NOTES ON THE GEOGRAPHY AND GEOLOGY OF LITUYA BAY

By J. B. MERTIE, JR.

INTRODUCTION

Lituya Bay (see fig. 4) is a narrow tidal inlet that cuts into the Pacific coast of Alaska about halfway between Cross Sound and Dry Bay. The earliest recorded description of this bay is that of the French explorer Jean François Galaup de la Pérouse,[1] who is credited with its discovery. M. de la Pérouse later, with certain misgivings as to the legality of his procedure, actually purchased the island (Cenotaph Island) inside the bay from the natives who lived along the beach, paying therefor several yards of red cloth, axes, adzes, bar iron, and nails. It is probable that the Russians had visited this inlet at an earlier date, but no record of their visits is known to the writer.

At some later date the Russians discovered that the sands along the Pacific beach at Lituya Bay were gold-bearing, and these beach placers were then mined sporadically until Alaska was purchased by the United States in 1867. From that date until the early nineties this place appears to have been little visited by white men, but in 1894 Americans are said to have begun work on the beach placers, and in 1896, it is said, between 150 and 200 men were prospecting and mining along the beach. Some placer mining was also in progress at the time of the visit of a Geological Survey expedition in 1906, and even at the time of the writer's visit to Lituya Bay in 1917 several men were prospecting there.

The earliest scientific observations at Lituya Bay were made by the naturalists and engineers who accompanied La Pérouse and by the explorer himself. The geography, geodesy, plant and animal life, and Indian life and culture were studied and recorded by these men in a most comprehensive and able manner. A map of Lituya Bay on a scale of 1:50,000 was also prepared at this time, and the heights of some of the near-by mountain peaks were determined by triangula-

[1] Voyage de La Pérouse autour du monde, publié conformément au décret du 22 avril 1791, et rédigé par M. L. A. Milet-Mureau, vol. 2, pp. 161–184, Paris, Imprimerie de la République, 1797.

tion. In 1874, almost a hundred years later, Lituya Bay was entered by a United States Coast and Geodetic Survey party, who made geodetic observations and added further to the La Pérouse map. W. H. Dall,[2] who accompanied this expedition, published subsequently a short note regarding the marine sediments of this area compared with other parts of Alaska. In 1894 a topographic map of

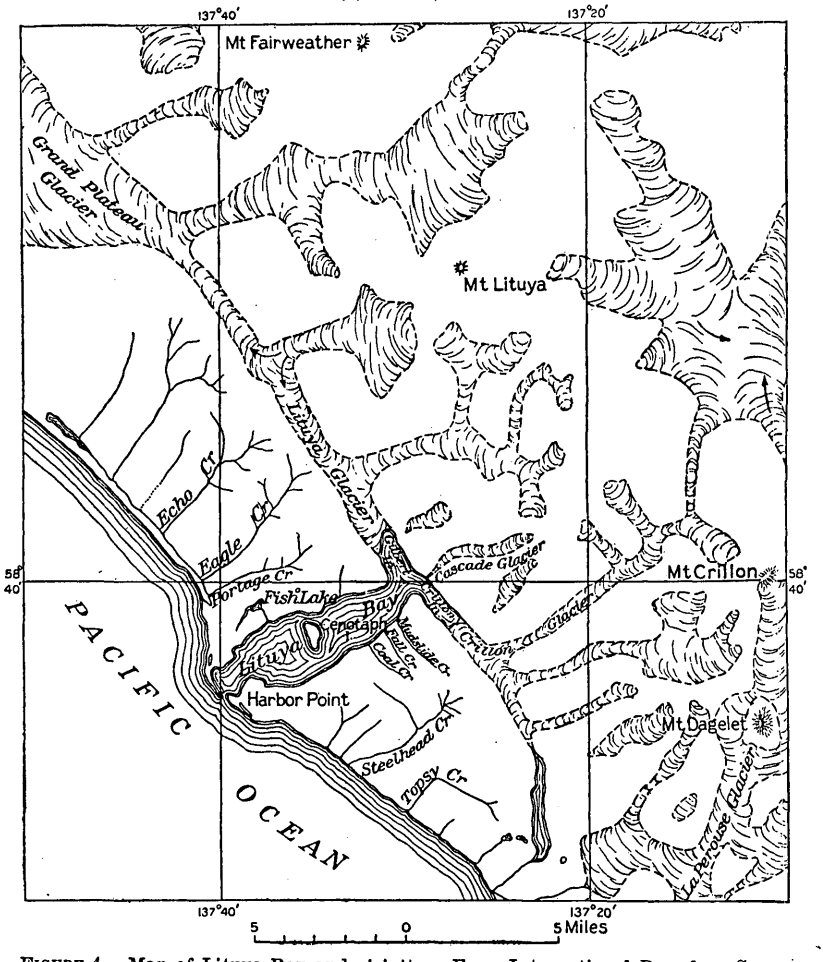

FIGURE 4.—Map of Lituya Bay and vicinity. From International Boundary Survey map, 1894

Lituya Bay and vicinity was made by the International Boundary Survey, and observations on the glaciers at the head of the bay that were made at that time were subsequently published by Klotz.[3] This general region was again visited by Gilbert,[4] with the Harriman

[2] Dall, W. H., Alaska Tertiary deposits: Am. Jour. Sci., vol. 24, pp. 67–68, 1882.

[3] Klotz, O. J., Notes on the glaciers of southeastern Alaska and adjoining territory: Geog. Jour., vol. 14, pp. 524–526, 1899.

