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THE

EARTHQUAKES AT YAKUTAT BAY, ALASKA

IN SEPTEMBER, 1899

BY

RALPH S. TARR AND LAWRENCE MARTIN

WITH A PREFACE BY

G. K. GILBERT

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ILLUSTRATIONS.

PREFACE.

By G. K. Gilbert.

In its relation to man an earthquake is a cause. In its relation to the earth it is chiefly an incidental effect of an incidental effect. It is the jar occasioned by a sudden faulting, and the faulting is a minor expression of deformation. The greater phenomena of deformation also, the differential movements of crustal masses, are themselves effects or expressions of fundamental earth processes—processes that are unknown or little known. Because of this twofold relation of earthquakes their study tends chiefly in two directions—on one hand toward the mitigation of their baleful influences on mankind, on the other toward the interpretation of crustal deformation. A third phase of the study is independent of the chain of causation but is connected with the transmission of earthquake shocks through the earth. As the mode of transmission depends on the physical properties of the transmitting material, the facts of transmission are being used to discover the physical condition and properties of parts of the earth body not accessible to direct observation.

The Yakutat earthquake, occurring in a region but sparsely settled, makes only small contributions to the problems connected with human welfare, but its contributions on the geologic side are so important as amply to repay the attention it has received. It also introduces a novel and valuable factor into the investigation of the variations of glaciers.

In the discussion of "world-shaking" shocks, or those which affect seismographs all around the earth, the positions of the origins of shocks and the times of their beginning are deduced from the seismographic records, but the formulæ for the deductions are necessarily based on instances in which the geographic position of the origin and the initial time of the shock are directly observed, and in which also the shock is so powerful as to give complete instrumental records at great distances. As precise seismography is a new science, the number of adequately observed great shocks is small and the formulæ are as yet tentative. The Yakutat shock of September 10, 1899, is now added to the group of shocks affording fundamental data, for it ranks high in the scale of energy, the position of its origin has been determined with unusual precision, and its initial time is known with close approximation.

The determination of surface deformation in connection with this earthquake, though restricted to a district which is manifestly only a part of the whole deformed area, is nevertheless exceptionally full and exceptionally valuable. Measurements of vertical displacement are numerous, nearly all of them are referred to sea level and are thus absolute instead of being merely differential, and the coast line is locally so intricate that the field of exact observation is areal instead of linear. The new configuration of the surface is compared with the old through an area of approximately 1,000 square miles, and the deformation is shown to include not only faulting, with associated uplift and downthrow, but tilting and warping of a complicated character. In the dominance of vertical displacement the tectonic changes of the Yakutat region are strongly contrasted with those of the California earthquake district, where horizontal movements dominate.

The response of neighboring glaciers to the seismic agitation is a phenomenon of capital importance to the study of glacier mechanics and glacier variation. If it can be traced through its complete cycle and observation extended to the reservoirs of the stimulated glaciers, an important body of data will be contributed to the subject of the reaction time of ice streams. And even if investigation stop at the present point, glaciology has the advantage of a new and independent explanation of glacier advance, coordinate with that afforded by the climate factors to which appeal has heretofore been made. It may reasonably be expected that seismic disturbance will successfully account for some of the outstanding anomalies and that the correlation of glacial with climatic fluctuation will eventually be improved by the elimination from the discussion of features presumably due to seismic influence.

Professor Ralph Stockman Tarr, senior author of this report, died suddenly at his home in Ithaca, New York, on the 21st day of March, 1912. His work on the report had been completed, except for the final revision of proof sheets. At the age of forty-eight, he was fairly at the zenith of intellectual activity; and as his life had been eminently fruitful, its untimely end occasions a loss which is far more than personal. His biography, when written, will be a record of distinguished achievement in physical geography. The present volume testifies to his high rank as an investigator, and his success was equally marked as a teacher and as an author of textbooks.

G. K. G.

THE EARTHQUAKES AT YAKUTAT BAY, ALASKA, IN SEPTEMBER, 1899.

By RALPH S. TARR and LAWRENCE MARTIN

CHAPTER I.

INTRODUCTION.

PRELIMINARY STATEMENT.

The earthquakes.—During the month of September, 1899, the region near Yakutat Bay, Alaska, was shaken by a series of severe earthquakes—so severe, indeed, that it seems probable that in the minds of geologists the name Yakutat will always be associated with these earthquakes rather than with the grand glaciers, fiords, mountain scenery, or any other features of the bay. The cause of these shocks was undoubtedly the renewal of growth in the St. Elias Range, one of the youngest and loftiest of mountain ranges.

Fortunately there was no great city near by, and in the small village nearest at hand there was no loss of life. Nor was there any injury to the few men who happened to be near the center of disturbance during several of the most severe shocks.

These earthquakes were attended by two notable results—great changes in the level of the land, incidental to faulting, and remarkable accompanying and subsequent changes in the adjacent glaciers. Preliminary descriptions of certain of the changes in shore lines and in glaciers in connection with the earthquake have already been published by both the authors of this paper, and a full description of the earthquake itself has been published by the junior author.[1]

The changes of level are the greatest recorded in historical times, the maximum uplift amounting to over 47 feet. The changes in the glaciers include a rapid retreat of Muir Glacier, 150 miles to the southeast, and a general advance of several glaciers near Yakutat Bay. Muir Glacier, which hundreds of travelers had visited annually up to 1899, became inaccessible to tourist vessels in that year and remained so till 1907. By 1903 it had retreated from 2½ to 3 miles, and by 1907 from 7½ to 8 miles, perhaps in part as an indirect result of this earthquake, and had lost much of its scenic interest. The advance of the glaciers near Yakutat Bay included the eastern or Marvine lobe of the great Malaspina Glacier and rendered that highway of glacier travel inaccessible through intricate crevassing. These and other effects will be discussed in detail after a brief topographic and geologic description of the region itself has been given.

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[1] Tarr, R. S., and Martin, Lawrence, Recent changes of level in Alaska: Science, new ser., vol. 22, 1905, pp. 879–880; Recent changes of level in the Yakutat Bay region, Alaska: Bull. Geol. Soc. America, vol. 17, 1906, pp. 29–64; Recent changes in level in Alaska: Geog. Jour., vol. 28, 1906, pp. 30–43; The National Geographic Society's Alaskan Expedition of 1909: Nat. Geog. Mag., vol. 21, 1910, pp. 1–54; Oscillations of Alaskan glaciers: Bull. Geol. Soc. America, vol. 21, 1910, pp. 758–759.

Tarr, R. S., Pacific coast earthquakes: Independent, vol. 60, 1906, pp. 954–962; The world's earthquake belts and causes of seismic shocks: Leslie's Weekly, vol. 103, 1906, pp. 422–423; The advancing Malaspina Glacier: Science, new ser., vol. 25, 1907, pp. 34–37; Second expedition to Yakutat Bay, Alaska: Bull. Geog. Soc. Philadelphia, 1907, pp. 1–14; Recent advances of glaciers in the Yakutat Bay region, Alaska: Bull. Geol. Soc. America, vol. 18, 1908, pp. 257–286; The Malaspina Glacier: Bull. Am. Geog. Soc., vol. 39, 1907, pp. 273–285; The Yakutat Bay region, Alaska: Prof. Paper U. S. Geol. Survey No. 64, 1909, pp. 35–95; The theory of advance of glaciers in response to earthquake shaking: Zeitschr. für Gletscherkunde, vol. 5, 1910, pp. 1–35.

Martin, Lawrence, Possible oblique minor faulting in Alaska: Econ. Geology, vol. 2, 1907, pp. 576–579; Alaskan earthquakes of 1899: Bull. Geol. Soc. America, vol. 21, 1910, pp. 339–406; The Hubbard Glacier, Alaska: Pop. Sci. Monthly, vol. 76, 1910, pp. 293–305; The National Geographic Society researches in Alaska: Nat. Geog. Mag., vol. 22, 1910, pp. 537–560.

Field work.—The authors were in the Yakutat Bay region from June to September, 1905, investigating its mineral resources, the senior author being chief of a United States Geological Survey party to which a grant, generously made by the American Geographical Society of New York, made it possible to add the junior author as physiographic assistant. In working out the stratigraphy and studying the coal resources and the placer-gold deposits, the party discovered evidences of the changes of level, the faulting, the advance of one glacier, and other changes, and made investigations of these phenomena in all parts of the fiord.

In the following year (1906) the senior author again visited the region for the United States Geological Survey, intending to cross the Malaspina Glacier and study the stratigraphy and the glaciers to the west. Although prevented from carrying out this plan by the great advance and accompanying crevassing of the glaciers, he made additional observations on the effects of the earthquakes, and special studies of the advancing glaciers.

In 1909 both authors and in 1910 the junior author revisited Yakutat Bay as leaders of expeditions sent out by the National Geographic Society of Washington to study the glaciers.

The two authors shared about equally in the field work of 1905 relating to the faulting and changes of level in the region. When they revisited this region in 1906, 1909, and 1910, they made slight additions to their first observations of the physical changes accompanying the earthquakes and also made the additional series of observations relating to the changes in the glaciers, as described in Chapter IV (pp. 55–57). The data in Chapters V–VIII (pp. 62–129), relating to the earthquake as a phenomenon, were obtained almost exclusively by the junior author.

Acknowledgments.—In the field work the authors are indebted for valuable assistance to B. S. Butler in 1905 and 1906; to O. D. von Engeln, J. L. Rich, and R. R. Powers in 1906; to W. B. Lewis, O. D. von Engeln, and E. F. Bean in 1909; and to W. B. Lewis, E. F. Bean, F. E. Williams, and R. B. Byers in 1910. They are also under obligations to Dr. G. K. Gilbert, of the United States Geological Survey, for reading and criticising the manuscript and for the preface which he has contributed to this volume; to Dr. R. D. Oldham, formerly superintendent of the Geological Survey of India, for the use of manuscript notes; to Mr. H. P. Ritter, for manuscript notes on the effects of the earthquakes at Cape Whitshed, west of the Copper River delta, and for the loan of newspaper clippings supplied through the courtesy of Superintendent O. H. Tittmann, of the United States Coast and Geodetic Survey; to several foreign correspondents, for seismograms, etc.; to Dr. H. F. Reid, of Johns Hopkins University, for critical suggestions and for the loan of newspaper clippings dealing with the earthquakes; to many persons in Alaska, British Columbia, Yukon Territory, and the United States, for replies to earthquake circulars; and to many others who have assisted in gathering the information concerning the earthquake itself, as it is recorded in subsequent pages.

GEOGRAPHIC RELATIONS.

The Yakutat Bay region (Pl. I) lies about midway on the great curve where the North American orographic axes bend toward Asia, the prevalent northwest-southeast trends of this continent being replaced by the east-west and northeast-southwest trends of western Alaska and eastern Asia. (See Pl. II.) The main ranges here are the Chugach Mountains (6,000–10,000 feet), near Prince William Sound and Copper River; and the St. Elias Range (10,000–19,000 feet) and Fairweather Range, to the southeast. Back of these are the Wrangell, Skolai, and Nutzotin mountains, eastward continuations of the great Alaska Range, of which Mount McKinley is the culminating point. Mount Wrangell, back of the Chugach Range, is an active volcano, and there are others in the Alaska Peninsula and Aleutian Islands, to the southwest. To the southeast of the Yakutat Bay region is the Canadian Coast Range, between which and the St. Elias and Fairweather ranges are Glacier Bay, Lynn Canal, and adjacent fiords and the cities of Skagway and Juneau. Valdez is on Prince William Sound, in the Chugach Mountains. Yakutat village is at the southeast entrance to Yakutat Bay.

The greater earth movements were probably confined to the Chugach, St. Elias, and Fairweather ranges. Although we have records of earth shaking over a wide area, our direct

observations were made only in the region about Yakutat Bay, which appears to have been the center of greatest disturbance during the earthquakes of 1899. A brief description of the physiography and geology of that region is presented in the following sections.[1]

PHYSIOGRAPHY.

