formations:

Lima sp.
Pteria sp.
Aucella sp.
Jurassic, Naknek formation.

Correlations and relations.—The Naknek formation had heretofore been traced by practically continuous outcrops from the type locality on the Katmai trail to King Salmon River, 50 miles northeast of Aniakchak. The abundant and distinctive fossil fauna and the lithologic character assure the positive correlation of the upper part of the Naknek in the Aniakchak area with the type outcrop to the northeast. A heavy conglomerate marks the base of the Naknek formation in the Cold Bay and Katmai areas. This basal portion is not recognized in the Aniakchak area, and it is probably not exposed. On the other hand, the conglomerate may pass by lateral gradation into some of the sandy zones with conglomerate lenses,

and accordingly the lower portion of the Naknek as mapped in the Aniakchak area may be the equivalent of the Upper Jurassic Shelikof of the Portage Bay-Wide Bay district. Field evidence, however, did not indicate that any of the Naknek as here mapped lay below the *Aucella* horizon. The strata that crop out beside Chignik Lake are far down in the Naknek. Martin, who with Stanton [23] described the Shelikof as part of the "Enochkin formation" at Cold Bay, regards the strata at Chignik Lake as Naknek.[24] All the identified fossils from this formation in the Aniakchak district are regarded by Stanton as Naknek in age. The consensus of evidence and opinion therefore indicates that the Shelikof is not represented by any beds that crop out in the Aniakchak area. According to Stanton and Martin [25] the basal Naknek is probably equivalent to the Sundance and Ellis formations of the northern Great Plains in the United States and is accordingly of Upper Jurassic age.

The Naknek formation lies conformably upon the Shelikof in the Cold Bay region, as shown by Smith and Baker.[26] In the absence of any evidence of the Shelikof formation in the Aniakchak district the only reasonable assumption is that here also, if the Shelikof is present, the two formations are probably conformable.

An unconformity separates the overlying Chignik formation from the Naknek. It appears at many places and is everywhere marked by moderate relief. Fresh, unweathered Naknek rocks lie below it, and fine-grained carbonaceous sands of the Chignik formation above. These facts indicate that the region was not subjected to peneplanation, with consequent deep weathering, nor was the uplift high enough to produce rapid streams and coarse gravel. In part the fineness of the lower Chignik beds may be due to the soft character and fine grain of the Naknek. Pebbles of Naknek sandstone are, however, identifiable in the basal Chignik, so that in part, at least, the formation was well indurated before the Chignik formation was deposited.

CRETACEOUS SYSTEM

CHIGNIK FORMATION

Lithologic character.—Atwood [27] described coal-bearing sand, sandy shale, and gravel largely of fresh-water origin and of Upper Cretaceous age under the name Chignik formation. The type locality

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[23] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Geol. Soc. America Bull., vol. 16, pp. 397–402, 1905.

[24] Martin, G. C., The outlook for petroleum near Chignik; U. S. Geol. Survey Bull. 773, pp. 209–213, 1925.

[25] Stanton, T. W., and Martin, G. C., op. cit., p. 407.

[26] Smith, W. R., and Baker, A. A., op. cit., p. 179.

[27] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, p. 41, 1911.

is on the southwest side of Chignik Lagoon, where the exposures of the beds are fairly good. The formation consists of both stream-deposited and marine materials. The largest boulders are 2 feet in diameter, but most of the pebbles are smaller than 3 inches. Some of the gravel has clearly come from the same sources as the conglomerate that occurs in the Naknek formation, for some conglomerate members in the Chignik and the overlying Eocene are lithologically indistinguishable from those in the Naknek. Their peculiar lithologic character and the absence of conglomerate pebbles of distinctive Naknek materials suggest, however, that some of the gravel came directly from the original source rather than from eroded Naknek strata. Other gravel deposits are reddish brown or dark chocolate-brown, consist of quartz, granite, chert, and sandstone pebbles, and are cemented by red-brown to brownish-black sand and sandy clay. Their origin has been distinctly different from that of the greenish gravel which is characteristic of the Naknek. Some sandstone pebbles and much of the matrix probably came from the Naknek, but the crystalline material came from an unknown source.

Most of the coarse sand is brown or chocolate-brown. As a rule it contains much quartz and feldspar and angular grains of green chert, magnetite, and hornblende. All these minerals are common in the coarser Naknek beds. Probably much of the brown sand is weathered and reworked Naknek material. Finer sand, silt, and clay in the Chignik are characteristically light to dark green or blue-green. Weathering changes these bright-green hues to black or very dark brown. Light-green and gray agglomerate and tuff occur in the lower part of the Chignik formation on Hook Head and near the sand spit in Chignik Bay, but elsewhere volcanic material is not common in this formation. Shale and fine sandstone are the chief components of the higher Chignik beds and are characteristically green or black.

Several coal beds occur in the Chignik formation. The unconformity that separates the Upper Cretaceous beds from the Naknek below is marked in many places by a bed of bony coal as much as 8 inches thick. The best coal bed of the Chignik formation lies about 100 feet higher and is distinctly lenticular, increasing from a thickness of a few inches to as much as 6 feet within 2 miles northeast of the sand spit at the mouth of Chignik Lagoon. Other coal beds appear at different positions, but so far as the scanty exposures indicate all of those that have potential value lie at the horizon noted. A detailed description of the coal is given in the section on mineral resources.

In general the exposures of the Chignik formation are poor, and unless distinctive fossils are found it is difficult to differentiate this

formation from the Naknek and the overlying Eocene. The green conglomerates in all three formations are practically identical in pebbles, matrix, and degree of induration. Gray arkose is abundant in the Naknek and Chignik, and many shales in all three formations are lithologically identical. The distinctive lithologic features of the Naknek formation are the olive-drab or yellow-green color of much of its arkose, the thick, unstratified mudstones, and the abundant Aucellas. On the other hand, the Chignik formation contains some chocolate-brown sandstone and conglomerate at the base, its green conglomerate is small in amount, and most of its sandstone and sandy shale is distinctly green when fresh and weathers to very dark brown or black. The Eocene is distinguished by its great thickness of laminated black shale, rich in plant fossils, and its lack of arkose. In the higher Eocene beds much ash and bentonitic clay occur, and the sediments are laminated clays.

Where the Chignik formation can not be distinguished from the Naknek in hand specimens or by the general appearance of the outcrop, the separation is made on the basis of structural relations or by traverses across the strike or laterally until the characteristic chocolate-brown sand or Chignik plant or marine fossils are found. So difficult is this separation that it is necessary to make a careful study of the two formations over a broad area and map the several outcrops before all the relations become clear.

The Chignik formation consists in general of soft green to black shale and sandstone. Because these rocks are easily eroded, steep cliffs are formed where waves or vigorous streams wash the bottom of a slope, but where no undercutting occurs weathering quickly breaks down the rocks and forms low, gently rolling surfaces. The steep cliffs northeast of Chignik post office and along the southeast side of Chignik Lagoon show the normal characteristics.

Thickness and distribution.—Atwood reports a thickness of more than 780 feet on the east side of Chignik Lagoon near Nigger Head. This section was not studied during the season of 1925 because of lack of water transportation. At no point northwest of the lagoon did the writer find the thickness of this formation to be more than 450 feet. This difference in thickness, however, does not imply erroneous measurements by Atwood, because the Chignik lies on an erosion surface at the top of the Naknek and is probably separated from the overlying Tertiary by another erosion interval. On the south side of Hook Head is exposed the maximum thickness of Chignik found in this study. At this place the upper part of the section has been eroded, and the original thickness was accordingly greater than the 450 feet measured in the field.

The Chignik formation crops out in a nearly continuous band from Chignik Lagoon northeastward to the head of the sand spit in Chignik Bay and thence to Hook Creek. On the north side of the mountain range the Chignik is not well exposed but was found at several points, as indicated on the geologic map, as far west as the Black Lake and Chignik Lagoon depression. Southwest of that lowland the formation was not recognized, and Tertiary strata lie on the Naknek. These two zones of Chignik outcrop represent the sides of a very gently plunging anticline whose axis pitches below the crest of the mountain range east of Hook Creek. Northeast of Black Creek the Chignik formation was not recognized. On the north side of Meshik River Tertiary beds lie directly on top of the Naknek, and there is no evidence of deposition during Upper Cretaceous time.

Paleontologic character.—The type section of the Chignik formation is in the Aniakchak district, and many collections of fossils were made in earlier years from outcrops there. These fossils have already been described in detail in other reports, which have been recently summarized by Martin,[28] so that the descriptions need not be repeated here. In the course of the present field work a number of additional collections of fossils were made, and as their identification has not heretofore been published they are given in full. All these recent collections were examined by T. W. Stanton, who identified the fossils as follows:

13484. Northwest side of Chignik Bay, 3 miles due north of end of sand spit, at base of Chignik formation:

Anomia sp.
Inoceramus undulatoplicatus Roemer. This is the I. digitatus Sowerby of earlier reports, now regarded as distinct from Roemer's species.
Meretrix? sp.
Upper Cretaceous, Chignik formation.

13470. Same locality as 13484, 20 feet higher stratigraphically and 100 feet below coal bed:

Inoceramus undulatoplicatus Roemer.
Upper Cretaceous, Chignik formation.

13472. Same locality as 13484, 25 feet below coal bed:

Inoceramus undulatoplicatus Roemer.
Upper Cretaceous, Chignik formation.

13467, 13478. 500 feet east of 13472, 15 feet above coal bed:

Anomia sp.
Inoceramus undulatoplicatus Roemer.
Upper Cretaceous, Chignik formation.

[28] Martin, G. C., The Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, pp. 295–308, 1926.