[4] Alaska, vol. 3, pp. 39–45, Harriman Alaska Expedition, 1904.

expedition, in 1899, by Martin in 1904, and by Tarr and Martin [5] in 1909, but these men did not enter Lituya Bay, making observations only from offshore, aboard ship. In 1906, however, a Geological Survey party headed by F. E. and C. W. Wright spent three days in Lituya Bay. The geologic results of this expedition have not been published, but a brief abstract of the results of their glacier studies in this general region was given by Reid.[6] It happens that most of the published data on Lituya Bay relate more particularly to the glaciers, and few other geologic facts are available about this interesting locality. In 1917 the writer spent three days in Lituya Bay and during that time made some geologic observations and collected fossils from the marine Tertiary strata along the foreland. During the summer of 1930 a Harvard expedition in charge of H. B. Washburn also entered the bay and collected some Tertiary fossils. With the fossil collections of the Wright brothers, the writer, and Washburn now available, it seems that a few of the geologic facts relating to Lituya Bay might well be assembled. This is the purpose of the present paper.

GEOGRAPHY

A short summary of the discovery of Lituya Bay by M. de la Pérouse and of the geographic work done by him and those who followed him seems desirable. La Pérouse discovered this bay in the course of a trip around the world, upon which he started in August, 1785. With two frigates, *La Boussole* and *L'Astrolabe*, he entered Lituya Bay July 2, 1786, and gave to it the designation Port des François. The present name is a phonetic transcription of the Indian name Ltua.

The mouth of Lituya Bay is a narrow entrance, beset with rocks and shoals, through which the tide runs with a velocity of 10 knots or more; and unless the ocean is more than ordinarily calm the sea breaks clear across the entrance. Only for about 15 or 20 minutes, at the slack water between tides, may the passage into the bay be considered safe. La Pérouse cautiously sent two scouts ashore to discover the channel and to locate a good anchorage inside the bay before attempting the passage. After receiving their recommendations, the two ships, towed by boats, entered on slack water but were nearly wrecked in the entrance by an unexpected northwest wind that arose suddenly and blew them shoreward. By the use of their sails, however, the passage was effected, with minor injuries to the ships. On July 13, when the expedition was preparing to leave Lituya Bay, a surveying party in charge of M. d'Escures

[5] Tarr, R. S., and Martin, Lawrence, Alaskan glacier studies, pp. 10, 193, Nat. Geog. Soc., 1914.

[6] Reid, H. F., The variations in glaciers, XII: Jour. Geology, vol. 16, p. 53, 1908.

came to grief at the mouth of the bay. This party, in three ship's boats, had set out in the morning to make a last tour of the bay, but, going too close to the entrance as the tide was going out, they were drawn into the bore, and two of the three boats were wrecked, the third escaping by a narrow margin. All the six officers and fifteen members of the crew in these two boats were drowned, and none of their bodies were recovered. In memory of his unfortunate comrades La Pérouse erected a monument upon the island in the middle of Lituya Bay, to which he gave the name Île du Cénotaph. It is now called Cenotaph Island. At the bottom of the monument he buried a bottle containing a paper giving a brief account of the disaster and the names of its victims. The following inscription composed by M. de Lamanon, one of the naturalists of the expedition, headed the account:

> A l'entrée du port ont péri vingt-un braves marins; qui que vous soyez, mêlez vos larmes aux nôtres.

At the time of La Pérouse's visit the Lituya Bay area was populated by Indians, who occupied several villages along the beach. They lived by fishing and hunting and traveled the bay and adjoining coast line in piroques, or canoes made by hollowing out logs. They were familiar with the use of iron—in fact, most of them had iron poniards suspended from their necks, that they had probably obtained from the Russians. They also had copper and bronze ornaments, evidently of local origin. Of all things they most desired to obtain iron, and most of the trading done with them by members of the expedition was based upon an exchange for bar iron, axes, nails, and other iron implements. They gave the impression of being sun worshipers and cremated their dead, except for the head, which with the ashes from the body was sewn up in skins, inclosed in a wooden container, and mounted on four stout poles driven into the ground.

La Pérouse found the natives of Lituya Bay to be a filthy, thieving lot, and the only reason that they were not openly hostile was that the members of the expedition took pains to demonstrate to them the superiority of the white man's weapons. An observatory and repair shop was established on Cenotaph Island by the expedition, a part of the officers and crew living ashore in tents; but the continuous thievery of the natives at night finally made it necessary to quit the island. La Pérouse, after examining their villages, concluded that these natives were about the lowest type of human beings he had ever seen. At present no natives live at Lituya Bay, for here, as elsewhere in Alaska, the descendants of the aborigines seldom visit the remote places familiar to their forebears but tend instead to remain close to white settlements.

The foreland of the Lituya Bay district, fronting upon the Pacific, is covered with dense vegetation, but at the head of the bay the vegetation becomes sparse. Near the Pacific beach the timber is small, averaging perhaps 1 foot in diameter, and is mainly spruce with some hemlock. Farther back on the benches the timber is larger and is about one-fourth yellow cedar. On these benches both cedar and spruce as large as 8 feet in diameter grow, and the average size is perhaps 3 feet. La Pérouse was much impressed with trees 5 feet in diameter and 140 feet high, but he failed to see the still larger trees back on the benches. Three-foot trees in this district will average 80 feet in height and when cut in 20-foot lengths will probably yield 3,000 board-feet of lumber. No study of the other vegetation was made, but among the edible fruits the strawberry, red and blue huckleberries, salmonberry, loganberry (dewberry), high bush cranberry, raspberry, and black currant were noted. The dwarf maple was also observed by La Pérouse, but this was not seen by the writer.