Yakutat Bay is a deep indentation in the otherwise almost unbroken concave stretch of coast line between Cross Sound and Controller Bay. This smooth coast is backed by the lofty St. Elias and Fairweather ranges, the first reaching culminating heights in Mount St. Elias and Mount Logan, 18,000 and 19,540 feet, respectively. The mountains do not, however, rise directly from the sea, but are faced by a low foreland, or coastal plain (Pl. I), of glacial débris. The Yakutat foreland broadens from the southeast toward the northwest, and on the northwest side of Yakutat Bay is still occupied by the ice plateau of the piedmont Malaspina Glacier. Yakutat Bay, which lies about 40 miles southeast of Mount St. Elias, pierces the Yakutat foreland as a broad V-shaped bay. (See Pl. XIV, p. 30.) On its west side the bay is bordered by a low foreland of glacial gravels which are still being deposited by streams issuing from the Malaspina and other existing glaciers that lie behind the narrow strip of gravel and moraine.

On the east and southeast sides of Yakutat Bay the foreland forms the coast for only about half its length. This part of the southeastern shore line is very irregular and is fronted by an archipelago of low islands composed of glacial débris. The northern half of the bay has for its eastern shore a mountainous land, rising abruptly to elevations of 3,000 to 4,550 feet. (See Pl. XXII, p. 54.) This shore is straight and precipitous, and the mountain front against which the foreland is built also rises abruptly along a straight line which truncates the mountain spurs. (See Pl. XIV, p. 30.)

Yakutat Bay merges northward into a narrower arm called Disenchantment Bay, which is a true fiord, walled on both sides by steep mountains. It extends from Points Bancas and Latouche on the south to Hubbard Glacier on the north. Thus its head is an ice wall from 4 to 5 miles in length, the terminus of the largest glacier in the inlet except the piedmont ice mass of Malaspina Glacier. A second tidal glacier, the Turner, enters this part of the fiord through a valley in its west wall.

At Hubbard Glacier the inlet turns at a high angle, and thence on to its head it is called Russell Fiord. Close by, to the north, northeast, and northwest, mountains rise to elevations of 10,000 to 16,000 feet; but along the immediate shores of the fiord the mountains, though abrupt, rise only to elevations of 2,000 to 6,000 feet. Russell Fiord, which extends back toward the Pacific, roughly parallel to Disenchantment and Yakutat bays, is divisible into three sections—(1) a northwest arm, with straight mountainous shores; (2) a longer south arm, with a much more irregular mountainous shore line, and (3) the head of the bay, an expanded extension of the inlet where it passes beyond the mountain front out into the foreland. A small bay, Seal Bay, up whose valley lies Hidden Glacier, forms the greatest irregularity in the coast line of the south arm; but at the angle between the south and northwest arms a large fiord extends eastward, known as Nunatak Fiord. The tidal Nunatak Glacier forms its head.

The entire inlet—Yakutat Bay, Disenchantment Bay, and Russell Fiord—has the general shape of a bent arm, with the shoulder at the Pacific, the elbow at the head of Disenchantment Bay, and the fist at the expanded head of the bay, where the inlet extends into the foreland within 13 or 14 miles of the ocean. The distance from the ocean around to the head of Russell Fiord by boat is 70 or 75 miles. Our studies of 1905 extended along more than 150 miles of shore line in the bay and fiord, all parts of which were seen, and most of which was studied critically. Short visits were also made to the head of the bay in 1906, 1909, and 1910.

Everywhere the indications are that the inlet is deep. Soundings by the United States Coast Survey in Yakutat Bay show an irregular bottom deepening toward Disenchantment Bay. At the head of Yakutat Bay, near Point Latouche, the depth is 167 fathoms, or 1,002 feet. Soundings made in 1910 by the junior author, assisted by E. F. Bean, show that Disenchantment Bay and Russell Fiord are uniformly deep, with maxima of 939 and 1,119 feet, respectively.

[1] A more detailed discussion of the physiography and geology of the Yakutat Bay region will be found in a report by the senior author and B. S. Butler, Prof. Paper U. S. Geol. Survey No. 64, 1909.

Offshore from the mouth of Yakutat Bay the 100-fathom line lies 50 or 60 miles from the coast; beyond it the ocean bottom descends to a depth of 1,500 to 1,800 fathoms in a distance of 25 miles. Farther southeast, along the irregular mountainous coast, deep water is found much nearer the land; for instance, at Sitka the 100-fathom line lies about 10 miles from the coast, and beyond it the ocean deepens rapidly. From these facts it is evident that the region of straight-edged coastal plain, in which the mouth of Yakutat Bay lies, differs from the irregular mountainous coast line farther southeast in possessing a fairly broad continental shelf beneath the sea. It has been, and is still being, loaded by sediment from the huge glaciers whose torrential streams pour into the ocean in this vicinity.

GEOLOGIC STRUCTURE.

The northeastern shore of Russell Fiord, from Hubbard Glacier to Nunatak Fiord, is bordered by highly inclined slates of undetermined age. (See Pl. XXII, p. 54.) Our expeditions into the mountains along this shore discovered a variety of crystalline rocks, both igneous and metamorphic, and the glaciers bring down only rock of these classes. It is therefore inferred that the rocks in the mountains beyond the head of Disenchantment Bay and the northwest arm of Russell Fiord are all crystalline. All the north shore and the eastern two-thirds of the south shore of Nunatak Fiord are also bordered by crystalline rocks—granite and steeply dipping gneiss, schist, slate, and schistose conglomerate with stretched pebbles.

These crystalline rocks abut abruptly against younger, practically unmetamorphosed strata, both in the Hidden Glacier valley and on the south shore of Nunatak Fiord. This line of separation, interpreted as a fault (see Pl. XXII), would, if continued, extend along the northwest arm of Russell Fiord, on one of whose shores the rocks are crystalline, whereas on the other (the southwest) they are unmetamorphosed.

From the crystalline rocks to the foreland a complex, called the Yakutat system by Russell and the Yakutat group by the U. S. Geological Survey, forms all the mountains that border this part of the fiord. The strata consist of thin-bedded black shales and sandstones, thick beds of conglomerate, and a massive gray sandstone or graywacke, which, in some parts at least, is an indurated tuff. There are other beds in lesser amounts, and the entire mass is complexly folded and faulted, both on a large scale and in detail. Some faults and folds occur in all the outcrops, and a score or more may appear in a single outcrop a few square yards in area. The group is literally crushed and "kneaded." The beds of the Yakutat group are nearly barren of fossils, and it has not been possible to determine their age from the fossils collected. There are some indications that they are of Mesozoic age, and some that they are older. Ulrich[1] has classed them as Liassic (Lower Jurassic).

A third series of rocks was found in a few outcrops on the west side of Yakutat Bay, 2 or 3 miles from the mouth of Disenchantment Bay, just outside the mountain front. These rocks are mainly gray sandstones, clays, and carbonaceous shales, with a few thin beds of lignite coal. They are tilted at a high angle but are not as complexly folded and faulted as the Yakutat rocks, from which they are evidently separated by a fault. On the evidence of fossil plants they are assigned to the Pliocene epoch.

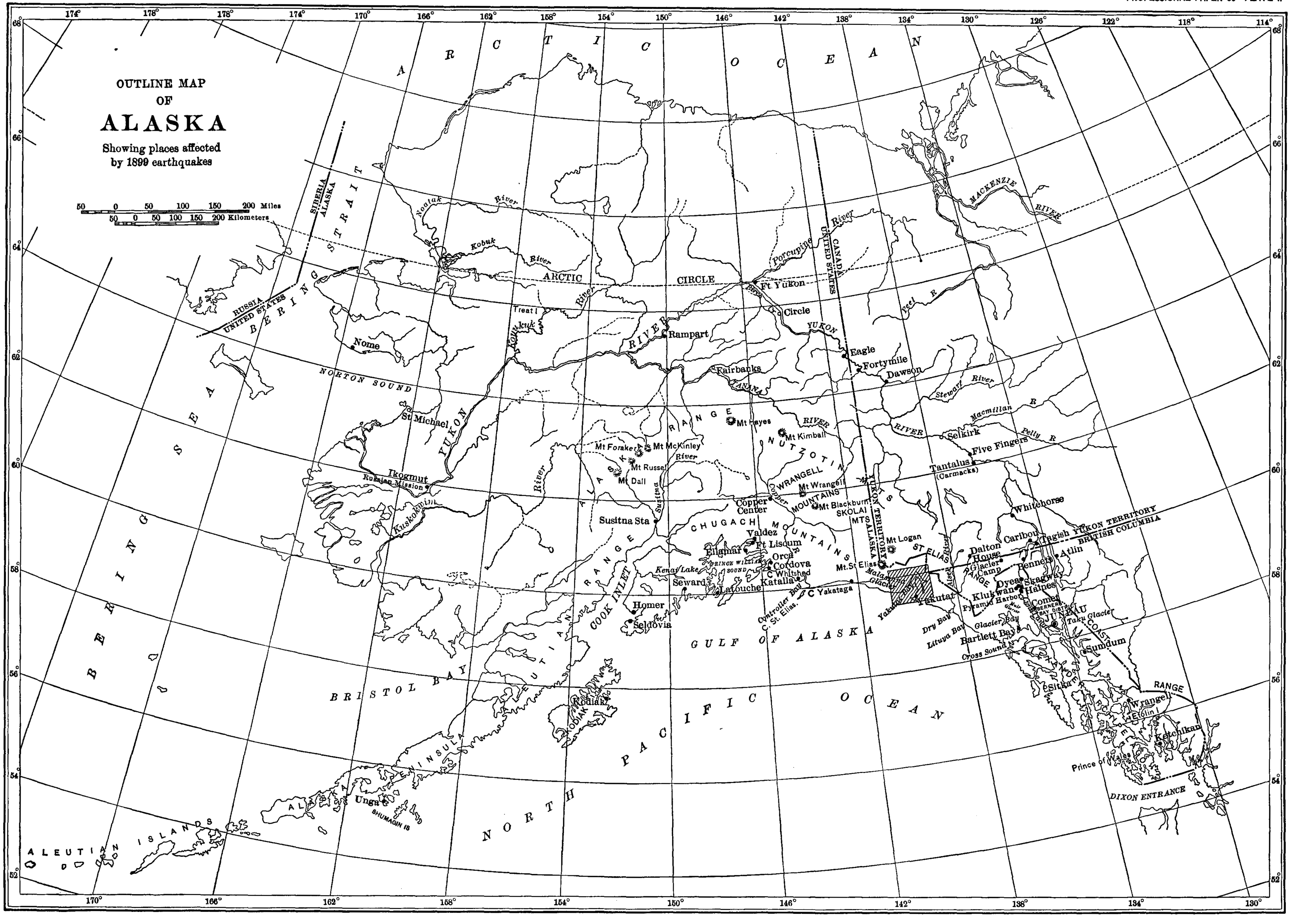
Outside of the mountain front, as already stated, a foreland of glacial gravels extends to the sea; but near the head of Russell Fiord it is underlain by planated Yakutat beds and granitic rocks. Elsewhere no indurated rock was found in the foreland; though a low, buttelike hill, that rises above it some distance from the mountains, is evidently hard rock.

EVIDENCE OF THE EARTHQUAKES.

FIELD EVIDENCE.

Before going to Alaska in 1905 we had seen one account of an earthquake in Yakutat Bay, in 1899, but many of the alleged facts were grotesque and failed even to encourage us to expect earthquake phenomena in the region. It was a thorough surprise to us, therefore, when, early

[1] Ulrich, E. O., Harriman Alaska Expedition, vol. 4, 1904, pp. 125-146.