13466, 13480, 13482. Northwest shore of Chignik Bay, 3.25 miles north of end of sand spit, 1,400 feet northeast of 13484, 65 feet above coal bed:

Inoceramus undulatoplicatus Roemer.
Inoceramus sp., fragment of nearly smooth, large compressed form.
Pachydiscus? sp., fragment of large ammonite.
Anomia sp.
Glycimeris veatchi Gabb.
Upper Cretaceous, Chignik formation.

13468, 13473. Northwest shore of Chignik Bay, 300 feet northeast of 13466, 1,700 feet northeast of 13484, and 100 feet above Chignik coal:

Inoceramus undulatoplicatus Roemer.
Pachydiscus sp.
Upper Cretaceous, Chignik formation.

13474, 13477. Northwest shore of Chignik Lagoon, 3,660 feet southwest of native village, 1.2 miles northwest of end of sand spit:

Inoceramus undulatoplicatus Roemer.
Anomia sp.
Inoceramus sp. related to I. vancouverensis Shumard.
Upper Cretaceous, Chignik formation.

13483. Northwest shore of Chignik Lagoon, 590 feet southwest of 13474:

Pachydiscus sp. related to P. newberryanus (Meek).
Upper Cretaceous, Chignik formation.

13481. Northwest side of Chignik Lagoon, about 4 miles southwest of native village, at Chignik-Naknek contact:

Anomia sp.
Inoceramus undulatoplicatus Roemer.
Protocardia sp.
Meretrix? sp.
Fusus kingi Gabb?
Cinulia sp.
Pachydiscus sp.
This is a characteristic Upper Cretaceous Chignik assemblage.

The only plant fossil collected from the Chignik formation during this study was a piece of wood which was associated with marine fossils in a sandstone on the northwest shore of Chignik Lagoon, 3,660 feet southwest of the native village. F. H. Knowlton stated that the wood is part of a conifer but that it can not be more definitely identified.

In addition to this meager plant material many excellent collections of plants have been procured from the Aniakchak area by Dall,[29] Stanton and Martin,[30] and Atwood.[31] On the basis of the invertebrate collections, the Chignik formation is correlated with the Chico formation of the Upper Cretaceous, which is typically developed in

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[29] Lesquereux, Leo, Contributions to the Miocene flora of Alaska: U. S. Nat. Mus. Proc., vol. 5, pp. 443–449, 1883. Dall, W. H., Report on coal and lignite of Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 844–845, 1896.

[30] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Geol. Soc. America Bull., vol. 16, p. 408, 1905.

[31] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, pp. 44–46, 1911.

northern California. The fauna is too scanty or too nearly unique to permit a more precise correlation.

Relations to adjacent formations.—A well-marked erosional unconformity with a relief of about 20 feet in a distance of 300 feet separates the Chignik formation from the underlying Naknek. In places the unconformity is marked by coarse gravel which is poorly sorted and only slightly worn, but in most sections the basal material of the Chignik formation is sand or clay. Much organic material is present in this basal zone, and in several places on the north shore of Chignik Lagoon a few inches of bony coal or very carbonaceous shale is present. The beds immediately above the unconformity in many places show stream ripple marks, stream cross-bedding, and mud cracks, indicating that they were laid down under terrestrial conditions. The upper portion of the Chignik formation is marine and indicates submergence of the region during Upper Cretaceous time. The coal is entirely confined to the lower 150 feet and is invariably associated with continental sediments. Atwood[32] reported that the Chignik grades imperceptibly into the overlying Tertiary beds. In the course of a brief examination of the west side of Anchorage Bay by the writer no evidence of an unconformity was found, but the exposures along Anchorage Bay are not good, and the boundary between the Chignik and Eocene beds could not be precisely determined. Accordingly an unconformity may possibly occur in that region. In the region north of Chignik Lagoon and east of the mountains the Tertiary is not known to be exposed in contact with the Chignik formation. At the localities on Hook Creek the Tertiary is thrust over the Chignik formation by faulting, and the stratigraphic relations are not directly determinable. On the north side of the mountains, both southwest of Black Lake and in the vicinity of Aniakchak Volcano, Tertiary beds lie directly upon the Naknek formation. Evidence could not be obtained in the exposures visited to prove whether these relations indicate an unconformity with resulting erosion in post-Chignik, pre-Eocene time, or whether the marine Chignik beds feather out toward the north and the Eocene strata overlap on the Naknek formation. The thickness of the Chignik formation south of the mountains and the marine character of the fine-grained higher beds strongly suggest that the formation must have originally continued considerably farther north. The writer believes that there was much erosion in post-Chignik time before the deposition of the Eocene sediments. The resulting unconformity would best account for the absence of the Chignik from much of the northwestern area.

[32] Atwood, W. W., op. cit., p. 58.

CENOZOIC ROCKS

TERTIARY SYSTEM

EOCENE SERIES

Lithologic character.—Above the Upper Cretaceous in the Aniakchak district lies a series of black fissile shale, fine to coarse sand, and a few beds of gray-green conglomerate, comprising a well-bedded series of chiefly fine-grained stream or lake deposits, apparently, for marine fossils have not been identified in them. Stratification and sorting are excellent, in general, but the green-gray gravel with characteristic stream cross-bedding indicates the presence of strong currents at times. In many places the gravel is uniformly bedded and well sorted, suggesting deposition in standing water. Nowhere, however, was positive evidence of its origin found. The formation is in a general way correlated with the Kenai formation of Kenai Peninsula. It grades upward into a series of unstratified bentonitic clay and volcanic sediments. The volcanic material is sharply distinguished from the normal beds of the lower part of the formation, but the gradation through the bentonitic layers is gradual, and the boundary drawn between the Eocene and the later volcanic rocks is not sharply defined. From bottom to top through this transition zone black shale is interbedded with the volcanic rocks in decreasing amount, and the percentage of clay as opposed to shale increases. This series of intermediate sediments ranges from 2,000 to 5,000 feet in thickness. Above these transition beds the rocks are entirely volcanic. Some well-bedded, waterworn, well-sorted stream-deposited tuff and agglomerate are present, but most of the upper material is rapidly deposited breccia and agglomerate which has had little or no water transportation. In this Eocene formation no lava flows are known, but numerous andesite sills and dikes have been intruded. Contemporaneous volcanic material appears only in the upper part or transition zone.

Most of the Eocene beds are soft and readily eroded, so that where there has been opportunity for considerable erosion they have been carved into wide valleys or broad rolling plains. The conglomerate is as well indurated and nearly as resistant as that of the Naknek. Hogbacks or high bluffs result from the erosion of the conglomerate and the underlying shale. In many places the cemented gravel forms overhanging ledges, with sheer cliff faces, which extend along the sides or crests of hills for a mile or more.

Thickness and section.—At no place was it possible to measure in detail an extensive section of the Eocene beds. The absence of distinct horizon markers and the poor character of the exposures

prevented detailed study in the time available. On the west side of Anchorage Bay there is at least 1,200 feet of black shale with minor amounts of interbedded sand and gravel belonging to this formation. At the head of Blue Violet Creek the apparent thickness of this black shale is fully 2,000 feet, where it crosses the axis of the anticline forming the Aleutian Range. At this place thickening of the incompetent beds on the anticlinal axis and some thrust faulting have probably increased the section 15 to 30 per cent. Northwest of Sleepy Creek 950 feet of this shale was measured, but erosion had removed the upper part of the beds in this place, and accordingly it seems certain that the original thickness of the lower part of the Eocene beds was more than 1,000 feet. Probably the true thickness was between 1,200 and 1,500 feet, but the evidence is too indefinite to justify a more positive statement. The higher partly consolidated, well-bedded clay and sand reach a maximum thickness of about 5,000 feet west of Plenty Bear Creek.

The Eocene beds crop out on each flank of the mountains outside of the area occupied by the Chignik formation. They are present in the region southeast of Chignik Lagoon, on Hook Head southwest of Hook Bay, on the headquarters of Blue Violet Creek, and in the valley of Black Creek, where the formation swings across the crest of the anticline. The black shale crops out intermittently from Bluff Creek southwestward beyond the limits of the present study. Minor outliers were found resting on the Naknek formation in the valleys of Waterfall, Plenty Bear, and Rainbow Creeks on the south slope of Aniakchak Volcano, and similar material has also been reported by W. R. Smith east of Lava Creek on top of Jaw Mountain. The fossils of this formation, so far as collections up to the present time have shown, are confined to plant remains. In the black shale leaves and stems are beautifully preserved in great abundance. A number of fossil collections have been made in the past from rocks in this district assigned to the Eocene. These collections have been described in detail in Atwood's report,[33] so that repetition here is not necessary. In the course of the present field studies additional collections were made by the writer, and as their identifications have not been published elsewhere they are given in full here. These recent collections were all identified by F. H. Knowlton as follows:

7819–7828. Shore of Anchorage Bay, a quarter of a mile south of Chignik post office, in bluff:

Sequoia langsdorfii (Brongniart) Heer.
Glyptostrobus europaeus (Brongniart) Heer.
Taxodium distichum miocenum (Heer).
Populus arctica Heer.
Morus or Celtis sp., probably new.

[33] Atwood, W. W., U. S. Geol. Survey Bull. 467, p. 54, 1911.

Carpites sp.
Large dicotyledon without margin.
Age, Kenai.

7830. North side of mountain, north of Bluff Creek, about 21 miles due north of Chignik post office:

Sequoia langsdorfii (Brongniart) Heer.
Glyptostrobus europaeus (Brongniart) Heer.
Taxodium tinajorum Heer.
Populus arctica Heer.
Tilia alaskana? Heer, without margin.
Carpites sp.
Fragments of dicotyledons.
Age, Kenai.

7816, 7817. 2 miles east of Black Pass, about 6 miles north and 1 mile east from extreme west point of Hook Bay, 600 feet above stream:

Sequoia langsdorfii (Brongniart) Heer.
Taxodium distichum miocenum Heer.
Populus arctica Heer.
Juglans nigella Heer.
Age, Kenai.