The animal life is most varied. Among the mammals noted by the writer were blue, black, and brown bear, wolves, goats, deer, cross fox, red fox, and squirrels, and in addition to these La Pérouse recorded marten, ermine, beaver, marmot, and muskrat. Sea otter were extremely plentiful in 1786. The members of the expedition obtained 1,000 skins from the natives by barter, and La Pérouse states that a trading company at that time could have taken 10,000 skins a year. The skins of the wolf, sea otter, and sea lion (?) were most prized by the natives at that time. Ptarmigan and grouse were seen by the writer, and in season ducks, swans, and geese are present. A variety of other birds also abound. The edible fish are mainly trout, salmon trout, and bass.

Lituya Bay itself is a T-shaped inlet from the Pacific Ocean. Its major trend is N. 65° E., and the head of the bay, which forms the upper part of the T, trends N. 40° W., so that the two parts of the bay depart from a right-angle relation by 15°. The mouth of the bay, from headland to headland, is about 700 yards wide, but the actual channel is only about 100 yards wide and lies between two sand spits. On the east side of the channel is a sunken rock, called Passage Rock, which is just awash at low tide. On the east side of the entrance are two prominent hills, called The Paps, along the north shore of which La Pérouse tried to obtain anchorage but found only hard bottom. The best anchorage is in Anchorage Cove, northwest of the entrance, where shallow water and soft bottom occur. As this anchorage is so close to the outlet of the bay, however, where the swift tidal currents run, it is safer to put out a shore line also.

The main arm of Lituya Bay is about 7 miles in length and from five-eighths mile to 1¾ miles in width. In the center of this part of the bay is Cenotaph Island, which is about 750 yards long in a direction parallel to the upper arm of the bay and about half as wide. It has a suitable anchorage on its east side, where the two frigates of the expedition of 1786 finally anchored. The top of Cenotaph Island is heavily timbered. East of the narrow neck of the bay the water is deep, ranging from 10 to 100 fathoms or more, and no other islands or rocks were observed above water. From Cenotaph Island to the mouth the shores are low and consist mainly of beaches. Above Cenotaph Island the walls of the bay become steep and fiord-like. The upper arm of the bay is narrow, ranging from 600 to 800 yards in width in the northwest branch and about 500 yards in the southeast. The total length of this arm of the bay is now about 3½ miles, but at the time of La Pérouse's visit it was about 9½ miles. The difference is due to the advance of glaciers at both ends of the arm since 1786.

Along the south side of Lituya Bay, east of Cenotaph Island, three short streams—Coal, Fall, and Mudslide Creeks—enter the bay from the hills. The writer went up Coal Creek to the coal outcrops and ascended Mudslide Creek to the crest of the ridge. On the north foreland of the bay, northwest of Cenotaph Island, is a triangular lake, called Fish Lake, which has a tributary from the southwest and discharges southward into Lituya Bay. From 2½ to 3 miles northwest from the entrance of the bay Portage and Eagle Creeks discharge into a peculiar stream channel that runs southeastward along the beach parallel with the strand line for 8 miles and, finally turning, runs backward to the northwest for a quarter of a mile before emptying into the ocean. About 2 miles northwest of Eagle Creek is another stream, Echo Creek, which drains a good-sized lake and empties into the channel just described. Three other creeks still farther to the northwest also drain into this beach channel. Along the beach southeast of Lituya Bay several creeks empty directly into the ocean, of which the two principal ones are Steelhead and Topsy Creeks, respectively 4½ and 7 miles from Harbor Point.

The northwest-southeast arm that forms the head of Lituya Bay is terminated at both ends by glaciers—Lituya Glacier at the northwest and Crillon Glacier at the southeast. Halfway between these two, along the northeast side of this arm and directly in line with the main part of Lituya Bay, is a dying glacier known as Cascade or locally as Dead Glacier. Both Lituya and Crillon Glaciers discharge into tidewater, the former into Gilbert Inlet and the latter into Crillon Inlet. Cascade Glacier no longer reaches tidewater. La Pérouse states that in 1786 each of these inlets was terminated by

two glaciers, but on his chart only one is shown at the head of the northwest inlet. The next recorded observations on these glaciers were made by the boundary survey party in 1894. By that time the twin glaciers at each end had coalesced and advanced about 3 miles, forming the fronts of what are now known as Lituya and Crillon Glaciers. On the other hand, Cascade Glacier, called Middle Glacier by La Pérouse, had retreated so that it no longer discharged at tidewater. Thus we have the anomaly, within a relatively small area, of two glaciers that advanced 3 miles in 108 years or less, whereas a third glacier lying between them sensibly retreated in the same interval. The explanation is that Cascade Glacier does not head in the main ice field and doubtless has been steadily retreating for centuries. Lituya and Crillon Glaciers could advance as a result of some dynamic or physical circumstances that affected their reservoirs; but Cascade Glacier could advance only by so great an expansion of the ice fields of this region that it might again be connected with an active névé. The Geological Survey party of 1906 reported that Lituya Glacier had advanced another half mile since 1894. No measurements of the positions of these two glacier fronts were made by the writer in 1917.