OUTLINE MAP
OF
ALASKA
Showing places affected
by 1899 earthquakes
50 0 50 100 150 200 Miles
50 0 50 100 150 200 Kilometers
ARCTIC OCEAN
BERING STRAIT
BERING SEA
NORTON SOUND
BRISTOL BAY
GULF OF ALASKA
NORTH PACIFIC OCEAN
ARCTIC CIRCLE
RUSSIA
UNITED STATES
SIBERIA
ALASKA
CANADA
UNITED STATES
YUKON TERRITORY
BRITISH COLUMBIA
Nome
St Michael
Ikogmut
Russian Mission
Rampart
Ft Yukon
Circle
Eagle
Fortymile
Dawson
Fairbanks
Selkirk
Five Fingers
Tantalus
(Carmacks)
Whitehorse
Caribou
Tagish
Atlin
Bennett
Dyea
Skagway
Haines
Klukwan
Dalton House
Glacier Camp
Pyramid Harbor
Comet
Juneau
Sumdum
Sitka
Wrangell
Etolin I
Ketchikan
Prince of Wales I
DIXON ENTRANCE
Yakutat
Dry Bay
Lituya Bay
Glacier Bay
Bartlett Bay
Cross Sound
Mt St Elias
Mt Logan
Mt Hayes
Mt Kimball
Mt Foraker
Mt McKinley
Mt Russel
Mt Dall
Mt Wrangell
Mt Blackburn
Copper Center
Susitna Sta
Valdez
Ft Liscum
Ellamar
Orca
Cordova
C Whitshed
Katalla
Seward
Latouche
Kenai Lake
PRINCE WILLIAM SOUND
Controller Bay
C. St. Elias
C Yakataga
Homer
Seldovia
Kodiak
Unga
SHUMAGIN IS
ALEUTIAN ISLANDS
ALASKA PENINSULA
ALEUTIAN RANGE
ALASKA RANGE
COOK INLET
CHUGACH MOUNTAINS
WRANGELL MOUNTAINS
NUTZOTIN
SKOLAI MTS
ST ELIAS
COAST RANGE
Treat I
Noatak River
Kobuk River
Koyukuk
YUKON RIVER
Porcupine River
Peel R
MACKENZIE RIVER
TANANA RIVER
Stewart River
Macmillan R
Pelly R
Susitna River
Copper River
Kuskokwim
Malaspina Glacier
Yakutat Bay
Alsek River
Muir Glacier
Taku Glacier
BERNERS BAY DISTRICT
174° 178° 178° 174° 170° 166° 162° 158° 154° 150° 146° 142° 138° 134° 130° 126° 122° 118° 114°
68° 66° 64° 62° 60° 58° 56° 54° 52°
170° 166° 162° 158° 154° 150° 146° 142° 138° 134° 130°

in our work, we came upon clear evidence of recent uplift, in barnacles attached to ledges high above the reach of the present tide and among land shrubs. The association of these barnacles with an earthquake uplift occurred to us at once. Several days before we had seen the same phenomenon in the form of blue mussel shells, resembling clusters of blue flowers, attached to the rocks a score of feet above sea level. At that time, however, we did not associate them with a change of level or an earthquake, not recognizing them as shells from a distance.

Detailed observations were immediately commenced and continued along the shore line and in all trips inland, until practically every foot of a shore line 150 miles in length had been examined, and evidences of uplift, depression, faulting, avalanches, earthquake waves, and notable changes in at least one glacier, had been found and associated with the earthquake, about which the native canoemen furnished much information.

On returning to Yakutat at the close of the field work, inquiry was made at the village and further information was gathered about the effects of the earthquake at Yakutat. Mr. Flenner, one of the prospectors who experienced the Yakutat earthquake in Disenchantment Bay in 1899, was seen and interviewed, and his experience was carefully noted down and afterward verified by comparison with newspaper accounts written independently by two of his companions. We also talked at this time with Mr. Beasley, storekeeper at Yakutat, who experienced the earthquake 30 miles from its center, and whose account is referred to on subsequent pages. The main facts of the prospectors' experience follow.

TESTIMONY OF PROSPECTORS.

During the first half of September, 1899, eight men were in the fiorded portion of the Yakutat Bay inlet, near the point where Disenchantment Bay merges into Russell Fiord. There they experienced great earthquakes on September 3 and September 10, as well as many smaller shocks. They were in camp just east of the moraine-covered margin of Hubbard Glacier, washing the supposedly auriferous gravels in search of gold and platinum, and during the severe shock of September 10 they lost their outfits and nearly lost their lives. The men were J. Bullman, L. A. Cox, S. Cox, A. Flenner, J. P. Fults, jr., A. (or J. W.) Johnson, T. Smith, and D. Stevens. Two of these men have written accounts of their experience,[1] and on August 31, 1905, we talked with a third, Mr. Flenner, who is a very intelligent man, then working as a carpenter at Yakutat. The accounts of these men agree as to the principal facts.

As nearly as can be made out from the prospectors' descriptions, their camps were on the moraines and alluvial fans of Hubbard and Variegated glaciers (Pls. I, p. 12 and XIV, p. 30) a mile or less southeast of the ice cliff of Hubbard Glacier. Capt. Smith and the two Coxes were in camp on one side of a glacial stream, presumably the southeast; the other five prospectors were on the opposite side, nearer Hubbard Glacier. Here they experienced the earthquakes. Mr. Flenner stated in 1905 that after the first shock on September 3 they rigged up a home-made seismograph, consisting of hunting knives hung so that their points touched and would jingle under a slight oscillation. With this instrument (rude, perhaps, but more delicate than their own perception) they counted 52 shocks on September 10, up to the time of the heavy disturbance that caused so much damage.

From the narrative which Mr. Flenner gave us, and the descriptions in the newspapers by Dr. Cox and Mr. Fults, as well as from compiled accounts based on interviews with other members of these parties, and by elimination of the impossible, the main facts of the experience of these eight men are brought out in the following paragraphs. In all its details it is a thrilling story, and one wonders constantly how all the men escaped with their lives.

L. A. Cox,[2] whose camp was about 6 miles from the point where the shore lines were uplifted 47⅓ feet and about 2 miles in the other direction from the point where they were uplifted 7 feet, says:

> About 9 a. m. on the 10th we had a very severe shock, so violent that one could hardly keep his feet, the ground being very active in its movements, and the low alder brush shook and bent like reeds in a gale of wind. This shake

[1] Fults, J. P., jr., Seattle Daily Times, Sept. 28, 1899 (reprinted in Seattle Weekly Times, Oct. 4, 1899, and in New York Sun, Sept. 29, 1899). Cox, L. A., The Sitka Alaskan, Oct. 14, 1899 (the longest and most rational account we have seen).

[2] Sitka Alaskan, Oct. 14, 1899.

lasted about one and a half minutes, but was followed by others not so hard at intervals of every few minutes, some of the boys counting 52 shocks between then and 1.30 p. m., when we got the king bee of them all and the one that caused us so much trouble, loss, and discomfort.

J. P. Fults, jr.,[1] who was in the other camp near by, says:

On Sunday, September 10, at 9.30 there came another severe shock that was enough to throw a man off his feet. This was followed by slight shocks and trembles of the earth all that day until at 10 minutes to 2 o'clock came the biggest shaking up of all.

Dr. Cox goes on to describe the principal shock, saying:

We were sitting in our tent at the time and in our efforts to get outside S. Cox was piled up in the corner after being thrown headlong over the camp stove, while Capt. Smith and myself succeeded in getting hold of the tent pole and as long as the shake-up lasted we held on to keep from being thrown to the ground. This shock must have lasted two and a half to three minutes, the ground cutting some of the queerest capers imaginable. In addition to the circular motion of the preceding heavy shock it was waving up and down like the swells of the sea, only with considerably more energy.

Mr. Fults says:

The moraine[2] on which we were camped swayed and undulated so that men could not stand. * * * We ran from our tents, leaving everything behind, and were never able to rescue anything from it after. In the course of five minutes the Hubbard Glacier, 5 miles across its face, ran out into the bay for half a mile.[3] * * *

About 20 yards back of the beach and above us about 100 yards was a lake about 2 acres in area and 15 to 30 feet deep. This lake broke from its bed and dashed down upon our camp while we ran along the shore and escaped its fury. Everything went before it or was buried by the thousands of tons of rock that came down.

This deluge was almost immediately followed by one from the sea. A wall of water 20 feet high came in upon the flood from the lake and carried all débris back over the undulating morainic hills.

Dr. Cox says:

We heard a terrible roar in the direction of the bay, and on looking that way we saw a tidal wave coming toward us which appeared to be about 20 feet high and was preceded by some great geysers shooting into the air, some of which were several feet across and 30 or 40 feet high.

Our observations in 1905 prove that various parts of the adjacent shores of Disenchantment Bay were uplifted from 17 to 47 feet, and that in Russell Fiord the uplift nearest the prospectors' camps was over 7 feet. This uplift would naturally cause even greater waves than those made by the icebergs. The observers mentioned no water waves accompanying the earlier shocks, a fact which clearly indicates that at least a notable part if not all of the uplift occurred during the great shock at noon on September 10.

While these great waves were washing up on the shore the ground—so we learn from the accounts—was swaying and undulating and breaking up along jagged cracks. Threatened thus from both front and rear by waves and floods, with the ground trembling beneath their feet, and the thunder of crashing bergs and avalanches in their ears, it is small wonder that the prospectors ran to and fro aimlessly, not knowing whether to run to the high land first or to return to their tents for some of the provisions and blankets which were threatened by the waves.

The Smith-Cox party saved a few provisions, narrowly escaping drowning by a second 20 to 30 foot wave, and sought the high land behind them. The five men of the Flenner-Fults party, unable to reach elevated ground directly, ran back and forth while "the earth was rocking and swaying continually." The stream which separated them from the other party being temporarily divided so that they could cross, they waded waist deep toward the other camp. A little later the stream was joined once more in a raging, impassable torrent, swollen doubtless by water supplied from lakes in the moraine or along the margin of the glacier.

After the shocks had quieted down somewhat the men returned to the Smith-Cox camp and found their "little 12-foot boat safely lodged up among the alders and securely fastened

[1] Seattle Daily Times, Sept. 28, 1899.

[2] Probably not a moraine but an alluvial fan.

[3] Undoubtedly the front of Hubbard Glacier was so broken that great numbers of icebergs were discharged into Disenchantment Bay and Russell Fiord. This circumstance in itself would be enough to cause enormous waves, if one may judge by the waves seen from the same point and formed by an ordinary small discharge of bergs from the ice front in 1905. Several of the observers assert that during the heaviest shock (Sept. 10) the front of Hubbard Glacier advanced, or was thrust bodily forward, a distance variously stated as one-half to three-quarters of a mile. This seems hardly probable, and the statement may have had its basis in the enormous mass of ice suddenly thrown into the fiord, or released from beneath the surface.

by the action of the water wrapping the painter about a small alder." They also found 6 pounds of corn meal, 3 or 4 pounds of flour, and a small piece of bacon, all wet, a few canned goods, and a wet tent and blankets. The boats at the other camp had been "smashed to kindling wood" and all the provisions lost.

The united parties spent an anxious, uncomfortable, sleepless night on the mountain side, wet, hungry, and afraid. Says Dr. Cox:

Imagine, if you can, one's feelings under such conditions; then add to that the continual reports of the ice breaking off the glacier, the roar of great landslides down the sides of the mountains every little while, the noise of the swollen mountain streams tumbling down loosened bowlders, continuous rain, an occasional earthquake, and then the uncertainty of what was to come next—then you can form some idea of our situation that night.

Mr. Fults states:

We protected ourselves from being carried away by tearing up clothes and tying ourselves to the small alder trees growing on the mountain sides.