7818. North slope of Big Butte, a large intrusive mass in fork of Landlocked and Braided Creeks, about 20 miles N. 20° W. from Chignik post office, in bentonitic clay of the transition zone between the black Eocene shale and the overlying volcanic rocks of the Meshik formation.

Fragments of coniferous wood, not determinable.

7814. North of Lost Horse Creek, on the south flank of Aniakchak Volcano, in the same general transition zone as 7818:

Fragments of what appear to be Taxodium distichum miocenum Heer and dicotyledons. Age, presumably Kenai.

7812. 16 miles N. 13° E. from Chignik post office, on mountain side above Flat Creek, in volcanic ash or tuff:

Minute fragments of a fern and of dictotyledonous leaves, but nothing determinable.

7813. 25 miles S. 82° W. of Chignik post office, on mountain between Bearskin Gulch and West Fork of Chignik River, in ash and soft clay, possibly of the transition zone:

Fragments, mostly detached coniferous leaves, but nothing determinable.

Collections 7818 and 7814 were made from beds definitely intermediate between the typical black Eocene shale and the overlying Meshik formation, and collections 7812 and 7813 came from volcanic ash which definitely overlies the Eocene black shale but whose relations to the Meshik are unknown. The last two collections may be from later Tertiary rocks, or even from Pleistocene volcanic materials.

Correlation.—From their plant content, Knowlton [34] correlated these beds with the Eocene Kenai formation of Kenai Peninsula. The same correlation was made earlier by Dall on both paleontologic and lithologic evidence. Only plant fossils have been found in this formation in the Aniakchak district, but Palache obtained a

[34] Atwood, W. W., op. cit., p. 54.

large Eocene fauna at Stepovak Bay, 80 miles southwest of this area. These fossils were described by Dall [35] and are the only marine forms so far collected from the Alaskan Eocene. Kenai plant fossils were interbedded with the invertebrates, making the correlation doubly certain.

An unconformity probably separates the Eocene strata and the Chignik formation. No break in the sequence of beds was noted on the slopes of Chignik Head, east of Anchorage Bay, but exposures are poor, and the unconformity could easily be concealed by moss and soil. Eocene beds lie on the Naknek formation east of Bearskin Creek and on the south slope of Aniakchak Volcano. This proves either pre-Eocene erosion and removal of the Chignik formation or else overlap of the Tertiary beds. Overlap seems improbable because of the fine grain and marine character of the upper Chignik within a distance of 10 miles to the southeast.

The upper limit of the Eocene is not well defined, for the formation is overlain by deeply weathered, bentonitic volcanic ash and soil, which are stratified in the lower part and not clearly separable from the better-indurated underlying Eocene. The fine-grained volcanic rocks grade upward into the coarser, poorly sorted red and gray agglomerates of the Meshik formation. Fragmentary plant remains in these weathered ash and soil beds have not been identified, and the uppermost of the strata here correlated with the Kenai formation may be later than Eocene.

MESHIK FORMATION (OLIGOCENE OR MIOCENE)

Lithologic character.—The name Meshik formation is here used for a series of sediments which are primarily of volcanic origin and which are typically developed along the sides of the valley of Meshik River and Meshik Lake. The formation consists of interbedded clay, fine sand, volcanic ash, and coarse agglomerate. In general the formation is fine grained in the lower part but becomes much coarser above until it consists entirely of coarse volcanic material and includes numerous lava flows. The clay is characteristically black, brown, or yellow, contains much ash, and is rarely well laminated. In general the clay is thoroughly weathered, and much of it is bentonitic in composition. Soil layers are intercalated between the clays without appreciable unconformity. Much volcanic ash is present in the lower beds. Where pure it forms conspicuous gray or white bands among the clay beds, and this ash is probably the source of the bentonite that occurs throughout the fine-grained portion of the formation. Because of the bentonite content many of these clays swell greatly on wetting and shrink equally on drying, producing deep cracks in the surface. In some places the clay ap-

[35] Dall, W. H., Alaska, vol. 4, pp. 99–111, Harriman Alaska Expedition, 1904.

pears to have been deposited by streams, but there are many structureless beds from 2 to 10 feet in thickness, which probably represent deeply weathered volcanic ash with a considerable mixture of organic matter. In other words, much of this fine-grained material is a series of volcanic-ash soils which have developed in a region that was being repeatedly covered with fine deposits from distant volcanoes. Sand and gravel of andesitic composition fill contemporaneous channels or spread out into thick beds. These gravel deposits reach 25 feet in thickness, and the boulders in them may be as much as 2 feet in diameter, although as a rule they are less than 3 inches. The gravel is probably stream-washed material carried into the area from the volcanoes that were also producing the ash of the fine-grained sediments. Bedding in the gravel is confused and indicates that the stream courses changed repeatedly, but the evidence points to a source of the gravel on the east or southeast. Probably some of the material came from volcanoes northwest of Sitkum Bay and west of Hook Bay. Some may have come from volcanic sources near the mouth of Aniakchak River. In time the volcanoes were either built higher so that their agglomerate was washed farther outward, nearer sources of the agglomerate developed, or relative elevation of the source increased the gradient of the streams so that the amount of coarse material became much greater. The upper portion of the Meshik formation consists very largely of agglomerate with a few lava flows. In the field the Meshik was divided into a lower fine-grained portion and an upper agglomeratic portion, and the upper portion was further separated into a lower purple-red and an upper gray agglomerate. The three divisions are not everywhere distinct, and until further studies can be made it has seemed best to map them as one formation. The lower beds of agglomerate are red or purple, but the higher beds are generally gray or pinkish gray. The change in color suggests that the earlier beds were much more thoroughly oxidized than the later ones. This difference in oxidation may have resulted from the deposition of the later material under the ocean, where air was excluded, or the rate of accumulation may have greatly increased so that the later beds were less oxidized. There is no evidence, however, that any of the formation was deposited in standing water, and it seems probable that difference in the rate of accumulation accounts for the difference in color. So far as studies have been made, there is no essential difference in the character of the andesitic and dacitic lavas that furnished most of the pebbles throughout the formation.

Topographic expression.—The Meshik beds are folded into a simple shallow syncline, in which Meshik River flows. The formation crops out both north and south of the river. It can also be traced south-

westward and along the north side of the mountains to the West Fork of Chignik River, where it is overlapped by ash and breccia from Mount Veniaminof. Throughout the outcrop area the beds dip toward Meshik Valley, and accordingly on a horizontal surface the older, finer beds are exposed near the mountains, and the younger, coarser, more resistant agglomerates crop out nearer the main valley. Through much of the area subsequent valleys have developed on the fine-grained beds, and the coarser sediments form distinct hogbacks, lying at the margin of the alluvial plain of Meshik River and of Bering Sea. In some places these hogbacks rise only 50 to 100 feet above the Recent alluvium. Elsewhere the agglomerate extends well up on mountain spurs, as, for instance, at the mouths of Bluff, Braided, and Landlocked Creeks. In each place the agglomerate forms the resistant rock through which the stream has cut a distinct canyon, whereas the finer beds nearer the mountains have permitted the development of broad parks or basins with more or less mature topography.

The thickness of these beds is not definitely known. At the mouth of Shoe Creek measurements indicate a thickness of about 1,800 feet; at the mouth of Bluff Creek the section is about 2,200 feet thick. Definite beds can not be traced from one exposure to another, and it is probable that none of the agglomerates were ever continuous throughout the area. In the eastern portion of the Aniakchak district the thickness of the agglomerates is fully 3,000 feet, and Smith and Baker's observations indicate that the thickness is still greater farther northeast. It seems, accordingly, that the Meshik formation has a minimum thickness of approximately 2,000 feet and that it may well reach 3,500 or 4,000 feet near the mouth of Aniakchak River.

Paleontologic character.—The clays of the Meshik carry numerous fragments of plants, both silicified and carbonized, but almost all the remains consist solely of parts of stems or bits of leaves, so that identification is extremely difficult. In the course of the present study no fossils were collected from the agglomerates. Poorly preserved material from the transition zone (lots 7812, 7813, 7814, and 7818) has been noted with the Eocene collections reported on page 197. Silicified stumps and tree trunks, some of which are 15 inches in diameter, are found at many places in the ash beds.

This formation rests upon the Eocene in all places where its base is exposed. There is no evidence of distinct erosion preceding the formation of the Meshik, and in all probability its fine-grained continental deposits can not be sharply distinguished from the similar beds in the upper part of the Eocene formation. Over much of the area the Meshik is apparently the last widespread consolidated formation that has been deposited, but it is overlain in the several valleys and along its northern margin by the Recent alluvium of

the numerous streams and of the Bering Sea coastal plain. The Recent volcanic products of Aniakchak Volcano, Purple Crater, and Mount Veniaminof also unconformably overlie the Meshik in many places. These younger deposits are distinctly different in color, mineralogic composition, and mode of deposition from the underlying Meshik, and the separation of the two formations is normally obvious.