Lituya Bay is surrounded at its upper end by high mountains. The ridge at the head of Mudslide Creek rises to an elevation of about 3,300 feet, but to the northwest, on the opposite side of Lituya Bay, the continuation of this ridge rises gradually in a distance of 11 miles to about 4,700 feet. Lituya and Crillon Glaciers lie in a great depression, which runs nearly parallel with the Pacific coast for 20 miles. Except for the tidal arms at the head of Lituya Bay, this depression is filled with ice, most of which drains into Lituya Bay. The northwest end of this ice-filled valley drains into and becomes merged with the Grand Plateau Glacier; the southeast end is terminated by a lake 3½ miles long which drains to the Pacific. This depression, with little doubt, represents a great fault rift, which may perhaps continue for considerable distances northwest and southeast of the ice-filled valley just described. To the northeast of this rift the mountains rise to great heights and are in large part blanketed by a permanent ice field. The higher ridges project above the ice, and topping all of these are three dominating peaks, Mount Fairweather, Mount Lituya, and Mount Crillon. Mount Fairweather was originally described by La Pérouse as Mont Beau-temps, of which the present name is a translation. It rises to an elevation of 15,300 feet; Mounts Lituya and Crillon reach respectively 11,750 and 12,725 feet. The average crest line of the ridges immediately bordering the great rift on the northeast is from 6,000 to 7,000 feet above sea level.

One of the most interesting physiographic features of the Lituya Bay region consists of the benches that front upon the Pacific. These are rock-cut terraces, with thin veneers of recent sand and gravel, and are developed both northwest and southeast of the entrance of the bay. The beach northwest of Lituya Bay is studded with great glacier-borne boulders for about 2 miles. Farther northwest the beach is for the most part sandy, though boulders occur at intervals. A low bench, from 10 to 15 feet high, composed largely of bedded sand, runs more or less parallel with the beach at an average distance of about 600 feet, though at places approaching close to tidewater. It is from this material that the gold placers have been concentrated by the sea. The first hard-rock terrace begins about a mile from the beach, with a sharp rise of 80 feet to a nearly flat surface about 200 feet above sea level. This bench is from 1,000 to 2,000 feet wide and at its back end rises gradually to the foothills. It runs nearly parallel with the beach and may be traced from Lituya Bay northwestward to Grand Plateau Glacier and beyond. Remnants of a still higher terrace, about 1,700 feet above sea level, may also be observed along this northwest foreland.

East of Lituya Bay, however, other conditions prevail. For about 3 miles southeast of Harbor Point the beach has a cover of glacial boulders, similar to the beach northwest of Lituya Bay. Thence southeastward for 7 miles, to a point within 5 miles of La Pérouse Glacier, Tertiary bedrock crops out along the beach, whereas northwest of Lituya Bay no bedrock was observed. Along this east foreland at least three well-defined hard-rock terraces are visible. The first bench begins about 3 miles southeast of Lituya Bay, about 300 to 500 feet back from tidewater, and extends inland about 800 feet. The second and third benches begin about 4 miles southeast of Lituya Bay, the second 200 feet above sea level and extending back 2,000 feet, and the third about 1,000 feet above sea level and rising gradually to the hills behind.

It is probable that a good map and a more intensive study of these rock-cut terraces would result in a correlation of the benches east and west of Lituya Bay, or at least in a better understanding of their differences. They represent, of course, various stages in the uplift of this coast line, but the dynamic features of this uplift are not well understood. It is probable that the foreland as a unit has moved upward by successive stages along the great rift line; but it is also possible that this uplift has been partly of a hingelike type, the axis of rotation coinciding with the rift line. If so, some of the terraces should show tilting away from the sea. Lituya Bay itself has also probably been a site of movement, for it can not be explained entirely as a result of glacial erosion.

GEOLOGY

The hard rocks of Lituya Bay and vicinity may be divided broadly into five groups, as follows:

Amphibolite and chlorite schists, the oldest rocks exposed.
A group of rocks composed of argillite, slate, and limestone with associated greenstone, of pre-Tertiary age.
Sandstone, shale, and conglomerate of Tertiary age.
Quaternary deposits.
Granitic rocks, probably of Mesozoic age.

Upon the basis of only three days' work the writer naturally is not prepared to present a geologic map of these stratigraphic groups, but their general distribution can be indicated by a brief description.

AMPHIBOLITE AND CHLORITE SCHISTS

The schistose rocks are found only about the head of Lituya Bay in Gilbert and Crillon Inlets. Along the northeast side of the bay the plane of schistosity dips steeply into the mountains, but higher on the mountains granitic intrusives appear. According to the notes of F. E. Wright, the plane of schistosity along the northeast wall of Crillon Inlet strikes N. 60° W. and dips 45° NE., but along the southwest side of the inlet the dip is to the southwest. Wright suggested that this reversal in dip might represent a folded anticlinal structure of which Crillon Inlet now occupies the center. The old cleavage planes may indeed have been folded, but the presence of granitic rocks on the upper northeast slopes of Gilbert and Crillon Inlets and the absence of such intrusive rocks along the southwest walls indicate that this reversal in dip is due to a displacement resulting from faulting whereby the foreland on the southwest has risen with regard to the high mountains to the northeast.

The schists have been observed only at the head of Lituya Bay, but they extend northward and eastward into the Fairweather Range, and little is known about them. Varieties of schist other than those above mentioned are also probably present. Moreover, no petrographic work has been done on the few specimens collected, so that their character and origin have not been determined. Their age is even more doubtful, for the schists are nonfossiliferous, and the overlying group of rocks, though not recrystallized, have not yet yielded organic remains. The general stratigraphy of southeastern Alaska is such as to favor the classification of these schists as metamorphosed early Paleozoic rocks of both sedimentary and igneous origin.

SLATE-GREENSTONE GROUP

The term "slate-greenstone group" is applied to the rocks that next overlie the schists. Other varieties of rock are present, but the two principal species are utilized for a group designation. The rocks are found on both sides of the upper part of the main arm of Lituya Bay, southwest of Gilbert and Crillon Inlets. Along the north side of the main arm, northeast of Cenotaph Island, there is a series of croppings of greenstone and slate. According to the notes of F. E. Wright, these rocks strike N. 25°–45° W., and their dip approaches the vertical at most places. Banding is common, and it is apparent that much slipping and shearing have taken place.