Three of the men had started next morning to Yakutat for aid when a damaged native canoe was discovered afloat in the fiord. It was procured and patched up, and the following morning the eight men, with scanty provisions, started in the two boats for Yakutat, over 30 miles distant. Indeed their provisions were so meager that they would have suffered from hunger before reaching Yakutat had not the earthquake waves cast upon the shores quantities of fish, killed by the shocks.

Had not the boats been at hand the position of the prospectors would have been desperate. They were cut off from escape in either direction by crevassed, impassable glaciers. They had practically no provisions. There was no timber, either trees or driftwood, to build a boat or even a raft. At that time of the year the natives rarely go up the bay, and it is doubtful if after the fright occasioned by the earthquakes either natives or whites would have ventured away from Yakutat to look for the missing men, even if anyone had remembered that they were there.

During the first day of their journey toward Yakutat the men encountered great difficulties because of the enormous quantity of floating ice, being obliged to carry the boats over some of the masses of bergs, but they succeeded in crossing the fiord. That night the sound of avalanches and the shifting of uneasy, overloaded streams made rest impossible. Next morning another start was made before daylight. By abandoning part of their outfit they lightened their load so that they reached the native sealing camp at Point Latouche (at that season abandoned) the next night. Here a delay was necessary because of the rough sea outside the point, and the load was further lightened by caching the tent, blankets, and part of their scanty supply of provisions. Dr. Cox says:

After getting outside we still saw the effect of the tidal wave and in places we could see where it had left its mark fully 60 feet up the bluffs. We then commenced to have grave fears for the safety of Yakutat. We knew if the wave had struck them with any such force the whole town was wiped off the face of the earth.

Yakutat was finally reached Thursday, September 14, and here the prospectors found the whole village camped in tents on the moraine back of the town, which to this day bears the name Shivering Hill.

EFFECTS OF THE EARTHQUAKES.

The physical changes brought about by the earthquakes, as already stated, include changes in the shore lines and changes in the glaciers. These changes will be described in some detail, as well as related accessory phenomena, such as notable faulting, earthquake water waves, and avalanches. Their essential unity will be made clear, the whole series of phenomena being correlated with the growth of the St. Elias Range and evidence of older faulting, changes of level, and glacial oscillations being brought out.

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CHAPTER II.

CHANGES IN SHORE LINES IN 1899.

RECENT UPLIFT.[1]

In the Yakutat Bay region, including Disenchantment Bay and Russell Fiord, the shore lines in some places show uplift; in others, less numerous, they show depression; and in other large areas outside the mountain front there has been no movement. By considering these and other differences in the deformed areas, a series of faults has been worked out, to movement along which are attributed at least some of the earthquakes which this paper discusses. The evidence of recent uplift is (*a*) physiographic, (*b*) biologic, and (*c*) human, and these three kinds of evidence will be discussed in the order named.

PHYSIOGRAPHIC EVIDENCES OF RECENT UPLIFT.

ELEVATED SEA CLIFFS AND ROCK BENCHES.

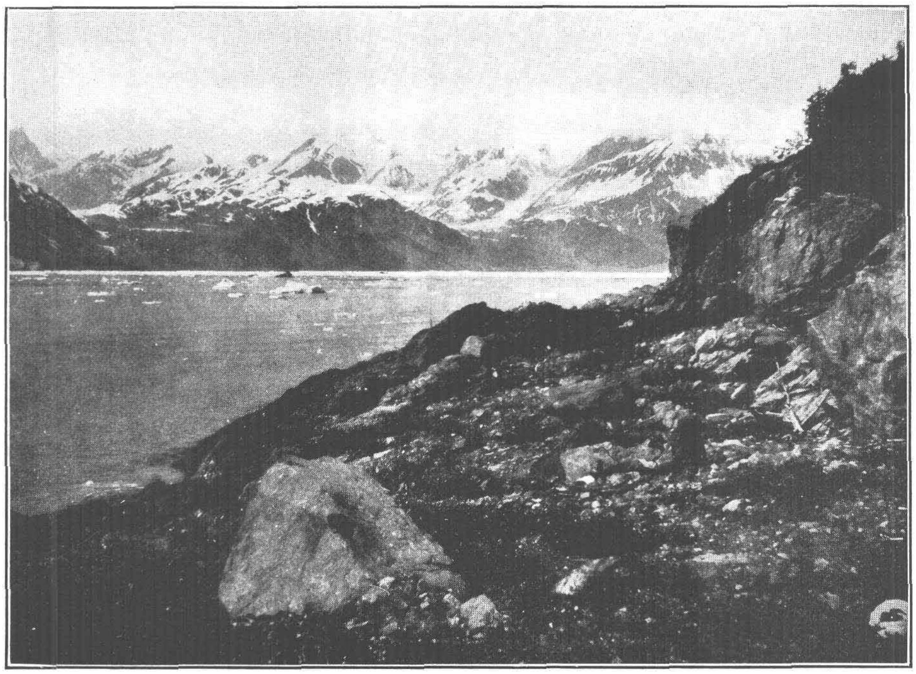
Notching the fiord walls at various levels is a series of sea cliffs, which the waves had cut in the headlands and mountain slopes before the earthquakes of 1899, and which, with their associated rock benches (Pl. III, *B*), were hoisted above sea level during the faulting. The benches are broadest and the cliffs highest where the weaker rocks outcrop on exposed points; and they are narrowest and the cliffs lowest where the more resistant strata occur. They are, however, planed back indifferently across weak and resistant strata, across vertical, highly inclined, faulted, and gently folded rocks. They vary in width from 2 to 40 feet (Pl. XI, *A*, p. 24) and are affected in size by opportunities for wave work as well as by resistance of rock, being usually widest on the headlands and narrowest where the coast is straight. Though generally flat-topped, the benches are in places diversified by remnants of the more resistant rocks, which form fossil reefs, stacks, or skerries upon the uplifted benches (Pl. V, *B*). They are not yet modified greatly, though the streams that tumble down over their edges to the new sea level have begun to cut gorges in their surfaces.

These cliffs and benches give an excellent illustration of the rate and amount of wave work, for in 1905, six years after the uplift, the sea had not cut an appreciable sea cliff or rock bench anywhere; indeed, in many places it had not even erased the glacial striæ at the new level. Doubtless many times six years will pass before travel will be possible along the new wave-planed notch, as it now is along the elevated bench above.

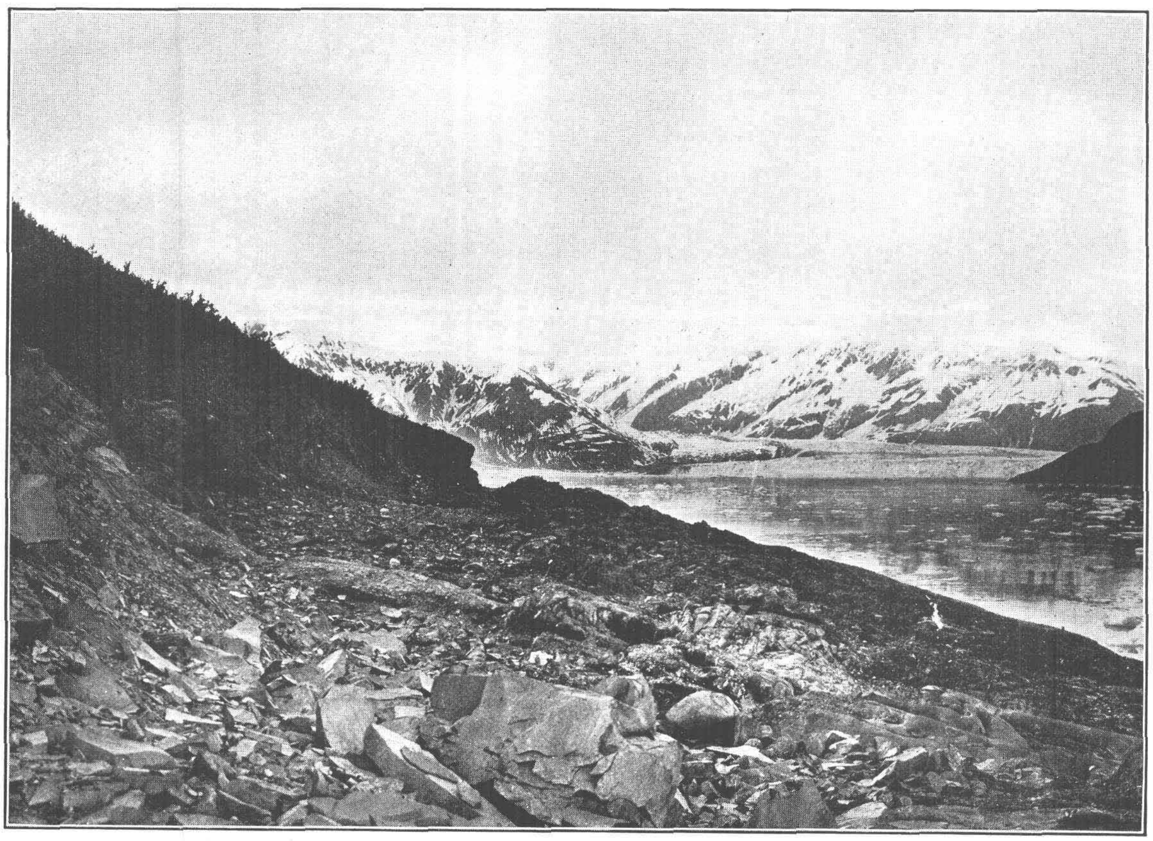
The old and new notches, of course, merge into each other where the uplift was slight; and the identification of a slightly elevated sea cliff and bench is complicated by the fact that in former times, when the glacier fronts were near by, iceberg waves had in places cut faster and 2 or 3 feet higher than the normal waves. These iceberg-generated waves have not seriously complicated the study of the elevated benches, however, for they occur at only two or three places, near Hubbard and Nunatak glaciers; the best elevated benches are far distant from the ice fronts and are uplifted from 10 to 40 feet (Pl. IV, *B*), so that they admit of no confusion as to origin.

These elevated benches are not remnants of glacial marginal channels, as is proved by the barnacles and other sea forms still attached to their ledges. All in all, they form one of the most striking, obvious, and spectacular of the physiographic evidences of uplift.

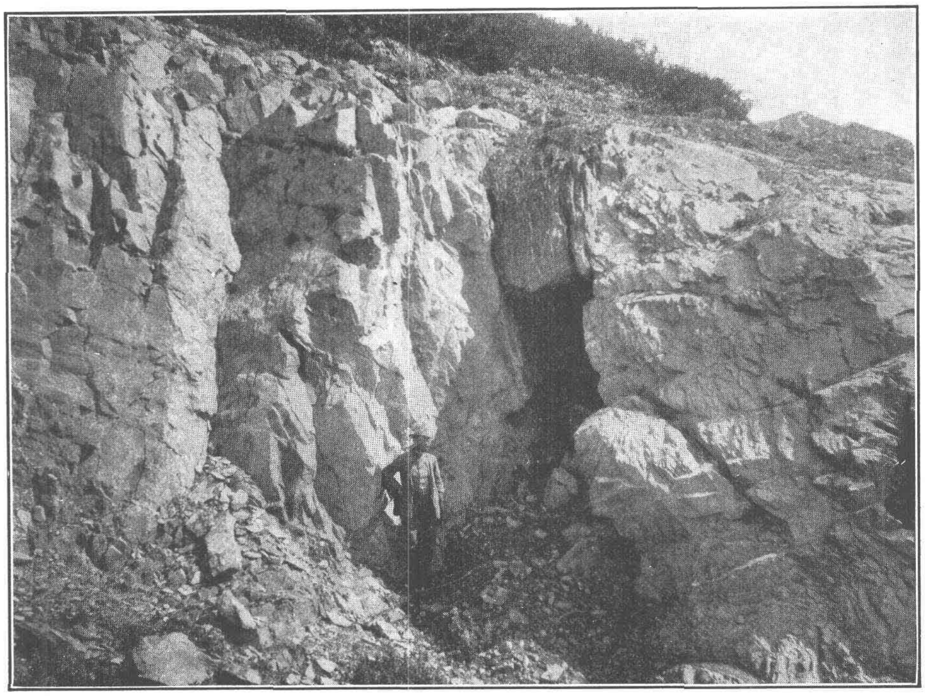
[1] Tarr, R. S., and Martin, Lawrence, Bull. Geol. Soc. America, vol. 17, 1906, pp. 29-64.