In the absence of fossil evidence the age of the Meshik formation can not be definitely determined. The thickness of the weathered ash and soil which overlie the Eocene beds suggests that the Meshik is considerably younger than Eocene. Before the Pleistocene epoch the formation had been folded and severely eroded, for it was not only deeply scoured by glaciation, but ash and breccia from Aniakchak Volcano, Purple Crater, and Mount Veniaminof rest on tilted and much eroded Meshik beds. The younger volcanic rocks are partly Pleistocene or earlier, for moraines on their lower slopes were notched and beveled by wave action before the last uplift of the peninsula. In the Aniakchak district the available evidence proves a post-Eocene pre-Pleistocene age for the Meshik and indicates that the most probable date for the formation is Oligocene or early Miocene.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT GLACIAL DEPOSITS

No regional ice cap covered this area in Pleistocene time, but a series of valley glaciers pushed down the existing stream valleys and spread out on the plains bordering the Pacific Ocean and Bering Sea. The glacial deposits recognized are all till. Undoubtedly gravel valley trains and outwash plains were formed, but they have been largely removed or masked by later erosion. Till accumulated chiefly in terminal and recessional moraines of the valley and piedmont glaciers and in ground moraines on the coastal plains. East of the mountains the till is limited chiefly to rolling, irregular knob and kettle areas on the uplands between the main streams. Minor lateral moraines were noted in the lower portions of Thompson Valley and other parallel valleys. The creek that enters the head of Hook Bay contains several lateral moraines, and two well-preserved recessional moraines loop across the valley just below its junction with the tributary creek followed by the trail from the west. A small crescentic lake lies between parts of the two moraines, and a considerable alluvial flat has been formed upstream by the ponding of the drainage.

North and west of the mountains glacial drift is more abundant and conspicuous. Great glaciers flowing down the soft cinder-built

slopes of Aniakchak Volcano in the past piled moraines 20 to 60 feet above the present level of the alluvium in Plenty Bear, Wind, and Barabara Valleys. On the northwestern slope there are features which suggest that formerly glaciers advanced 5 miles beyond the base of the mountain. A series of knobs which are interpreted as possibly representing a medial moraine with numerous remnants of recessional deposits extends nearly to Bering Sea and provides the only semidry route across the coastal plain near Aniakchak Volcano. Farther north a similar series of low hills was seen, extending to the seacoast at a point roughly estimated to be 20 miles north of Meshik Village. Possibly these hills are also of glacial origin. Subsequent wave erosion has beveled some of them and has cut distinct notches in the seaward sides of others. Other glacial deposits probably exist on the flanks of the volcano, but they are difficult to distinguish from the slightly consolidated volcanic breccia. In the valley immediately south of The Gates, through which Aniakchak River leaves the crater, a well-developed terminal moraine occurs at an altitude of 1,800 feet, and a medial moraine, 150 to 300 feet high, extends back up the valley for about a mile. The former glaciers in this valley were of considerable size, but because much of the material of the crater is entirely unconsolidated, even a little plucking and erosion were capable of supplying great quantities of débris to the ice. The head of Birthday Creek is a beautifully scoured U-shaped valley, which is beheaded at the crater wall. In the head of this valley about a quarter of a mile from the rim of the crater is a recessional moraine about 70 feet high which is not covered by later ash. Originally the crest of Aniakchak Volcano must have been much higher than now, for the present interior walls were exposed only after the crater was filled with lava. A glacier may have descended from this higher peak and formed the moraine. If so, the present crater was formed by the collapse of the old cone, for an explosion would have completely buried the moraine under ash and breccia. It is possible, however, that the valley was scoured and the moraine was built by a glacier that partly drained the great ice field which may have occupied the crater recently. Such an ice field now fills Mount Veniaminof and overflows through three gaps, producing conditions that are essentially similar to those that may have existed on Aniakchak Volcano in the past. The original source and distribution of the ice on Aniakchak Volcano present complex problems whose solution will doubtless throw much interesting and valuable light on the history of the region in the recent past.

Undoubtedly glacial deposits of Pleistocene and Recent age underlie much of the Bering Sea plain and Meshik Valley, but Recent alluvium covers most of the drift in that region, so that it can not

be critically studied in surface exposures. Between Landlocked and Braided Creeks a long medial moraine extends 2½ miles from the mountains and stands 10 to 35 feet above the adjacent alluvium. There are smaller moraines at the mouths of Sleepy, Blue Violet, and Shoe Valleys.

The north side of the Black Lake Basin is interpreted as a terminal or recessional moraine of a glacier that once filled the valley of the West Fork of Chignik River and pushed northward beyond Black Lake, building a moraine in places approximately 50 feet high, in a nearly flat plain. According to this interpretation Alec River and possibly the West Fork of Chignik River originally flowed northwestward to Bering Sea. These streams being ponded by the moraine, a lake resulted, and through a complex series of events it later overflowed southeastward to Chignik Lake and eventually to the Pacific Ocean.

The most extensive recent glacial deposits in the Aniakchak district are those still being formed on the northwest side of Mount Veniaminof, and of these probably the largest are those being made by Fog Glacier. Here the ice is retreating and its moraines are spread out more than 2 miles beyond the present glacier terminus. An extremely hummocky knob and kettle topography marks the latest deposits. Slope wash, however, rather quickly reduces the relief and fills many of the depressions of these moraines. Because of its lobate character and recent retreat the deposit exhibits excellent examples of terminal, ground, and medial moraines, which are unusually well exposed, as practically no vegetation grows at so high an altitude.

RECENT DEPOSITS

In addition to glacial drift Recent deposits of five other types are prominent in this area. In relative order of abundance they are volcanic materials, marine alluvium, stream alluvium, beach deposits, and sand dunes.

Volcanic materials.—Since the deposition of the Meshik formation three great volcanic centers have been active north of the mountain range. In order of size they are Mount Veniaminof, Aniakchak Volcano, and Purple Crater. Each consists of a main volcanic vent, which has built a great cone, and several auxiliary vents, from which minor amounts of ash, pumice, breccia, and lava have come.

Mount Veniaminof, which apparently had never been examined in any detail heretofore, is one of the largest volcanoes in the world. It rises about 8,400 feet above the Bering Sea coastal plain, the great cone at its base has a radius of over 20 miles, and its crater is roughly 6 miles in diameter. The southern and western sides have

not yet been explored. Black and dark-brown pumice and scoria constitute the bulk of the cone, with roughly one-half as much basaltic and andesitic lava interbedded in flows. Breccia, consisting of dense lava fragments, is subordinate to the more porous pumice. Ash probably forms a considerable part of the cone, but as it is rapidly blown away by winds little ash is exposed at the surface. East of Fracture Creek a series of satellitic cones and associated flows extend northwestward along a radial line from the crater. A few similar scattered vents also occur at places on the other flanks of the volcano. Probably Mount Veniaminof is the volcano whose eruption is reported to have darkened the southwestern Alaska skies in 1892.

Aniakchak Volcano has already been briefly described by W. R. Smith,[36] who, together with R. H. Sargent, discovered it in 1922. It rises 4,200 feet above the adjacent lowland, has a crater 5 to 6 miles in diameter, and is about 30 miles in diameter at the base. On the northern and western flanks it consists almost entirely of black and brown pumice, scoria, and ash. The southeastern wall of the crater consists of Naknek and Eocene beds, with approximately 1,200 feet of volcanic materials piled on top. Several lava flows crop out on the southeast side, but none are known on the north and west. Seven vents on the crater floor are marked by cinder cones or necks. The largest cone rises 2,200 feet above the crater floor and has been active recently, as shown by the great quantity of black obsidian fragments and black pumice from it which are scattered over all the area as far south as Hook Head.

Purple Crater is much smaller than either of the other two, being only 1.8 miles in diameter, and has a much less distinct conical form. The crater is now more than half filled by a plug of lava which has been thrust upward and rises several hundred feet above the surrounding crater walls. Several adjacent plugs, necks, and partly dissected cones indicate that Purple Crater is only the last of a long series of post-Meshik volcanoes that have existed near this site. Volcanic deposits do not extend far from these centers at the surface, but probably much of the alluvium of the coastal plain adjacent to Bering Sea has come directly from these sources.

Marine alluvium.—Of great volume and covering a still larger area than the volcanic materials is the marine alluvium that was deposited in Bering Sea when its relative level to the land was higher than at present. Along the northwest flank of Aniakchak Volcano and on the north side of the mountain range south of Meshik River well-marked wave-cut terraces are recognizable 75 to 325 feet above the present sea level. At the time of the cutting of these

[36] Smith, W. R., Aniakchak Crater, Alaska Peninsula: U. S. Geol. Survey Prof. Paper 132, pp. 139–149, 1925.

terraces much material must have been deposited directly by streams flowing into the ocean, by wave distribution of materials cut from the land, and by volcanic activity. The alluvium of the Bering Sea plain has little slope and has not been much dissected by erosion. The rank vegetation that grows on the surface interferes with drainage, and over much of the area so much water is present that the surface is an impassable morass. Lakes are scattered through this area, and quaking bogs cover much of it. Deposition exceeds erosion at present on this plain. The deposits result not only from volcanic activity but are augmented by the accumulations of plant material from the rank growth of grasses and other plants. Streams flowing from the mountains also carry much material which is dropped in the course of their meandering across the plain. It was of course impossible to determine by direct observation what is the character of the movement of the coastal plain at the present time. The indentation of the shore line at Port Heiden and at the mouths of some of the other streams both north and south of that bay suggests that there has been some recent depression of the coast.

Stream alluvium.—Practically every large stream in this region has partly filled its valley with alluvium. There are few falls and rapids, but meanders uncover bedrock on the valley sides in many places. Terraces are rare, partly because most of the material is weak and does not preserve these features well and partly because accumulation rather than removal of the alluvium seems to be dominant. Exceptions to this condition are found where moraine or rock dams have temporarily delayed the down-cutting stream. Although deposition of alluvium is a normal process in the development of a river, this process has been greatly facilitated in the Aniakchak area by the overdeepening of the valleys by the ancient glaciers. Detritus brought in by soil creep and swift tributaries overloads the main streams, which meander or form a braided network of channels over their flood plains. In the longer valleys these alluvial deposits range in width from a few feet in the smaller valleys to a mile or more. Gravel and sand predominate, but much clay is also dropped in the quiet waters of the flood plains.

Northwest of the mountain range and around Aniakchak Volcano streams on emerging from their rock-walled valleys divide into many distributaries and build great marshy alluvial fans that merge insensibly with the marine alluvium. Because of the difficulties of distinguishing between the two types of alluvium and because of the poor exposures, the two types were not separated in field study nor on the map. In the valleys the alluvium may reach 150 feet in depth but probably in most places does not exceed 25 feet. In the alluvial fans it may amount to several hundred feet.