On the south side of the bay these rocks crop out in Mudslide Creek and possibly in Fall Creek, but they end somewhere northeast of Coal Creek, for the bedrock of Coal Creek is composed of Tertiary rocks. In Mudslide Creek, 500 feet above tidewater, greenish crystalline limestone or dolomite was observed by the writer. This rock is cut by many veinlets and stringers of calcite and is pyritized along the old crevices. Farther up this creek the limestone is still more metamorphosed, and at one locality it was observed to be a green calcareous schist. At 600 feet above sea level a red metamorphic micaceous mineral is present in the country rocks which are also pyritized. From the calcareous mud formed by the disintegration of this rock, Jack Campbell, an old prospector in Lituya Bay, took a sample, which is reported to have carried copper and nickel. Chalcopyrite was identified among the sulphides by the writer, but pyrrhotite was not observed.

At an elevation of 1,200 feet above tidewater, in Mudslide Creek, considerable masses of greenstone occur in the limestone; and at the top of the ridge at the head of this creek the country rock is mainly argillite and slate, in considerable part graphitic. The strike of this whole group of rocks appears to be about N. 60° W., with a general dip of 45° or more to the southwest. Both the strike and the dip, however, are irregular, for the structure is not simple. On the top of this ridge erratic boulders of the rocks found farther east in the Fairweather Range were observed. These were chiefly hornblende schist and granitic rocks.

Along the south side of Lituya Bay, somewhere between Crillon Inlet and Coal Creek, F. E. Wright also noted greenstone and greenstone tuff in this series of rocks, but it is possible that some of the tuffs may be a part of the Tertiary sequence.

It is evident from the notes above given that the slate-greenstone group comprises sedimentary rocks interbedded with basic lavas. Intrusive greenstone is probably also present. The sediments are

predominantly argillaceous but are also in part calcareous. Presumably the basic eruptions that produced the beds of greenstone were of submarine origin, though no examples of pillow-lava structure were observed.

No fossils have yet been found in the rocks of the slate-greenstone group, but no inherent reason exists for their absence. In the lack of organic evidence the exact age of the rocks can not be stated. Similar rocks of Carboniferous and Mesozoic age are widely distributed elsewhere in southern and southeastern Alaska, but the presence of limestone in this group favors their assignment to the Carboniferous or Triassic rather than to the Jurassic or Cretaceous. Such a correlation, however, is based merely upon lithologic similarity and should be understood to be suggested rather than determined.

TERTIARY ROCKS

Rocks of Tertiary age form the foreland of the Lituya Bay district from Coal Creek southwestward to the Pacific. Along the shores of Lituya Bay these rocks are for the most part covered by glacial débris, but they are well exposed on Cenotaph Island and along the Pacific beach southeast of the bay.

The Tertiary rocks are well-indurated sediments consisting of sandstone, shale, and conglomerate, with a few beds of coal and also some tuffaceous beds. Cenotaph Island presents a very interesting and instructive section of these rocks. Here they consist mainly of sandstone and conglomerate, with some beds of shale and a few thin beds of coal. The sandstone is massive and more or less cross-bedded and is evidently of near-shore origin. The shale is hackly and nodular and shows numerous folds of small amplitude which do not appear in the bordering sandstone. Both sandstone and shale contain scattered cobbles similar to those found in the conglomerate. The conglomerate contains pebbles and cobbles of granite, slate, and greenstone. At the northeast end of Cenotaph Island is a waterlaid tuff or agglomerate. It contains boulders as much as 3 feet in diameter and is greatly shattered and seamed with calcite. The calcite seams are bordered on both sides by layers of hematite, and the resulting rock has indeed a curious appearance. The included subangular boulders are composed mainly of volcanic rocks of surficial origin, with a fine-grained to aphanitic groundmass in which are set phenocrysts of feldspar and hornblende.

At the northeast end of Cenotaph Island, where these agglomerates occur, the rocks strike N. 50°–60° W. and dip 50°–55° SW., but at the south end of the island the dip is 30° or less. These rocks have been much compressed but are still only moderately indurated. The in-

competent shale beds have taken up considerable compression in the deformation. Cenotaph Island is evidently a monoclinal sequence of these rocks, at the base of which are the tuffaceous rocks above described. The fossils collected from the Tertiary rocks of Cenotaph Island come from the sandstones and shales that overlie these tuffaceous rocks, but the stratigraphy indicates that the tuffs grade upward into the overlying beds without any discontinuity of sedimentation.

The tuffaceous rocks above described occupy a considerable area along the beach of Lituya Bay east of Coal Creek and also crop out in the valley of Coal Creek. About 200 yards up this stream from tidewater shale crops out on the northeast bank and tuff on the southwest bank. Such alternate croppings of shale and tuff continue upstream for about half a mile to the forks of the creek in such a manner as to suggest that Coal Creek follows closely the contact between the tuffaceous beds and an underlying shale. Continuing up the right fork, the tuff formation is the main bedrock, and about a quarter of a mile above the forks an 8-inch seam of lignitic coal was observed by the writer. Coaly shale adjoining the lignite contained fossil imprints of dicotyledonous leaves, which, however, were not collected.