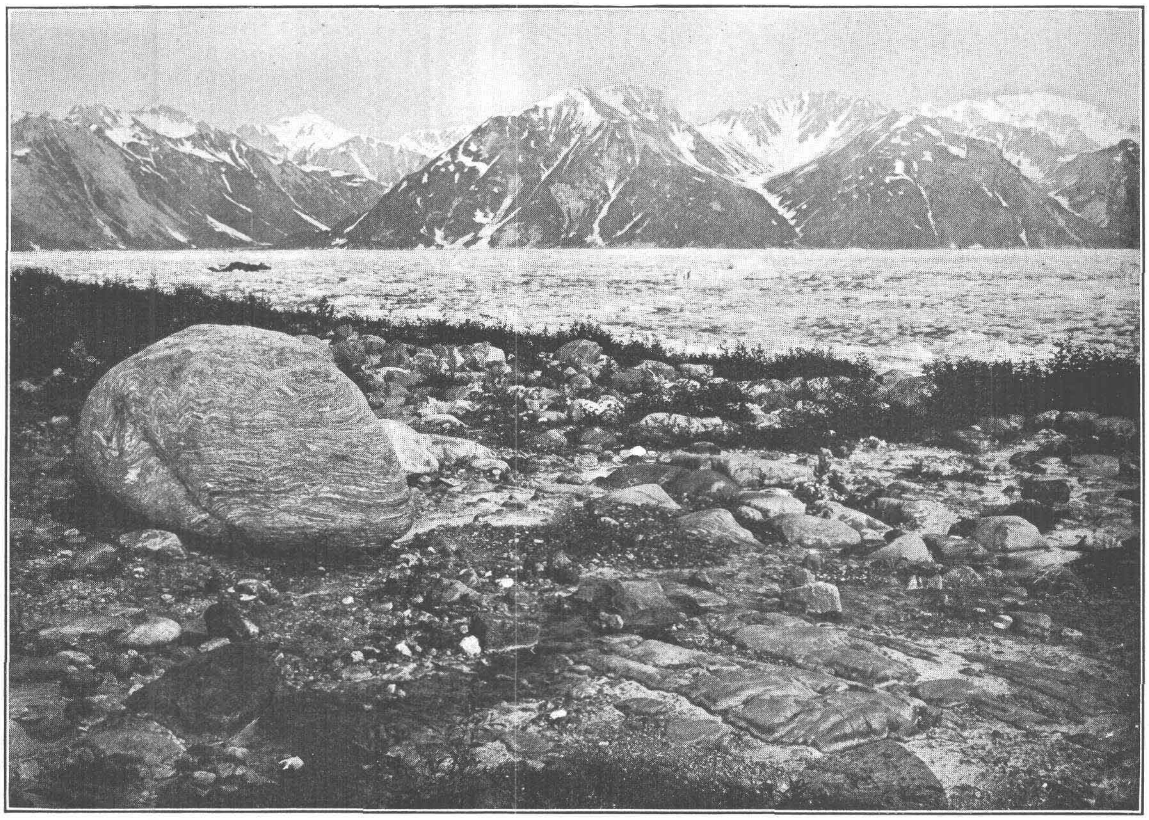
A. WAVE-CUT BENCH ON EAST SHORE OF DISENCHANTMENT BAY.
Uplifted 17 feet 8 inches. Photographed in summer of 1905.



B. WAVE-CUT BENCH AND SEA CLIFF ON EAST SHORE OF HAENKE ISLAND.
Uplifted 17 feet 7 inches. Photographed in summer of 1905.



A. ELEVATED SEA CAVE ON EAST SHORE OF DISENCHANTMENT BAY NEAR HAENKE ISLAND.
Uplifted 17 feet. Photographed in summer of 1905.



B. WAVE-PLANED BENCH AT BANCAS POINT, MOUTH OF DISENCHANTMENT BAY, WEST SIDE.
Uplifted 42 feet. Photographed in summer of 1906 by O. D. von Engeln.

ELEVATED BEACH BETWEEN BANCAS POINT AND TURNER GLACIER (IN BACKGROUND), ON WEST SIDE OF DISENCHANTMENT BAY.

Uplifted 47 feet 4 inches. White bryozoan patches on cliff in foreground. Photographed in summer of 1905.

ELEVATED SEA CAVES AND CHASMS.

As the tops of the elevated rock benches are diversified by reefs, stacks, and skerries, so the sea cliffs at their backs and edges are made irregular by chasms and sea caves, due also to the variable resisting power of the component rocks. In the Yakutat group, for example, many chasms and caves are cut in thin-bedded black shales and sandstones and roofed by more resistant indurated tuff, graywacke, and conglomerate strata (Pl. IV, *A*). Chasms are just beginning to be cut at the new sea level, but both sea caves and chasms were formed and perfected at the old sea level and were uplifted with the benches; they now form sheltered retreats for ferns and land shrubs whose roots are growing in the gravel and sand which, before the uplift, the waves used as tools to hollow out these irregularities in the coast. The dead barnacles and mussels form incongruous neighbors for the living shrubs, which would formerly have been killed by the salt water or uprooted by the waves.

Some caves, not uplifted greatly, are only half dry, the waves still coming into their lower portions, and some are not appreciably changed. One great cavern on the south side of Haenke Island is of this semiabandoned type, as a comparison of its present condition with that before 1899 described by the natives attests, although the uplift here was fully 18 feet. There are scores of uplifted sea caves and hundreds of abandoned chasms in different parts of the fiord.

RAISED BEACHES AND SAND DUNES.

Of course, when the waves excavated caves, formed sea cliffs, and planed back benches at the older stand of the land, they disposed of some of the material by building at accordant levels (Pl. V, *A*) sand, gravel, and bowlder beaches, which were also uplifted in 1899. Practically all this material above tide level was built into pocket beaches; for the depth of water and the short time since the glacier retreated from these shores usually prevented the formation of bars, spits, and barriers, as is shown by the general immaturity of the elevated shore lines and the notched headlands associated with them.

These beaches have been best preserved where they were lifted highest, or where streams do not cross them or waves cut directly into the gravel at their bases. Some such beaches, built upon a rock platform not gullied by streams nor reached by the present waves, look at first glance like present-day strands (Pl. V, *B*, *C*). They might be thought to be only ordinary beaches at low tide, were it not for the scarp at the front or the young shrubs beginning to spring up on the sand of the idle sea mill (Pl. V, *A*). One such beach south of Turner Glacier, uplifted 37 feet (Pl. V, *B*, *D*), presents expanses of deserted shore line half a mile long and 200 feet or more in width, between headlands, making excellent camp sites or highways of travel, especially on stormy days or at high tide, when the present beach is in places impassable.

Not all such beaches are well preserved, many of them being nearly destroyed by stream gullying and many being cut back by the present waves, although where the cross-bedded sand and gravel of the elevated beach rests on a bedrock basement (Pl. VI) the waves are relatively impotent and the life of the elevated beach is long preserved. Many elevated beaches which were well preserved in 1905 were nearly destroyed by streams and waves when we revisited them in 1909.

Still other upraised beaches are only slightly recessed behind the present beach (Pl. VII, *A*, *C*), outbuilding having gone on rapidly after a relatively slight uplift. Here and there an exceptionally broad beach, such as the one over 300 feet wide southeast of the delta of the Variegated Glacier stream, is made up of the continuous slope of an old, slightly elevated beach, and a new one (Pl. VII, *B*), the two being separated only by a line of driftwood or seaweed or an inconspicuous storm-beach crest. When it is desired to camp back of the highest storm beach of the former strand a long carry is often necessary for camp outfit and provisions and boats from sea level at low tide across the double beach to the camp site.

A belt of sand dunes, uplifted 42 feet with the raised beach on the west side of Yakutat Bay near Black Glacier, is no longer in the active movement usual in sand dunes, for the beach does not now supply the sand for the wind to heap up in dunes. Accordingly, grasses have grown freely upon its surface, and in 1909, 10 years after the uplift, this belt of dunes bore no traces of its former active condition except the hummocky surface and the sandy soil.

UPLIFTED DELTAS AND SPITS.

While benches were being carved in the headlands and beaches built in bay heads and other places along shore before 1899, the streams flowing into Yakutat Bay and its branches were building deltas at their points of discharge. Such of these deltas as were uplifted during the changes of level are not at all different from actively growing deltas except as they have been affected by the change of base-level. The effects of this change, however, are notable. One is seen in the trenching of the fan-shaped deltas by gullies, a process directly consequent on the uplift and rejuvenation of the stream. Many of the gullies are 20 feet or more in depth and reveal both the steeply dipping foreset beds and the gently inclined topset beds (Pl. VIII, *A*). Doubtless this dissection was quickly done by the streams whose base-level was abruptly lowered by the uplift. Most of these streams have now resumed the aggradation characteristic of well-loaded streams either at their mouths or at places of change of grade (such as that below the lip of a hanging valley), and are building new deltas, whose alluvial fans may extend up into or even partly through the bisecting gully or gullies.

Another quick change consequent on the uplift is the nipping back of the front of each delta by the waves and its fashioning into a low cliff 5 to 25 feet high (Pl. VIII, *B*), the height varying with the amount of uplift, the part of the delta reached, the steepness of the surface slope, the exposure to wave cutting, and the time available before the material brought down by the stream, carried by alongshore currents or eroded from the cliff, checked the process of wave cutting by building a deposit in front of the cliff, such as was built in many places between 1899 and 1905. A growth of annual, perennial, and woody plants has followed the abandonment of the uplifted delta tops, which make excellent camp sites where they are not too deeply gullied and on which gulls and ptarmigans now nest—a thing they would never do if the slope was made dangerous by the shifting of heavily loaded streams.

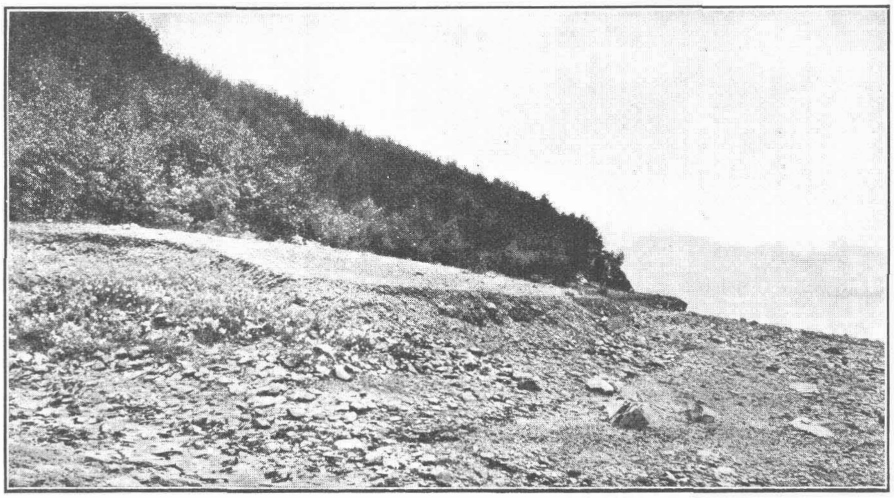
As already stated, sand spits, bars, and barrier beaches are uncommon in the uplifted parts of the Yakutat Bay inlet. One of the three sand spits that existed in Russell Fiord before 1899—a spit at Cape Enchantment that connected an island with the mainland at low tide—was uplifted so much that the highest tides do not cover it.