Beach deposits.—On the Pacific Ocean coast the unconsolidated deposits of the promontories are being rapidly eroded by the vigorous attack of storm waves and currents. The sand and gravel thus produced are deposited in near-by coves and bays, so that broad sandy beaches are found in all sheltered places. Sand spits are common. A long sand spit nearly shuts off Chignik Lagoon from Chignik Bay, so that at low tide the cannery tenders can not cross the bay into the lagoon. Across Mud Bay two similar spits have formed complete bars, which are exposed at low water. Prominent curved spits are growing in Hook and Anchorage Bays. The great range of tides produces sand and gravel deposits at least 15 feet thick. Coming from shale and shaly sandstone, the gravel and sand are neither sharp nor strong. Black sand, consisting chiefly of magnetite, forms thin layers at many places along Chignik Bay. No gold, however, could be obtained by panning.

The Bering Sea plain slopes gently seaward, and the water is shallow for a long distance offshore. On this gently shelving surface waves have built a beach of fine sand 50 to 300 feet wide. Near Meshik village, Port Heiden, the only coarse material on the beach is pumice, the largest pieces of which are an inch in diameter. The sand is black but contains little magnetite. Black slate and shale grains are most common, and black pumice and obsidian fragments are also numerous.

In addition to the beaches, offshore bars and reefs extend intermittently along the coast. In places these stand at distances as great as 2 miles from the shore. Some of them are exposed only at low tide, but a few are above high-water mark. Strogonof Point and the islands that prolong this barrier across the mouth of Port Heiden are partly of similar origin but have been tied to the mainland at the southwest side of the harbor.

Sand dunes.—In spite of the great precipitation in the region, sand dunes have been formed under two distinct conditions. Along the Bering Sea coast on-shore winds blow sand from the wide beaches and form dunes 20 to 60 feet high in a narrow strip along the shore. The dunes make only a single line, because before they can advance far inland they become fixed through the growth of the rank beach grass. These dunes appear to extend along the entire shore, in interrupted series.

Dunes have also been formed on the slopes of the volcanoes where the high altitude or the dryness of the porous ash retard the growth of vegetation. These dunes are seldom 25 feet high and are normally irregular in outline. Many of these dunes take on a U-shaped outline. Perhaps a hundred such dunes are moving northward on the north slope of Aniakchak Volcano, and a few moving in the same direction were seen northwest of Purple Crater. The sand consists

of volcanic breccia and pumice. Pieces of the light pumice an inch in diameter are commonly included in the dunes.

STRUCTURE

In general, the major structural feature of the region is the great anticline of the Aleutian Range extending along the peninsula in a northeasterly direction, with the axis lying much closer to the Pacific Ocean than to Bering Sea. Meshik Valley constitutes a diverging syncline on the north side. Hook Head and the area southeast of Chignik Lagoon are independent of this general structure. Similarly on the northwest, the Bering Sea coastal plain and the three great volcanoes lie outside the regional anticline. The anticline was folded under a moderate cover, and the folds are accordingly of the type that develop within the zone of fracture. The rocks are much jointed, and faults are numerous in the area. The largest faults are thrusts in which the northwestern block has sheared along a general northeasterly line, moving northeastward a considerable distance and overriding the southeastern block to a slight or moderate extent. In other words, the movement has not been purely compressional, or perpendicular to the strike of the fault, but the peninsula has been subjected to shearing forces which tended to move the northwest side northeastward, and the thrusting and overriding have been incidental to a much more extensive horizontal movement. The result of thrust faulting is well exhibited at the head of Hook Creek, where the Naknek beds have ridden up over and crumpled the Chignik coal. A similar thrust fault can be followed northeastward beyond Blue Violet Creek to Black Creek but is lost under the Meshik deposits. Dislocation of the Meshik was not recognized. Exposures of these rocks at that place are good, and accordingly there is little doubt that the faulting took place before the Meshik formation was laid down. A parallel thrust fault occurs on the northern flank of the mountains. It is a strike fault and has produced slipping nearly parallel to the Chignik-Eocene contact. As a result the Chignik coal is greatly deformed, is faulted out in some places, and is sheared and broken severely at other points. Here, as in the other localities, the northwestern block has ridden up over the southeastern or downthrown block.

In connection with this shearing, it is only natural that many tension faults should have developed. Because of lack of time and of good horizon markers only a few faults were surveyed in the field in sufficient detail to be plotted accurately on the accompanying geologic map. Many more were inferred from sharp changes in the attitude of the beds, with no apparent folding, but these inferred

faults are not indicated on the map. The most pronounced system of tension faults is a general east-west series which intersects the anticlinal axis at an angle of about 45°. One of these faults extends westward, and along or near it lie Purple Crater and 10 auxiliary necks, plugs, or volcanoes. Some of these volcanoes are well preserved; others have been eroded until only a neck or plug remains. It seems probable to the writer that Aniakchak Volcano and Mount Veniaminof lie on similar fractures, for these three volcanoes lie at the end of spurs that extend westward from the main mountain range. Lavas would readily escape along such fractures. The common origin of the ridges and their accompanying volcanoes seems probable.

Numerous other tension faults occur through the Naknek beds, but most of them are short and can not be readily grouped into definite systems. They trend across the mountain range at angles of 50° to 90° with the axis of the range and are believed to have resulted from tensional forces that accompanied the elongation of the region.

A great fault extends along the northwest side of Chignik Lagoon and has brought the Naknek formation in contact with the Tertiary andesites on the southeast side of the fault. The folding of the Chignik beds southeast of the fault bears no relation to the folds in the rocks on the northwest. The fault plane itself was not recognized, but it is apparently concealed under the water and alluvium of the western part of Chignik Lagoon. The structure of the rocks in the northwestern block suggests that the fault is of the thrust variety, for the beds become steeper as they approach the fault. If this is true, this fault is parallel to and probably comparable in origin with the fault at the head of Hook Creek and the bedding-plane fault that has so seriously affected the Chignik formation north of the mountains.

As a result of the general faulting, a considerable amount of shattering of the rocks has occurred. Through the broken rock much water has circulated, producing in the characteristically dark Naknek rocks zones of fault breccia cemented with calcite. So much of this white mineral matter has been introduced that many of these broken zones are noticeable from distances of several miles. In many places in zones 100 feet or more wide the original bedding of the rocks has been entirely destroyed by the shattering and the mineralization that followed.

In general, the structure of the region is determined by the attitude of a series of fault blocks, rather than by the regular folding of the beds. This is a consequence of the slight cover under which the rocks were folded and is to be expected where moderately strong

beds are deformed without an overlying mass to compress the rocks and force them to bend rather than break. As indicated on the geologic map, the anticlinal axis follows approximately the crest of the mountain range but trends a few degrees more to the east of north, so that in the southwestern part of the district the crest of the main range is on the southeast flank of the anticline, and at the northeast the crest is slightly north of the anticlinal axis.

There are no synclines paralleling the anticline. On the north the beds dip 20° to 70° NW. and are flanked by recent volcanic rocks or the alluvium of the Bering Sea coastal plain. On the south side the dip is gentler, ranging from 8° to 20° SE. as a rule, but in places it is very steep or even vertical. The dip decreases somewhat toward the ocean but is not reversed, except on Hook Head and in a fault block southeast of Thompson Valley.

The attitude of the beds in the marine alluvium and stream deposits of the Bering Sea plain is concealed, but presumably they are relatively undeformed, except for settling and possible displacement by intrusions connected with the three big volcanoes. An open syncline pitching north of west is formed by the beds of the Meshik formation in the valley of Meshik River. An unconformity separates these beds from the Naknek, and the structure of the Jurassic beds under the valley is unknown. In view of their steep northwestern dip south of the valley and the nearly horizontal position on the south side of Aniakchak Volcano, a fault is inferred beneath Meshik Valley, displacing the Mesozoic sediments. Its position, character, and amount of displacement can not be estimated. The volcanic cones of Aniakchak, Purple, and Veniaminof consist of outward-dipping beds of ash, cinders, scoria, and breccia and of lava flows, with many small intrusive masses, such as dikes, sills, and plugs. Their structure is normal for volcanoes.

Hook Head shows a series of Eocene and Upper Cretaceous beds, flat lying at the west but dipping 15° to 30° N. on the south side. Above them is a series of volcanic rocks, including much agglomerate and many flows, with minor amounts of intrusive andesite. Two distinct volcanic vents are known, and possibly others will be found by a more thorough exploration of the promontory.

Southeast of Chignik Lagoon the Chignik and Eocene beds and the overlying Meshik volcanic rocks have been separated from the general structure by an inferred fault, which lies beneath the lagoon. So far as they were explored, all the rocks on Nigger Head and on the promontory between Mud Bay and Lake Bay have a general northwesterly strike. An anticlinal axis, striking N. 70° W., can be traced through these promontories to the east side of Anchorage Bay and into the hills a short distance north and east of Chignik post office. Northeast of this axis the beds dip 4° to 9° NE., and

southwest of this axis the dip increases rapidly and ranges from 14° to 25° SW. in the area surveyed.