Along the Pacific shore southeast of Lituya Bay the Tertiary rocks are well exposed and form a ragged beach upon which the surf breaks with impressive splendor. About 4 miles southeast of Harbor Point the country rock is a brownish clay shale, striking N. 40° W. and dipping 50° SW. The rock has prominent joint planes that strike N. 40° E. and stand vertical. This shale is conglomeratic in places, with strata containing subangular boulders a foot or more in diameter. The shaly beds proper are thin-bedded and fissile. Sandy beds also occur, but this part of the Tertiary sequence is dominantly argillaceous, in contrast with the dominantly sandy beds of Cenotaph Island. Fossils are present in all the beds, including the conglomeratic layers. Were it not for these fossils some of these shales with their unsorted boulders might suggest glacial débris to an enthusiastic searcher for tillites. At a point 6½ miles southeast of Harbor Point the bedrock face of the first terrace was found to consist of fossiliferous gray shale.

The Tertiary sequence at Lituya Bay is discontinuous and thus not susceptible to accurate stratigraphic measurement. It is a suggestive fact, however, that the competent beds, wherever observed, dip 30°–60° SW. If there were no reversal in this structure, it is evident that as much as 12,000 feet of Tertiary sediments might be present. Such a thickness seems very doubtful, and the figure is mentioned merely to indicate the upper possible limit. From the

stratigraphic observations so far made it is believed that the sequence is somewhat as follows:

Shale, of unknown thickness; top of section.
A covered zone, comprising perhaps the major part of these rocks.
Tuffaceous beds and conglomerate, overlain by a dominantly sandstone sequence, the whole aggregating about 1,000 feet of sediments.
Shale.
Tuffaceous beds; base of section.

The age of these Tertiary rocks has been closely determined from fossils collected by F. E. Wright and the writer. Some additional material was collected by H. B. Washburn in 1930. All these fossils, with the exception of the Washburn collections, were examined and determined by W. H. Dall, formerly of the Smithsonian Institution. The Washburn collections were determined by W. C. Mansfield. The localities and fossils are listed below.

643. East side of Cenotaph Island, Lituya Bay. Collector, Fred E. Wright, 1906:

Arca sp.
Cardium cf. C. grönlandicum.
Cardium cf. C. islandicum.
Cardium cf. C. corbis.
Panomya n. sp.
Mya cf. M. arenaria.
Leda sp.
Yoldia cf. Y. montereyensis.
Nucula sp.
Acila sp.
Macoma cf. M. sabulosa.
Macoma cf. M. balthica.
Cast of large pholad burrow like that of Parapholas californica.
Diplodonta cf. D. aleutica.
Pandora cf. P. grandis.
Saxicava sp.
Hinnites? sp.
Purpura cf. P. crispata.
Chrysodomus? sp.
Lunatia sp.
Worm tube.
Echinarachnius sp.
Fucoid? impression.

7930. Pacific beach, 4 miles southeast of entrance to Lituya Bay. Collector, J. B. Mertie, jr., 1917:

Nucula cf. N. tenuis Montagu.
Macoma n. sp.
Macoma calcarea Gmelin.
Angulus sp.
Corbula sp.
Colus sp., fragment.
Cervical vertebra, probably seal or sea lion.

7932. Southeast side of Cenotaph Island, Lituya Bay. Collector, J. B. Mertie, jr., 1917:

Yoldia sp.
Pecten coosensis Shumard.
Cardium coosensis Dall.
Serripes grönlandicus Fabricius.
Macoma n. sp.
Macoma calcarea Gmelin.
Macoma cf. M. balthica Linnaeus.
Macoma cf. M. edentula Broderip and Sowerby.
Saxicava arctica Linnaeus.

17932. Southeast side of Cenotaph Island, Lituya Bay. Collector, J. B. Mertie, jr., 1917:

Chrysodomus cf. C. fornicata Gray.
Thais sp., fragment.
Priene pacifica Dall.
Eudolium? oregonense Dall, fragment.
Turritella n. sp.?
Natica cf. N. galianoi Dall.
Solen cf. S. sicarius Gould.
Machaera sp.
Cardium coosense Dall.
Cardium n. sp.?

Venericardia? sp., fragment.
Macoma cf. M. secta Conrad.
Mulinia densata oregonensis Dall.
Chione securis Shumard.
Chione staleyi Gabb?
Thracia sp., fragment.
Mya truncata Linnaeus.
Mya cf. M. arenaria Linnaeus.
Cryptomya quadrata? Arnold.
Saxicava arctica Linnaeus.
Echinarachnius gibbesii Rémond.

12180 a. Cenotaph Island, Lituya Bay. Moderately indurated gray sandstone, weathering brown. Collector, H. B. Washburn, 1930:

Semele? sp.
Cardium, 2 sp.
Macoma, 2 or 3 sp.
Siliqua sp.
Mya sp.

12180 b. Cenotaph Island, Lituya Bay. Indurated dark-colored sandy shale. Collector, H. B. Washburn, 1930:

Nucula (Acila?) sp.
Leda sp.
Pecten? sp.
Venericardia sp.
Cardium sp.
Saxicava? sp.
Mya? sp.
Fish scale.

12180 c. Cenotaph Island, Lituya Bay. Moderately soft greenish shale. Collector, H. B. Washburn: 1930:
Spisula? sp.