TILL SHORE LINES.

The presence of glacial till as the material of a shore that is exposed to vigorous wave attack would of itself be good evidence of the youth of the beach; and about the shores of Yakutat Bay this phenomenon furnishes clear proof of the recency of the change which has started the waves to cutting at a higher or lower level. At several places on the east and west shores of Disenchantment Bay the beach consists of compact, unoxidized blue till with abundant small, angular, striated pebbles.

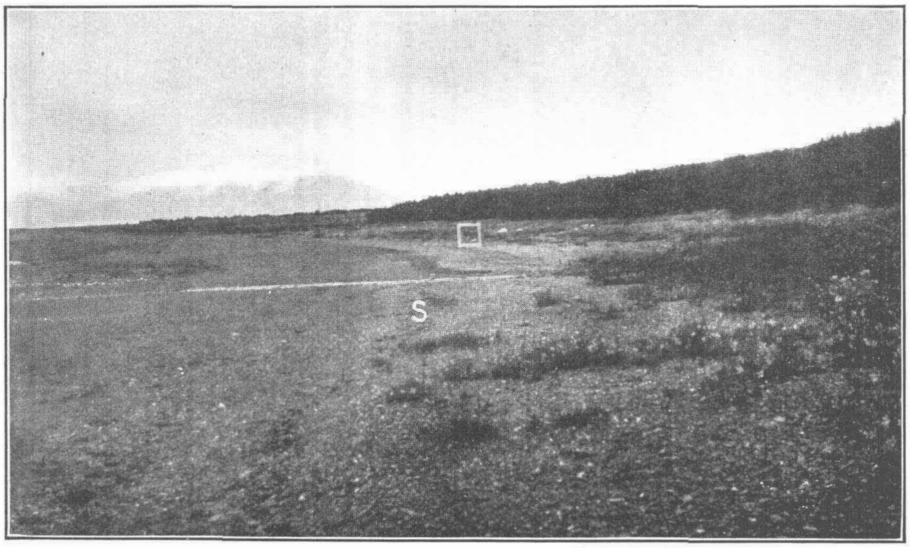
From the character alone of these till shore lines it would be impossible to say whether uplift or depression had taken place, but it happens that they all are so located, with raised beaches on each side and above (Pl. VIII, *B*) or with barnacles or mussel shells on the rocks above, as to denote uplift. Although the material is classified as till it is possible that some of it is a marine silt filled with angular scratched pebbles supplied by melting icebergs.

The till shore lines were seen only in protected spots along rock shores and in front of narrow pocket beaches, the till elsewhere being doubtless deeply buried before the uplift. These will be the first of the physiographic evidences of uplift to be destroyed, and it is rather remarkable that any of them persisted from 1899 to 1905, for the waves are fast rounding the angular pebbles and erasing their glacial scratches, and the blue clay is fast going offshore in suspension, as can be seen by the muddy water offshore from each till shore line—a visible evidence of the evanescent character of these strands and the relative recency of the uplift that produced them.



A. ELEVATED BEACH AND SEA CLIFF ON NORTHEAST SHORE OF RUSSELL FIORD OPPOSITE MARBLE POINT.

Uplifted 7 feet 1 inch. Dissected by streams and waves at present level of land. Notch at left represents older elevated sea cliff. Photographed in summer of 1905.

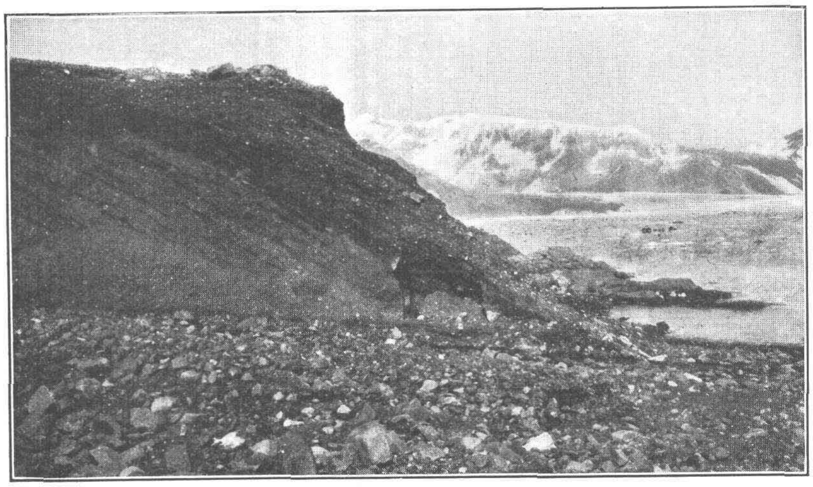


B. ELEVATED BEACH ON NORTHEAST SHORE OF RUSSELL FIORD. JUST SOUTH OF CAMP OF PROSPECTORS, NEAR VARIEGATED GLACIER.

Uplifted 7 feet 7 inches. Young plants in foreground; present seaweed line at S. Square shows uppermost limit now reached by waves. Photographed in summer of 1905.

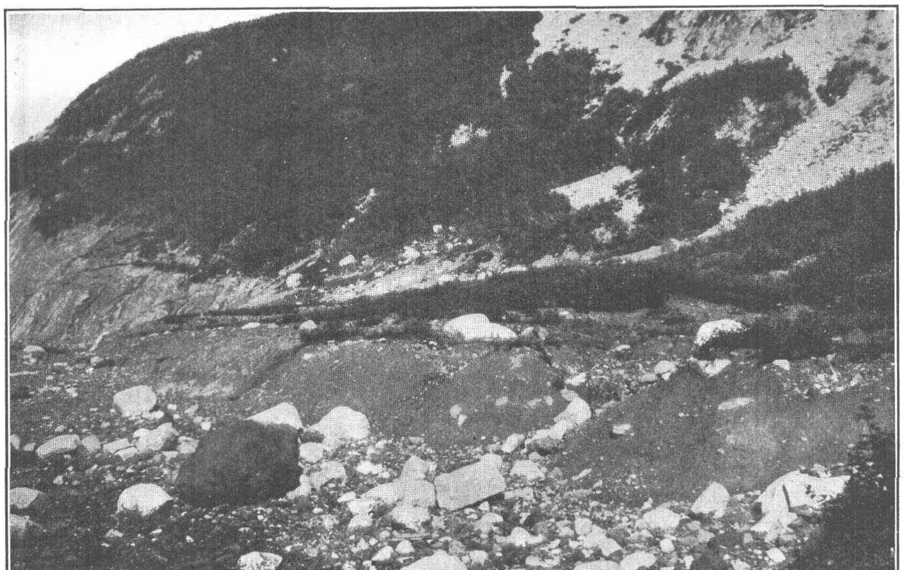
C. ELEVATED BEACH ON NORTHEAST SHORE OF RUSSELL FIORD OPPOSITE MARBLE POINT.

Uplifted 7 feet. Scattered annual plants growing on elevated beach. Photographed in summer of 1905.



A. DISSECTED DELTA ON WEST SHORE OF DISENCHANTMENT BAY NEAR TURNER GLACIER.

Uplifted 38 feet 8 inches. Photographed in summer of 1905.



B. ALLUVIAL FAN ON EAST SIDE OF DISENCHANTMENT BAY NORTH OF HAENKE ISLAND.

Uplifted 17 feet 11 inches, causing dissection by waves and streams. Photographed in summer of 1905.

NEW REEFS AND ISLANDS.

A striking example of the hazard involved in sailing uncharted waters is afforded by one of the reefs uplifted during the 1899 earthquake. In June, 1899, when the Harriman expedition vessel *George W. Elder* sailed into Yakutat Bay and followed Russell Fiord to its very head, she must have passed very close to a couple of concealed reefs between Haenke Island and the Hubbard Glacier (see Pl. XIV, p. 30), which were hoisted above water three months later. W. H. Dall, of the Harriman expedition, states that a native pilot told him of a submerged rock thereabouts. In 1905 our native canoemen, who frequent this part of Disenchantment Bay every year while seal hunting, assured us that these rocks were not visible, even awash, before September, 1899. There are now two long, narrow reefs, the largest perhaps 50 by 250 feet. They are awash at high tide and thoroughly uncovered when the tide is low. All about them the fiord is deep, icebergs never stranding here. Unfortunately no soundings were made in this part of Yakutat Bay before 1899, so that it is impossible to prove anything here or elsewhere in the fiord by soundings.

Small icebergs now strand on the rounded, glaciated surfaces of these reefs, depositing their burden of small bowlders as they melt. Numerous large bowlders on the crest of the islets, too high to have been deposited since 1899 unless pushed up in winter by ice shove, suggest deposition by stranded icebergs before 1899, when the water is thought not to have been very deep on the reefs;[1] this is also suggested by the sea weed growing upon these bowlders.

Another group of new islets rose above the sea in 1899 southeast of Knight Island, near the head of Eleanor Cove. (See Pls. IX, *B;* XIV.) The native canoemen state that of the four small islets now here, none were formerly visible at high tide and only two showed at low tide. Now two are exposed at all stages of water and the other two between mid and low tide. Three of these islets are rock and one of gravel, perhaps covering rock. The two smallest are 50 feet long, the two largest each 450 feet long and 75 feet wide. The longer axes of these reefs are parallel to one another and to the mountain front near the foot of Mount Tebenkof. They lie almost exactly along a fault line of which we have other evidence, and we believe them to have been uplifted by movements along this fault line during the 1899 earthquakes. The natives' testimony supports this theory, as does also the fact that at the top of the highest islet, 3 feet above high tide, are dead barnacles attached to the bedrock.

In many other parts of the inlet, notably on the east side of Disenchantment Bay, there are numerous channels, not now passable for canoes, along which, according to the natives, boats could formerly pass between small reefs and stacks and the shore. Dead barnacles attached to the rocks in several such localities support this statement.

LAND AREA ADDED BY UPLIFT.

The amount of land which emerged from the sea during these changes of level far exceeds the amount submerged by the sea in places where there was depression, both the length and the width of the depressed shores being slight. The amount added by uplift was not very great, however, considering that the vertical uplift was from 10 to 47 feet over large areas, because the shores of the fiord are steep and the water near shore is deep. Slopes as great as 30° between the new and the old strands are the rule, and vertical or overhanging slopes are not uncommon. (See Pls. III, p. 16; V, p. 18; VI, p. 18.) Of course on the beaches and deltas this is not true. the coast there having migrated seaward in places as much as 100 yards.

Haenke Island forms a fair criterion for conditions in the whole region, the shores being about as steep as those anywhere else and the beaches forming the average small percentage of the whole coast. Russell speaks of only one place on the island where it was possible to land in 1890, while now there are a good many; one other landing place, however, seen in 1905, must have been available in 1890 though probably not noticed by Russell.

[1] The uplift on the nearest land raised in 1899 is 17 and 18 feet.

The uplift of this island was 17 to 19 feet, the rock bench being in places at least 100 feet wide. On the beaches the breadth of the upraised strand is wider still. It is estimated that 25 or 30 feet of new land, on the average, was added along the whole shore of Haenke Island, increasing the area of the island by 8 or 9 acres.

Assuming that there was uplift along 100 out of the 150 miles of coast of Yakutat Bay and its branches, and that an average width of 25 feet was thereby added to the land, we should still have a total area of only about half a square mile taken from the sea.

BIOLOGIC EVIDENCES OF RECENT UPLIFT.

BARNACLES.