ECONOMIC GEOLOGY

OIL AND GAS

The essential conditions for the production of oil and gas in any area are (*a*) an adequate source of the hydrocarbons; (*b*) porous reservoir rocks in which these fluids may accumulate; (*c*) structural features that will trap the hydrocarbons; (*d*) an impervious overlying cover to hold the oil in the reservoir rock; and (*e*) an adequate cause of movement of the oil. In this region there is considerable organic material buried in the dark shales of the Naknek and Chignik formations. These beds were in large part deposited in the ocean, and apparently many of the conditions that are believed to be necessary for the production of oil from organic matter are present. In a few places rocks of Naknek and Chignik age have a distinct petroliferous odor when freshly broken. This is especially notable on the northwest side of Chignik Bay at the mouth of Dago Frank Creek and in Chignik sandstone along the shore of Chignik Lagoon. Satisfactory reservoir rocks are present among the sandstones of the Chignik formation but are rare in the Naknek formation. The conglomerate of the Naknek consists of pebbles set in a dense, fine-grained chloritic matrix containing much clay; the sand is exceedingly fine, approximating silt in most places, and contains a large percentage of clay; and the great bulk of the formation is itself clay. The Naknek is thus not well provided with suitable reservoir rocks in most of the area, but in the northeastern part, in the vicinity of Aniakchak Volcano, a considerable quantity of porous arkose occurs, and oil might accumulate in such a rock. There is an abundance of impervious overlying rocks, so that if satisfactory reservoirs are present there is no danger of the oil escaping through the covering rock where it is unbroken. On the other hand, the shattering which the region has suffered has been unfavorable, and the rocks in general may be described as lying in broken arches, rather than warped or folded. Such oil and gas, then, as may have been present in the sandstones have had many opportunities to escape along these zones of shattering, which are naturally most marked on the crest of the anticline, where the load was least and the tension greatest. The numerous broad calcite-veined zones of shattering previously described indicate a great and unfavorable circulation of water across these beds. The rocks which cover the Chignik formation have been so thoroughly removed that if that formation ever carried oil there is no place in the region where it would be likely to be still retained. A cause of movement of oil and gas was present in the character of

the original sediments, which were deposited as fine muds and which, during their compression and consolidation, must have had vast quantities of water squeezed out. The escaping water would tend to carry with it any available oil or gas that were then present and would tend to accumulate them in the porous rocks. At the present time there is, so far as known, no considerable underground circulation of water, and, because of the scarcity of porous rocks and lack of outlets through which the water might circulate, there is probably no extensive deep-seated artesian flow.

North of the Aniakchak district, in the vicinity of Portage and Cold Bays, oil seepages are known in the Shelikof formation of the Upper Jurassic, and probably this formation underlies certain folds northwest of Portage Bay, which were drilled for oil. From analogy with these regions it seems probable that the possible petroliferous formations in the Aniakchak district lie in or below the Shelikof formation. It is not, however, advisable to drill for this formation in the Aniakchak district until oil is much more valuable than at present, because (1) it is not certain that the Shelikof formation underlies the district, as it has not been identified within 55 miles of the district; (2) there is no certainty that even if the Shelikof formation is found in this district it carries a commercial quantity of oil here, although it probably does near Portage Bay; (3) probably the Shelikof formation becomes finer grained and is therefore a less valuable reservoir rock toward the southwest, just as the Naknek is much more impervious; (4) any oil and gas which the Shelikof may once have carried in this area may have escaped during the faulting and deformation of the district, as is indicated by the calcite-veined zones in the Naknek formation, which prove a vigorous circulation of ground water; (5) a thoroughly satisfactory structure for oil accumulation is not known; and (6) the probable depth of the Shelikof below the surface is not known in this area, and it may lie below reasonable drilling depths. The lowest formation exposed is the Naknek, and as definite horizons in the Naknek of this region have not been correlated with those of that formation near Portage Bay the depth to the next underlying formation, which may be the Shelikof, can hardly be even roughly approximated.

If, however, drilling should be undertaken the most favorable locations for test wells appear to be west of Thompson Creek about 3 miles from the coast and in the next two valleys to the west at similar distances from the ocean. The locality on Thompson Creek is on the anticlinal axis in a region of little faulting. No igneous rocks are known within 3 miles. The well would start at least 2,000 feet below the top of the Naknek, though the total thickness of that formation measured in other parts of the district and else-

where may exceed 6,400 feet. Coal can be mined 4 miles distant from this site; water is abundant; transportation for equipment and supplies would be fair in winter but difficult in summer because of marshy ground. The other locations to the west have similar conditions, but the closure of the anticline is less toward the west than on Thompson Creek. There are extensive intrusions on the northern tributary of Flat Creek which probably would have driven away any oil from the anticlinal axis there.

Probably the lowest strata in the region are exposed on the divide between Bluff and Flat Creeks and in the valley north of the divide. At these places, however, these beds have ridden up on a thrust fault, and very detailed studies, probably involving core drilling and necessitating an intimate knowledge of the stratigraphic distance to the sand desired, must precede the location of a well on the axis of the asymmetric anticline. Farther northeast the anticlinal axis pitches, and the depth to a given formation increases accordingly. The fault continues to the agglomerate, and no drilling suggestions can be made without much more field work. None of these locations are recommended as sites for wells, but they are the most favorable areas if a test is to be made.

Martin [37] has discussed the chances of finding oil near Chignik Lake and has also reported unfavorably on the probabilities. This area and all the Mesozoic rocks to the south lie on the southeast side of the prolongation of the anticlinal axis. The lowlands of the Bering Sea coastal plain lie against the Naknek beds, which dip eastward. Although no fault plane was seen, a fault is confidently inferred from the relations of these rocks, and consequently there seems to be no prospect for oil production southwest of Chiaktuak Creek.

COAL

The distribution, character, and economic possibilities of the coal in part of the Aniakchak district were described by Atwood,[38] who gave detailed sections and outlined the developments up to 1908. Atwood's report has long been out of print, and to make the data available G. C. Martin prepared a summary of the information on coal, which was included in Smith and Baker's report on the Cold Bay-Chignik district. This summary is repeated here with slight modifications and with the addition of a description of the recently discovered coal on the north slope of the mountain range.

Competition of California fuel oil and British Columbia coal has caused the abandonment of the small mines in this district. With

[37] Martin, G. C., The outlook for petroleum near Chignik: U. S. Geol. Survey Bull. 773, pp. 209–213, 1925.

[38] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, pp. 104–105, 109–116, 1911.

the exception of some development in 1913 at a mine on Thompson Creek, no coal has been mined in the region since 1912. Bunkers were built on the beach at the mouth of Thompson Creek, a road was constructed to the mine, 2 miles from the shore, and a drift was run 300 feet in the coal. No coal has been shipped from the property.

GEOLOGIC AND AREAL OCCURRENCE

Coal occurs in the Chignik formation, of Upper Cretaceous age, and in the Eocene beds. Only the coal in the Chignik formation is of probable commercial importance. The coal measures are a succession of alternating beds of sandstone, arkose, conglomerate, and shale. This lower, carbonaceous portion of the Chignik is largely of continental origin. The upper part of the Chignik is finer grained, consisting largely of shale, and is entirely of marine origin. In this region the Chignik is evidently unconformable on the underlying Naknek formation (Upper Jurassic). The strata in the two systems are parallel, but a well-marked erosional unconformity separates the formations. Probably the Eocene is unconformable upon the Chignik, but the unconformity was not recognized in the field. The Chignik formation is best exposed along Chignik River and on the shores of Chignik Lagoon.

Coal of possible economic importance underlies at least 5 square miles in the Aniakchak district. Structural conditions indicate that the coal zone lies within 3,500 feet of the surface under about 25 square miles. The lenticular character of the coal and its occurrence among conglomerates and coarse sandstones suggest that workable coal is not present throughout this area of 25 square miles.

Coal from Cretaceous rocks has been mined along Chignik River, on Whalers Creek, on Thompson Creek, and northwest of Hook Bay on Hook Creek. Although the mine on Chignik River is owned by the Alaska Packers' Association, that company at present brings all its fuel from San Francisco.

Thin seams of lignite occur in the Eocene and in the partly indurated clays that lie between the Eocene and the overlying Meshik formation. These lignite seams reach a thickness of 8 inches. They are not known to be extensive, but detailed study may show that some of the beds are persistent. The lignite checks badly and crumbles on exposure to the air. In no place in the district is it regarded as of present economic significance.

COAL BEDS

Chignik River.—The coal bed that has been worked crops out on the river bluff 3 miles above the head of Chignik Lagoon and has been traced inland for a little more than half a mile. At this

locality it strikes N. 2° E. and dips 24° E. A section of the bed measured in the drift is as follows:

Section of Chignik River coal bed

	Ft.	in.
Dry bone, with thin coal streaks		3
Coal		6
Coal and dirt		8
Coal	1	
Bony coal	1	5
Coal	1	4
	5	2

The roof, which is of shale with thin layers of coal overlain by sandstone, is very even. The floor, however, is not so regular, and the roll or swelling in it reduces the thickness of the bed at the end of the drift from 5 feet to 9 inches. It is possible that the roll, which is known to be rather long, may be narrow, and that a short tunnel driven through it would discover the full thickness of the coal bed on the other side.

The coal is solid and bright and comes out in good-sized pieces. When used under a boiler it has to be stoked very frequently to keep it burning freely. It is a fairly satisfactory steaming coal when it is properly handled, but it makes a large amount of ash, and the fires have to be cleaned often. An analysis of this coal is given on page 221.

The Chignik River mine was formerly worked throughout the year by two men without machinery, the coal being undercut by hand and shot down. Coal outcrops appear at several other places on the north bank of Chignik River east of the mine, but the beds do not seem to be of as good grade as that at the mine and have not been worked.

Whalers Creek.—Whalers Creek is a small stream entering Chignik Lagoon from the north a short distance below the mouth of Chignik River. Coal is exposed for 600 feet along the northernmost of the three main branches of the creek, the exposure being along the strike of the coal measures, which crop out at the coal mine on Chignik River. The strike of the coal is N. 5° E., and the dip is 22° E. The section of the coal is as follows:

Section of Whalers Creek coal bed

	Ft.	in.
Shaly sandstone roof.		
1. Coaly shale		10
2. Shale		8
3. Coal	1	
4. Coaly shale		4
5. Sandy shale		7

	Ft.	in.
6. Coal with slate partings	5	
7. Coaly shale		6
8. Sandstone	1	6
9. Coal	1	10
10. Shaly coal		1½
11. Coal	3	4
Sandy shale floor.		