In all, 40 genera have been recognized. When Wright's collections were first examined by Dall in 1906 he determined them to be probably of Pliocene age. These fossils, however, were found in much crushed blackish shale and sandstone and were themselves so badly crushed that it was found to be impracticable to compare them exactly with analogous species in Recent faunas. Dall, when he examined the collections made by the writer in 1917, reported that collection 7930 was probably Pliocene; 7931 was Miocene, Astoria horizon; and 7932 Astoria or Etchegoin Miocene.[7] Subsequently, when requested by the writer to make a comparison of lot 7932, which came from Cenotaph Island, with the Wright collection from the same locality, Dall reported as follows:

I found Mr. Wright's collection and compared it with your material. The differences between the two lists arise from several factors: First, Mr. Wright's collection happens to include more of the species found in the Recent than yours; and second, some of the names have been changed since my former report. Nevertheless, more than half the species are common to both lists and, while there are only one or two distinctively Miocene species in Wright's lot, and it has a distinctly younger look, I think now that this is accidental. Such differences are not unlikely to occur in any fauna not exhaustively known. There should be, by analogy, some 400 species at least in the Astoria fauna, and small collections, even from closely adjacent stations, may naturally differ widely; and if the proportions of recent forms in different collections do vary widely, inaccurate conclusions may be drawn.

In the present case I think there is no doubt that the horizon is upper Miocene and that Mr. Wright's material and yours belong to the same horizon.

[7] The Etchegoin formation, of southern California, is now considered to be wholly of Pliocene age and is so classified by the United States Geological Survey.

With some assurance, therefore, it may be stated that the rocks of Cenotaph Island, which are near the base of the Tertiary sequence, are of upper Miocene age. It is probable that the shale near the top of the sequence, as exposed along the Pacific beach, is Pliocene.

It is also of historical interest to note that M. de Lamanon, one of the naturalists of La Pérouse's expedition, found a "manteau royal," or shell of St. John, at an elevation of 200 "toises" (about 1,200 feet) above sea level. The exact locality where this pecten was collected is not recorded, but evidently it was found on one of the rock-cut terraces of the Pacific foreland, probably northwest of Lituya Bay.

QUATERNARY DEPOSITS

The Quaternary deposits consist of morainal débris of Pleistocene and Recent age and of Recent stream detritus and beach sands, which in considerable part are reworked Pleistocene detritus. No study of any of the unconsolidated deposits has been made, and the following data are merely fragmentary notes recorded in conjunction with other observations.

During Pleistocene time the region about Lituya Bay was an enormous ice field that discharged directly into the Pacific Ocean. This ice, accumulating in the Fairweather Range at elevations of 5,000 to 15,000 feet, moved forward as an irresistible mass and overrode completely all of the Lituya Bay foreland, or that portion of this district southwest of the great rift. This condition persisted throughout the Pleistocene epoch and probably for some undetermined time into the Recent before the general retreat of the ice began. From that time until the present the glacial history of this district has been essentially a history of the withdrawal of the ice. First the foreland area was evacuated, and then the main ice fields shrank progressively until the glaciers came to be fairly well restricted, particularly in their lower courses, to the old preglacial valleys. The distribution of the ice, shown on the accompanying sketch map, was that observed by the boundary survey party of 1894. Since that time a further shrinkage of marked proportions has taken place, but data are not available for plotting the present positions of the ice fields. Even in 1906 the ice fields, as observed by the Wright brothers, were much smaller than in 1894. The Wright glacial data show that the lower ends of several glaciers had become detached from the main ice field between 1894 and 1906, just as Cascade Glacier had become severed at some earlier date. Also the upper névés in 1906 were markedly smaller than in 1894. The 3-mile advance of Lituya and Crillon Glaciers in the interval between 1786 and 1894 and the further half-mile advance of Lituya Glacier

between 1894 and 1906 have no necessary meaning in the larger question of the general retreat of the ice. The retreat or advance of an ice sheet is established beyond question by the relative areas covered by it at different times; and here the areal data are adequate to show a generally continuous retreat of the ice in historic time. It is very probable that the local advances of the glaciers at the head of Lituya Bay are due mainly to earthquake action, which is common in this district. The dynamic effects of earthquakes upon glaciers, however, form a topic that needs elaboration, and to one interested in glaciology, here of all places is the site for accumulating the necessary data for some generalizations on this interesting subject.

The Fairweather Range, of course, is still covered with ice, but no quantitative data are available for determining whether the present ice fields will continue to decrease in size under present climatic conditions, or whether a condition of stability has been established. The very recent shrinkage of the ice, however, encourages the idea that a condition of relative stability has not yet been reached. If the volume of ice in this district could be plotted against some selected time interval, an interesting ice accumulation curve would result. With the volumetric ice data afforded by the boundary survey map of 1894, the similar data acquired by the Wright brothers in 1906, and a third survey of present date a start could be made upon a quantitative examination of the retreat of the ice. The study of such a curve might yield considerable information about the past and present rates of retreat of the ice, from which one could possibly reach some general conclusions regarding the late glacial history of this region that might even be extrapolated into the future.

Most of the glacial deposits produced by the Fairweather ice sheet have been transported and dumped out upon the continental shelf at an unknown distance from the present strand line. A sample of these materials, however, may be seen at the entrance of Lituya Bay and for several miles along the beach on each side of the entrance. Passage Rock, in the channel at the entrance, is a huge glacial erratic. The large boulders strewn along the beach on both sides of the entrance are similar material. In the densely forested peninsula back of The Paps the writer observed immense morainal boulders, some of which are as large as 100 feet in diameter. The scattered erratics on top of the ridges in the foreland area are further samples of the coarser glacial débris. The finer materials are either concealed by vegetation or else have been reworked by present streams and ocean waves.

The present beach sands are the best examples of recent alluvial deposits. At Echo Creek a 10 to 15 foot bluff of this material is typically exposed. It is composed largely of sand, gray when dry,

with some thin strata of coarser material as much as 2 inches in diameter. There are also layers an inch or two thick of finer sand, particularly rich in garnet. This is the so-called "ruby sand," which carries most of the placer gold and platinum. These sediments are well bedded and are unquestionably of marine origin. The sands upon which the waves now beat are made up of the same sort of material as the low bluffs above described.