It seems doubtful whether barnacles have ever before served as an evidence of faulting, as they have done along the shores of Yakutat Bay. Here dead forms of two species (*Balanus cariosus* Darwin and *B. porcatus* Darwin[1]) still cling to the rocks of the elevated shore lines, in many places in far greater abundance than the living forms at present sea level. Few of the living barnacles have attained a diameter of over three-eighths of an inch, and they contrast strongly with the giant dead barnacles (Pl. X, *A*), many of which are 1½ inches in diameter. The forms were well preserved in 1905, six years after they were killed by being hoisted out of the reach of salt water; in many of them the valves were still held together by the organic tissue, though most retained only the outer shell.

These white shells, firmly attached to the rocks upon which they grew till 1899 (Pl. IX, *A*), are a striking feature along the shores of the fiord, especially upon precipitous and overhanging cliffs. They are rarely absent where other evidence suggests that the shore lines have been uplifted, except where the ledges are weathering too rapidly to retain them, and they are usually the first evidence of uplift seen from a boat, though in some places they were hidden in 1905 by annual plants and by 4 or 5 year willow and alder shrubs.

Dead barnacles no longer attached to the rocks are not convincing evidence of uplift, nor are the dead barnacles adhering to beach bowlders, because such objects might be thrown up during an earthquake wave to a point higher than the sea level where the barnacles lived. The barnacles on bowlders were never accepted as evidence of uplift during our study, unless others were found adhering to the adjacent ledges at points equally high.

It was the dead barnacles fastened to the ledges among grasses and alder shrubs that first called our attention to the change of level, for we noted these even before we had observed any of the uplifted physiographic forms or had recognized other biologic evidence or had gathered evidence from men. The barnacles were even more important as the chief source of specific information with regard to the amount of uplift at various points (see p. 29), and in this way were markers for the faulting.

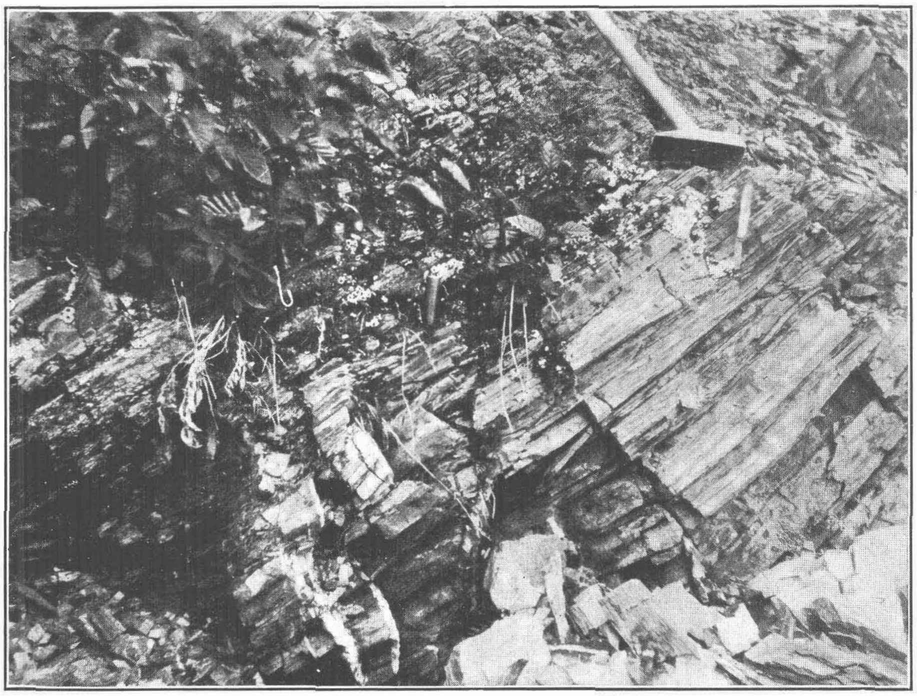
MUSSELS.

Another marine animal whose fossil remains furnish proof of the uplift is the common mussel, *Mytilus edulis* L. (Pl. X), these forms being only a little less widely distributed than the barnacles on the rocks of the uplifted shore lines. Where found they are even more abundant than the barnacles. This is one of the forms which Russell found 5,000 feet above sea level at Pinnacle Pass near Seward Glacier in 1890.[2]

As previously stated, one of our early observations, before we realized that an uplift had taken place, was that what seemed to be clusters of blue flowers were attached to bare ledges 18 feet or more above present sea level. These, we found later, were mussel shells which had turned blue since the death of the animals, caused by their removal from salt water.

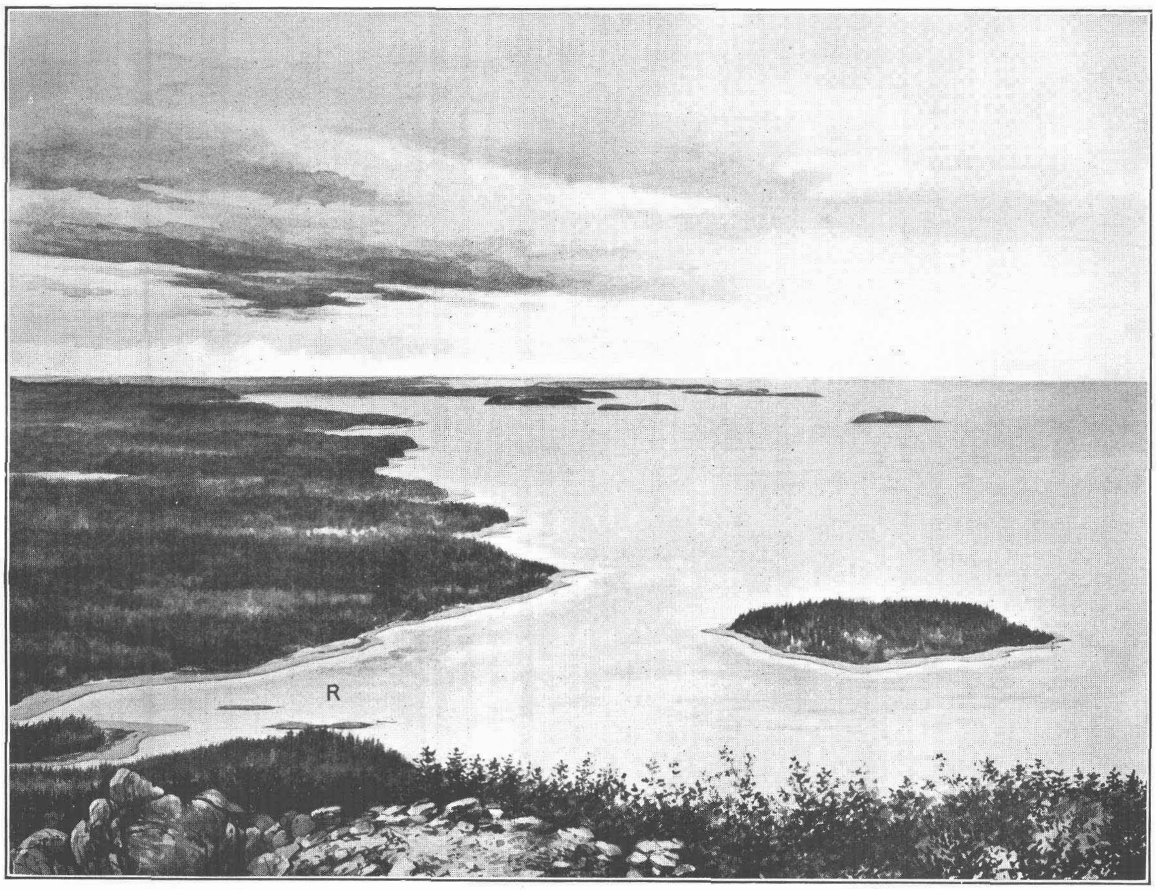
In many places these mussel shells were still firmly attached to the rocks by the delicate hairlike byssus. That the organic parts were still preserved in 1905 is additional proof of the recency of the movement.

[1] We are indebted to Dr. W. H. Dall for the identification of the marine animals collected on the elevated shore lines in 1905.
[2] Russell, I. C., Nat. Geog. Mag., vol. 3, 1891, p. 172.



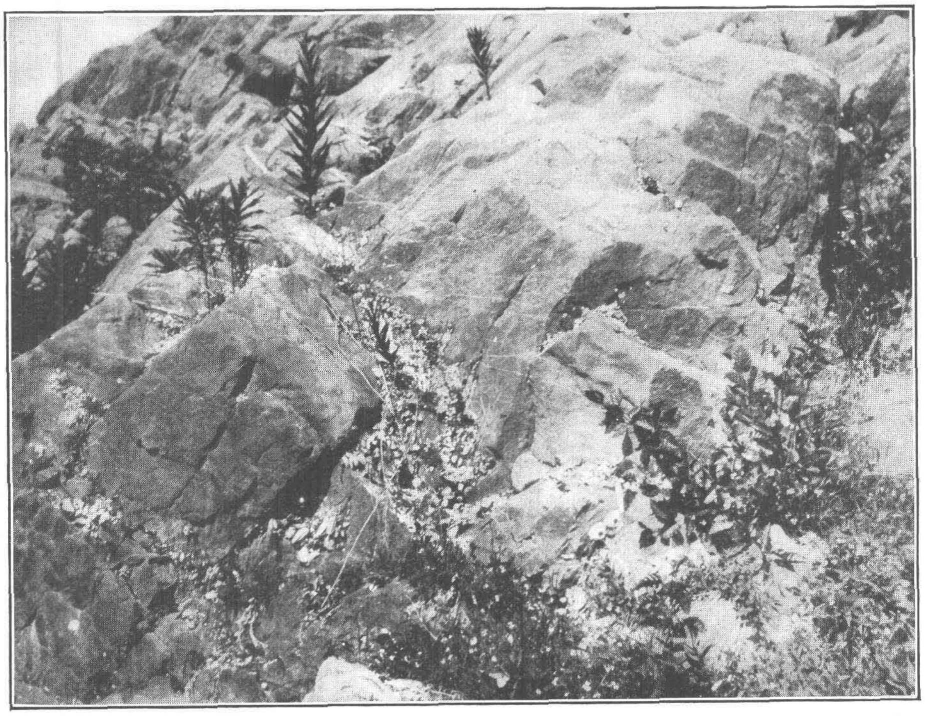
A. DEAD BARNACLES CLINGING TO ROCK AMID FOUR-YEAR-OLD ALDER BUSHES ON NORTHEAST SHORE OF RUSSELL FIORD, NEARLY OPPOSITE MARBLE POINT.

Uplifted 7 feet 6 inches. Photographed in summer of 1905.



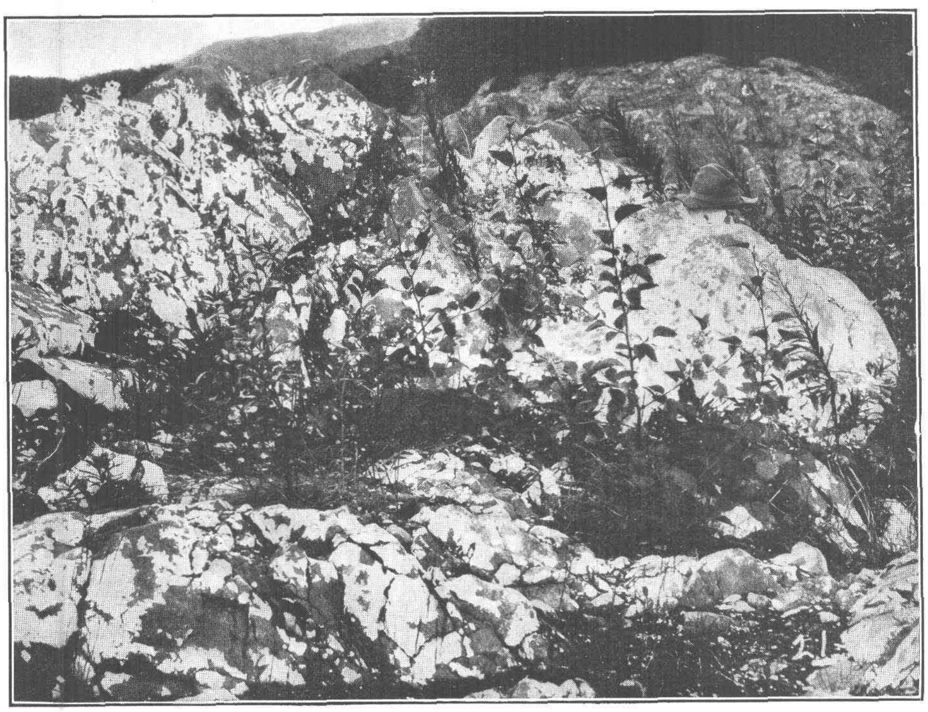
B. NEW REEFS (R) IN ELEANOR COVE, UPLIFTED IN 1899.