The slope, which has been driven 130 feet on the coal, follows the lower part of the bed and includes the strata numbered 8 to 11 in the above section. The coal bed (Nos. 9 to 11) was sampled in the usual way and analyzed, with the result given on page 221 (laboratory No. 6955).

The coal is bright, black, and blocky, very much like that mined at Chignik River, but at this locality the section of the coal is better in that the partings are thin. A nearly vertical fault, about 500 feet downstream from the mine opening, probably cuts off the coal bed. On the upstream side, about 40 feet from the opening, a vertical fault throws the coal down 6 feet, and 115 feet upstream from the mine another fault, which cuts off the coal, has been reported. Although faults have disturbed the coal somewhat, there appears to be a very considerable body of good coal available. The location of this coal favors shipment on small boats down Chignik Lagoon or by rail. A railway might be built across Chignik River a short distance above the mouth and thence across a lowland area to the head of Kuiukta Bay, where excellent harbor facilities are reported. The distance from Whalers Creek to the head of Kuiukta Bay by the proposed railway route is about 5 miles.

Thompson Valley.—Thompson Valley lies west of the northern part of Chignik Bay and is a broad, open glaciated valley extending deep into the mountain range. A smaller, unnamed cirquelike valley lies to the north and in its lower portion is separated from Thompson Valley by a ridge less than 300 feet high. Coal is exposed on the northeast side of Thompson Valley and on both slopes of the smaller valley at a distance of about 2 miles from the Pacific Ocean. A small prospecting drift has been opened in Thompson Valley, but the main exploration has been made about 400 feet above the valley floor on the northwest side of the smaller valley. A drift has been carried 325 feet in the coal. The character of the coal varies greatly in this distance. The coal zone averages 6 feet in thickness. Partings of shale, fine sand, and even of arkose are present. At one point fine partings having an aggregate thickness of 19 inches were measured. In general, the beds strike N. 60° E. and dip 10° to 18° NW., but minor faults and flexures disturb the continuity and attitude of the bed. The coal could not be recognized west of Thompson

Valley, and farther to the east in the valley of Flat Creek, its normal position is covered by a thrust fault except at the head of that stream. The following section was measured by Atwood[39] and is typical of the coal, though at a distance of 300 feet the section is quite different, because of lateral changes in thickness and character of the members.

Section of coal bed in Thompson Valley

	Ft.	in.
Cross-bedded sandstone roof.		
1. Clay		2
2. Coal		8
3. Coaly shale		4
4. Shale		8
5. Coal shale		4
6. Coal	1	
7. Clay parting		1
8. Coal	2	6
9. Coaly shale		8
10. Coal	4	
11. Bone		8
12. Coal		5
13. Shale		5
14. Bony coal		8

The analysis of a sample taken from beds Nos. 6, 8, and 10 in the foregoing section of the upper coal is given on page 221 (laboratory No. 6956).

A large body of good coal is available at this locality. The conditions for mining are favorable, and the space at the base of the bluff is ample for mine buildings and mine bunkers. The chief difficulty in the way of exploiting this coal is in making arrangements for shipping. The beach at the mouth of Thompson Valley is exposed to the severe storms from the Pacific Ocean. A railway from the valley to Chignik Lagoon could be easily built, for the route would be over a lowland area and not more than 9 miles in length. The conditions in Chignik Lagoon, however, are not favorable for loading large ocean-going vessels. Hence it would probably be necessary to continue the railway along the northwest shore of the lagoon and then by the same route as that from Whalers Creek to the head of Kuiukta Bay, as already described.

Hook Bay.—Hook Bay is in the northern part of the field examined. The coal in this vicinity occurs near the headwaters of the right-hand branch of the stream entering Hook Bay from the west and in the foothills of the main mountain range. The general strike of the beds is N. 11° E., and the dip 34° E. The section of the coal is as follows:

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[39] Atwood, W. W., op. cit., p. 113.

Section of Hook Bay coal bed

		Ft.	in.
	Firm sandstone roof.		
1.	Coal	1	3
2.	Clay		8
3.	Coal		4
4.	Clay		7
5.	Coal	1	6½
6.	Clay parting		2
7.	Bony coal		5
8.	Coal	1	5½
9.	Bone		1
	Shale floor.		

Above this bed is an 8-foot bed of sandstone overlain by a thin layer of coal. Below the main bed of coal lies a 4-foot layer of shaly sandstone, underlain by a 3-foot bed of coal, in the middle of which is a 6-inch parting of shale. The exposures in the tunnel show the coal to be uniform in thickness and quality.

In sampling this bed a cut was made across Nos. 5 to 8, inclusive, in the above section. The analysis is given as laboratory No. 6952.

The strike, so far as the beds could be examined, is uniform and appears to continue without notable break for at least half a mile to the northeast. To the northwest the coal is probably badly shattered by thrust faulting. A drift was run in this coal, starting about 50 feet above the valley floor. This drift has caved and is inaccessible. Space for mine buildings is available on the valley bottom, but some flood-protection work would be necessary. The valley side is a nearly vertical, bare wall. A road was built some years ago from Hook Bay, distant about 8 miles. It has been washed out in many places but could probably be rebuilt and maintained without great expense along most of its course. Marshes and two narrow canyon sections will necessitate considerable expenditures in several places. Hook Bay is an excellent small harbor, well protected from storms, and a deep-water wharf could be constructed at moderate expense. The mine is about 6 miles from the harbor. Four claims were staked in this field and development work was carried on in 1908 and 1909. Since that date no work has been attempted.

Northwest of the mountains.—On the northwestern flank of the mountain range the Chignik coal crops out in several places. A strike thrust fault closely follows the coal bed between Chiaktuak and Boulevard Creeks, and the coal is lost along much of this distance. Farther northeast the Chignik formation is missing. Between Braided and Black Creeks the Chignik reappears with lenticular coal, but the thicknesses vary greatly within short distances. For instance, west of Sleepy Creek the coal thins from 3 feet 2 inches to only 1 inch within a distance of 3,000 feet. Northwest of the

mountains the partings are as numerous as on the south side. Because of the irregular character of the coal and the extreme difficulty of transporting the coal to a protected harbor, the beds are not likely to be of value in the near future.

The most favorable outcrop is located on the northwest side of Fan Creek, about 6 miles in a straight line from the south end of Black Lake. Here the coal lies in a series of soft buff arkosic sandstones that strike N. 25° E. and dip 65° NW. The following section was measured 700 feet above the valley floor:

Section of Chignik coal on Fan Creek

	Ft.	in.
Shale, soft, gray, sandy (roof).		
Coal, bright, black, blocky		5
Bone		4
Coal, bright, black, blocky		11
Slate, gray		1
Coal, black, blocky, rather dirty; checks badly on weathering	2	
Shale, black, and bone	1	2
Coal, black, dirty, of doubtful value	1	10
Sandstone, shaly, gray (floor).		
Total thickness	6	9
Total coal	5	2

This coal is lenticular, pinching out completely about 350 feet to the northeast. On the southwest talus and alluvium conceal it. It could not be recognized on the ridge south of Fan Creek, although the exposures there are fairly good. Probably the lens does not extend to the ridge crest.

Next to the Fan Creek outcrop, the most promising exposure of coal occurs on the ridge west of Sleepy Creek. Because of talus, the coal could be examined only along the crest of the hill. Here the coal is 310 feet above the base of the formation, with green-gray sandstone below and 40 feet of massive green conglomerate above. The strike is N. 68° E., and the dip 45° N.

The following section was measured 900 feet above the valley floor. It is unsatisfactory because the softer beds show thickening by drag folding, and the coal may also be thicker than normal for the region.

Section of coal in Chignik formation on hill west of Sleepy Creek

	Ft.	in.
Conglomerate, gray-green (roof, with uneven base).		
Bone		8
Coal, dirty, with bone partings	3	2
Shale	1	2
Coal, bright, blocky		11

	Ft.	in.
Coal, bone, and slate in thin, crumpled beds, practically of no value	8	
Coal, bright, blocky; checks badly on weathering		8
Sandstone, green-gray, fine-grained (floor).		
Total coal	4	
Good coal		8

The coal does not extend to the next ridge west, at a distance of 2½ miles. To the east it passes beneath the broad alluvial floors of Sleepy and Blue Violet Creeks. Farther east its trend if projected would carry it either beneath Black Creek or near creek level on the east side of the valley, but no coal was exposed, and it may not extend that far.

CHARACTER OF THE COAL

The coal from the Chignik River mine is bright black and of medium hardness. It was worked out in lumps as much as 10 or 12 inches in diameter. The seam, as exposed late in the season of 1908, showed some crushing at the front wall and at the end of the tunnel. The section in the mine shows sufficient shale partings and bony streaks to indicate the general bedded structure of the coal, which corresponds to the general dip of the formations in that part of the field. The coal, when taken from the mine, was dumped upon a barge near the entrance of the tunnel and was unloaded from the barge and dumped into the coal bins at the cannery, where it was used. In the process of handling the coal usually became broken into fragments, the largest 3 or 4 inches in diameter. This coal does not appear to slack badly. The best exposures in Whalers Creek are in a prospecting tunnel, where the coal seam is firm and the bedded structure pronounced, the structure being emphasized by certain shale partings. The coal is a dull black on the weathered surfaces but is bright in fresh exposures. The Thompson Valley exposures are only a little beneath the surface and not beyond the zone of weathering. This coal, however, is in a heavy, firm bed, more resistant than the shale and sandstone associated with it, as is indicated by the rapids or falls where streams cross the coal seam.