Little stream alluvium has yet been produced, as the streams at the head of the bay have only recently been evacuated by ice and are, moreover, short. Some striking fans of coarse material, however, have been produced at their mouths, where they debouch into the bay.

GRANITIC ROCKS

Granitic rocks are exposed at the head of Lituya Bay, in an intrusive body that invades the ancient schists. They probably also intrude the slate-greenstone group, but this relation has not been confirmed. Practically nothing is known of the petrographic character or age of these rocks, as no one has examined them in place. With little doubt, however, they are identical with the rocks found at many places on tidewater in Glacier Bay, to the east. The Glacier Bay granitic rocks consist of both granitic and dioritic species and include also basic segregates from the granitic magma. A study of the petrographic character of these rocks will doubtless be made in connection with a forthcoming report on Glacier Bay.

PLACER MINING

Placer mining has been carried on intermittently at Lituya Bay for many years. The first work by Americans, however, appears to have been done in 1894. The best year for mining at this locality is reported to have been 1896, when from 150 to 200 men were mining along the beach.

The record of these mining operations is incomplete, but during 1917, when the writer visited Lituya Bay, and for two years before, the number of people at this place and their activities are fairly well known. Thus, in 1915, 21 people, of whom 14 were men, were directly or indirectly engaged in mining at Lituya Bay. In 1916, 8 men and 4 women were present, of whom 6 men were engaged in mining. In 1917, 6 men, 4 women, and 3 children were living there, but all the men were prospecting rather than mining.

Mining at Lituya Bay is carried on along the beach. It is said that 1896 was one of the best years on record, because the storms during that year were particularly heavy and frequent. Yet the miner has to work quickly after a storm, as another storm may arrive before he has cleaned up the beach concentrates and either

dissipate or cover them. These conditions make small-scale beach mining an intermittent and uncertain undertaking.

About 4 miles northwest of the mouth of Lituya Bay, between Eagle and Echo Creeks, is a small stream known as Fourmile Creek. Discovery claim for this northwest beach is 2 miles northwest of Fourmile Creek, and the other claims are staked lengthwise along the beach east and west of Discovery. Auriferous sands occur along this northwest beach from 2 to 16 miles northwest of Lituya Bay to mile 16 but have also been reported to exist as far as Sea Otter Creek, which is 20 miles northwest of Lituya Bay, halfway between Lituya and Dry Bays.

During stormy weather the surf cuts away the soft sand bluffs and concentrates at or near the surface of the beach a thin layer of heavy sand. These concentrated sands, which are usually 1 or 2 inches in thickness, are reddish owing to the high percentage of contained garnets, and resemble very much the similar material along the beach at Nome. The other principal heavy minerals in the garnet sand are magnetite and ilmenite. The quality of these placers may best be judged by some of the mining and sampling that have been carried on. Thus at Echo Creek a 10-foot bank of sand was concentrated to a 6-inch bed along the beach by a heavy storm that occurred in November, 1916, thus representing a concentration roughly of 20 to 1. From the 6 inches of concentrates 100 square feet, or about 2 cubic yards, was taken as a sample, which is said to have yielded about an ounce of gold and 0.15 ounce of platinum. The platinum, which is exceedingly fine, is said to be associated with a slimy brown mud in the concentrated sands, but pieces as large as 1 grain by weight have also been recovered. The coarsest gold pieces are reported not to have exceeded 8 cents in value.

Auriferous sands have been found on the beach from 4 to 9 miles southeast of Lituya Bay. About 6½ miles southeast of the bay there was a thin bed of auriferous garnet sand, covered by a foot of sand and gravel. This sand, in addition to its content of gold, also contained a little platinum. The best pay sands appear to have been found between 7 and 9 miles southeast of the bay. In this stretch 104 ounces of gold was recovered from April to October, 1915, and about 300 ounces in 1916. The gold recovered in 1915 had a value of $18.40 an ounce after melting, and assays as high as $18.92 an ounce have been reported. The largest piece of gold known to have been recovered at this locality was worth 74 cents. The placers mined 7 miles southeast of Lituya Bay are said to have yielded $20 to the square yard of bedrock, but the areas where pay dirt was found were few and small. Eight miles southeast of the bay a quar-

ter of an ounce of platinum was hand picked from 40 ounces of gold, without separating out all the platinum.

Gold prospects have also been reported on the benches, but little is known of the results. On the first terrace, just at the base of the second terrace, about 5 miles southeast of Lituya Bay, a prospect hole was sunk, and as much as 40 cents to the pan was reported from some of the auriferous sands. There are no inherent reasons why these upper benches should not have pay streaks, but no great amount of prospecting has been done on them.

Most of the mining so far done has been accomplished by means of sluicing and by the use of a long tom. One great handicap to placer mining on the northwest beach is the difficulty of obtaining sufficient head in ditches or flumes without going back too far in the hills. This difficulty is not present on the southeast beach, owing to the disposition of the benches back from the beach. It is possible that these sands will eventually be mined by dredging.

It is estimated that about $75,000 was recovered from the beaches northwest and southeast of Lituya Bay from 1894 to 1917. Full data of production since 1917 are not available, but it is likely that the recovery of gold has not been large. The gold so far recovered has made no serious drain upon the gold reserves, for practically all this gold has been recovered after severe storms from the southwest; and similar conditions will continue to occur intermittently. As a commercial venture, the bench sands and the beach sands that are back far enough from the breakers might well be prospected as possible low-grade placer ground suitable for dredging.