In the short tunnel in the coal northwest from the head of Hook Bay the coal is in seams 18 inches or less in thickness, separated by thin beds of shale. These shale partings indicate the general bedded condition of the sediments and correspond with the general dip of the strata. The upper portion of the seam is bright and black and of medium hardness and appears to be a high grade of bituminous coal. The lower portion of the seam has more bony streaks but would average a fair grade of bituminous coal.

The following table gives the results of the analyses of some of the coals from the Chignik field. The samples were obtained at the following localities:

6952. Coal bed on west side of main stream, 7 miles northwest of Hook Bay, west side of Chignik Bay, Alaska Peninsula.
6956. Chignik Bay, Thompson Valley, three-quarters of a mile above mouth of stream.
6955. Chignik Lagoon, Whalers Creek, three-quarters of a mile above mouth.
6953. Chignik River, north side, 2 miles below Chignik Lake.

Analyses of coals from the Aniakchak district

[Analyses by F. M. Stanton, U. S. Geological Survey]

Samples as received

Laboratory No.	Locality	Proximate analyses				Ultimate analyses						Calorific value	
		Loss on air drying	Total moisture	Volatile combustible	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British thermal units
6952	Near Hook Bay	4.00	5.07	27.24	42.42	25.27	2.26	4.53	55.76	0.59	8.38	5,618	10,112
6956	Thompson Valley	6.50	10.77	30.37	43.99	14.87	.70	4.98	55.27	.61	23.57	5,356	9,641
6955	Whalers Creek	2.50	5.02	34.28	45.45	15.25	1.75	4.87	62.04	.56	15.53	6,245	11,241
6953	Chignik River	5.20	7.06	31.48	39.68	21.78	1.30	4.83	55.14	.61	16.34	5,470	9,846

Air-dried samples (calculated from table above)

Laboratory No.	Locality	Proximate analyses			Ultimate analyses						Calorific value	
		Moisture	Volatile combustible	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British thermal units
6952	Near Hook Bay	1.11	28.38	44.19	26.32	2.35	4.26	58.08	0.61	8.38	5,852	10,533
6956	Thompson Valley	4.57	32.48	47.05	15.90	.75	4.56	59.11	.65	19.03	5,728	10,310
6955	Whalers Creek	2.58	35.16	46.62	15.64	1.79	4.71	63.63	.57	13.66	6,405	11,529
6953	Chignik River	1.96	33.21	41.86	22.97	1.37	4.48	58.17	.64	12.37	5,770	10,386

ORE DEPOSITS

In connection with the intrusion of some andesite dikes the country rock has been bleached and pyritized on an extensive scale. The dark sediments became gray; the chlorite, hematite, magnetite, and other ferruginous minerals were modified; and pyrite was produced. No quantitative data are available to show whether iron has been introduced, but all the disseminated pyrite could probably have been formed from the original iron of the sediments. On Bearskin Creek Naknek beds form a hill about 2,000 feet high between the forks of the stream. Practically all the north face and extensive areas on the west side of this hill have been pyritized. Weathered surfaces are red from oxidation of the pyrite, but fresh fractures show a light-gray rock with abundant scattered pyrite in grains 0.05 to 0.1 millimeter in diameter. Similar contact metamorphism is conspicuous on the west and north sides of the valley of the western tributary of Flat Creek and in smaller areas in the volcanic rocks on the divide southeast of Purple Crater and on Hook Head. Careful panning of the sands below these outcrops failed to show any colors of gold. No lead, copper, or zinc sulphides were noted, even in traces. Probably sulphur was the only element introduced, and the iron sulphides in their disseminated condition have no value.

Atwood,[40] however, earlier reported that rocks showing sulphide mineralization, on which some prospecting work had been done, occurred at Mallard Duck Bay, within the surveyed region adjacent to Chignik Bay, and at Prospect Bay, about 12 miles directly south of Chignik post office, but outside the surveyed area. Concerning the occurrence at Mallard Duck Bay, Atwood states:

> The claims along the shores of Mallard Duck Bay are in mineralized crushed zones in an andesitic lava. These zones contain galenite, sphalerite, pyrite, and a large amount of quartz. The wall rock carries a noticeable amount of pyrite. The exposures seen in 1908 were scarcely below the surface soil. The most richly mineralized zone seen is on the southwest side of the bay near the head. This zone is from 4 to 6 feet wide and appears to have a linear extent of at least 100 feet. A mantle of glacial drift made it impossible to trace the zone farther without doing some prospecting work.

The mineralized zone at Prospect Bay was described by Atwood as follows:

> The ore body is located at the west shore near the head of Prospect Bay and fortunately near an excellent little harbor behind a sand and gravel hook. The zone that has been staked is about 50 feet wide. It is a crushed zone, and in the fissures the minerals, which include pyrite, galena, sphalerite, chalcopyrite, and quartz, are in the crystalline form, the crystalline development being in places of the geode type. When these claims were visited during the early part of the

[40] Atwood, W. W., Geology and mineral resources of parts of Alaska Peninsula: U. S. Geol. Survey Bull. 467, pp. 128–129, 1911.

1908 season no large body of high-grade ore had been developed, as was currently reported. Hand specimens fairly rich in copper minerals may be procured from the fracture cavities.

Thin films of magnetite-bearing black sand occur on the beaches of Chignik and Hook Bays. No gold was obtained from several samples. The amount of magnetite available is negligible.

No other metallic minerals are known in the area, and judging from direct observation as well as from the absence of all mining work in this region at this time the results of former prospecting are not sufficiently encouraging to warrant continuation of prospecting for metallic minerals.

INDEX

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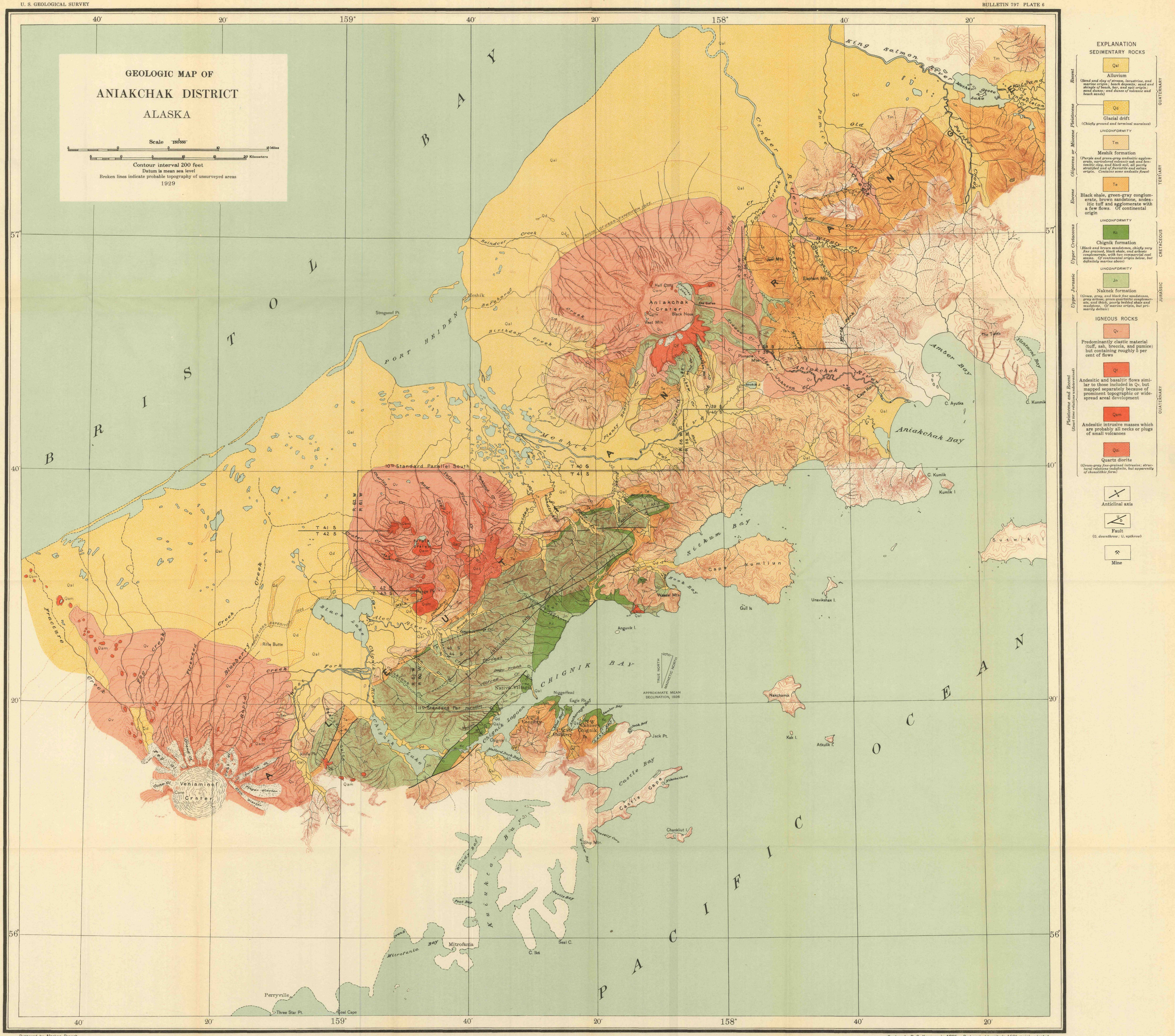

Prepared by Alaskan Branch
Topography by R. H. Sargent
Geodetic position, control Pacific coast line, and adjacent topography from data by U. S. Coast and Geodetic Survey
Land net from information by U. S. Land Office
Surveyed in 1922 and 1925

Geology by R. S. Knappen in 1925. Part east of longitude 158° mainly adapted from Surveys by W. R. Smith and A. A. Baker. in 1922