Photographed from an elevation of 1,600 feet in summer of 1905.



A. MUSSELS AND LARGE BARNACLES CLINGING TO ROCK 17 FEET 11 INCHES ABOVE HIGH TIDE, JUST NORTH OF HAENKE ISLAND.

Photographed in summer of 1905.



B. WHITENED ZONE OF BRYOZOAN REMAINS, SHOWING ELEVATION, ON WEST SHORE OF DISENCHANTMENT BAY.

Uplifted 39 feet 11 inches. Young alders growing among the Bryozoa. Photographed in summer of 1905.

JUXTAPOSITION OF LAND AND SEA LIFE.

Incongruity in the flora and fauna of the shore strip is a natural though transitory consequence of changes on the earth's surface. It looks odd, nevertheless, to see the same zone occupied by representatives of two ordinarily distinct regions. Before the uplift the realm of the barnacle, the mussel, and allied marine forms was reserved to them alone; any alien, like an alder bush, was quickly killed by a splash or two of salt water. Then came the uplift. Now the willow and alder, the wild geranium, and other land plants are springing up in the old habitat of the sea plants and animals, which, unable to persist out of salt water, have died, some of them leaving their limy skeletons as if in mute protest against the invasion of their territory (Pls. IX, *A;* X).

These land plants, which are found on nearly all the raised beaches and deltas and on some of the uplifted rock benches, form a valuable part of the record, affording a minimum determination of the time since salt water has washed the elevated strands (Pl. VII, *C*, p. 18). Of course the grasses and the flowering annuals and perennials (Pl. XI, *B*) tell but little, though their scattered condition plainly demonstrates recency of uplift; but the woody shrubs, like the willow and alder, are significant. They are invariably small (Pl. XII), and of all we cut down in 1905 none showed more than five annual rings, and most had only three or four. Evidently these shore lines had been open for occupation by land plants for only four or five years. The earthquake was in the autumn six years before.

One large willow tree growing upon a beach near Black Glacier, on the west side of Yakutat Bay, 42 feet above sea level, was at first rather puzzling, for it was 3 inches in diameter and 10 feet or more in height. It proved, however, to have five rings of new wood outside a heart of old wood and had evidently been uprooted somewhere and thrown up by the earthquake wave to sprout upon the sands of the raised beach.

In 1909 and 1910 we were very much impressed by the rapid increase in vegetation on the elevated beaches having favorable soil, drainage, and other conditions, since we made our first observations in 1905. Some of the beaches were covered by thickets of alder and willow, which greatly obscured the physiographic and biologic evidences of uplift. Even then these evidences were less clear than when the photographs used as illustrations in this book were taken, and after a few years more they will be still more obscured.

DESTRUCTION OF ORGANISMS.

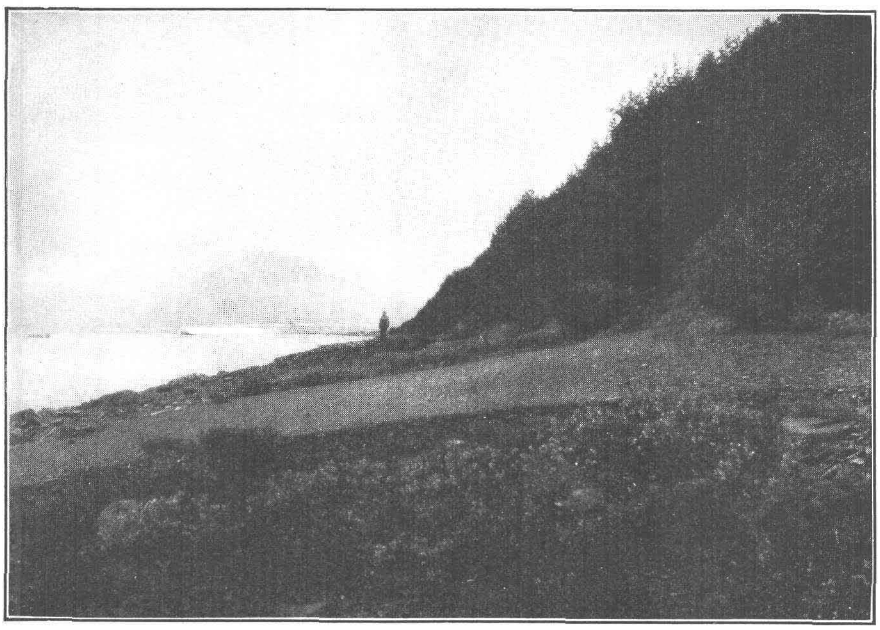
Just how much life was destroyed during the earthquakes of 1899 will never be known, though it is certain that many fish were killed by the shocks and thrown up by the earthquake waves, as we learned from the natives and from the prospectors who were in Disenchantment Bay; that much land life was destroyed by the earthquake waves, which uprooted trees and killed vegetation by saturating its roots with salt water; and that wholesale destruction of marine life along the uplifted littoral zone and of land life along the submerged stretches of coast followed the permanent removal of the marine forms from salt water and the exposure of the land plants to salt water and to wave action. The slaughter caused by uplifting the marine forms out of the sea was, of course, the greatest, resulting probably in the death of millions of individuals.

REHABITATION OF THE LITTORAL ZONE.

Where the shore lines were uplifted 10 feet or more the destruction of fixed intertidal life was almost absolute and migration was necessary, not from above downward to the new sea level, but laterally up or down the coast from some point where there was little or no uplift. The scarcity and small size of some forms in places indicates how slowly this reoccupation goes on. The smallness of the barnacles in 1905 has already been mentioned. On some rocks, smoothed and polished by glaciation and not yet notched by the waves, as on Haenke Island, the seaweed has not yet been able to secure a foothold except along joints, where it grows in narrow lines of small individuals.

A. ELEVATED BEACH AND BROAD ROCK BENCH NEAR HEAD OF RUSSELL FIORD.

Uplifted 8 feet. Shows parallel lines of driftwood. Shore lines in extreme background depressed in 1899. Fault line A lies between rock bench and background of this picture. Photographed in summer of 1905.



B. ELEVATED SLATE BEACH ON NORTHEAST SHORE OF RUSSELL FIORD.

Uplifted 9 feet. Shows plant growth on strand. Photographed in summer of 1905.

On some of the coasts life had not yet begun to reassert itself in 1905. For example, south of Turner Glacier, where there was an uplift of 30 to 47 feet, which destroyed absolutely all marine forms attached to the rocks, no fixed intertidal forms were seen at the new sea level for 4 miles along the coast. Dead barnacles, mussels, bryozoans, etc., were abundant on the uplifted beaches, benches, and headlands, but none of these—not even any seaweed—were growing at the new sea level. In six years the marine forms had not migrated to this temporary desert, where the uplifted shore lines testify that conditions have been favorable for abundant marine life.

For this delay there are several good reasons—(*a*) an ice barrier (Turner Glacier) to the north; (*b*) a sand and gravel barrier to the south; (*c*) a permanent out-moving current of iceberg-laden, freshened water from Hubbard and Turner glaciers; and (*d*) a very deep fiord to the east. When it is remembered that there was complete destruction of littoral life on this coast, and that barriers stood between this and every adjacent strip of rocky coast whence allied marine forms could migrate, the delay is readily understood.

If such changes in life conditions and delays in reoccupation of a habitable zone are consequent upon a single change of level like the one here discussed, it is easy to see why there have been changes in forms and in conditions of living—even extinction of species—in the geologic past during the oscillations of sea level attendant on the deposition of the rocks of the earth's crust and the evolution of the present continents.

HUMAN TESTIMONY TO UPLIFT IN 1899.

EVIDENCE OF RECENCY.

The state of preservation of the beaches, cliffs, benches, and deltas suggests not only that they were recently uplifted, but that the movement occurred essentially at the same time for all. No beach or delta seen by us in 1905 was more dissected than any similar beach or delta of the same height and exposure to streams and waves. The barnacles and mussels also support the same conclusion, and the living plants, none over 5 years old, seem to have begun to encroach on all the elevated strands at the same time (in the spring of 1900, or five years before 1905), the vegetation, so far as we could see, being no more advanced in any one place than in another, whether as to location on raised beach, height of elevation above the sea, or proportion of beach or bench or delta covered. In addition to this physiographic evidence, which leads us to conclude that the uplifts were simultaneous and relatively recent, and to the biologic evidence, which showed us in 1905 that the uplifts had taken place at least five and probably not more than six years before, we have clear and specific human evidence that they occurred in connection with the earthquakes of September, 1899.

TESTIMONY OF I. C. RUSSELL.

The several reports of the late I. C. Russell[1] indicate that the uplifts here described had not taken place at the time of his visits to Disenchantment Bay and Russell Fiord in 1890 and 1891. The fact that he does not describe them is not proof that they had not yet taken place, for geology affords some famous instances of failure by a skilled observer to see what he later realizes is a very obvious fact. Nevertheless, the fact that Prof. Russell, whose studies of the abandoned shore lines of Lake Lahontan, etc., are well known, did not see in 1890 or 1891 so clear a series of abandoned shore lines as we saw in 1905 is fair presumptive evidence that the shore lines had not been abandoned at the time of his visit. We know from his papers that he visited several points, notably Haenke Island, where the beach on which he landed has since been raised 19 feet. Moreover, his description of the difficulties of landing on this island shows clearly that its coast line then differed greatly from its present one, which is easily accessible at any one of a dozen points.

[1] An expedition to Mount St. Elias, Alaska: Nat. Geog. Mag., vol. 3, 1891, pp. 53-204; Second expedition to Mount St. Elias: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, pp. 1-91.

TESTIMONY OF THE BOUNDARY SURVEY PARTY.

In 1895 the Canadian surveyors and topographers of an Alaskan boundary commission party made a series of photographs of the Yakutat Bay region while engaged in making the maps to be submitted to the Alaskan Boundary Tribunal. Several of these photographs illustrate sections of the coast where the uplift in 1899 was great, but they show no sign of elevated shore lines. Among others, there is a photograph showing Cape Enchantment as an island, whereas in 1905 it was a peninsula connected to the mainland by a bar, which was covered only at the very highest tides. Other photographs of various parts of the shore line of Disenchantment Bay and Russell Fiord show no evidence of uplift, whereas if taken 10 years later (in 1905) they could not have failed to do so clearly. From this it seems practically certain that the uplift had not taken place as late as the spring of 1895.

TESTIMONY OF THE HARRIMAN EXPEDITION.

Three months before the earthquakes the Harriman expedition spent several days in Yakutat Bay. Among the many noted scientific men accompanying this party was G. K. Gilbert, of the United States Geological Survey, the most eminent of American students of abandoned shore lines. From the reports of this expedition, especially Dr. Gilbert's volume,[1] we learn of their landing upon beaches which have since been uplifted 15 feet or more. This, like the evidence of Prof. Russell, is not presented as absolute scientific proof that the uplift did not take place before June, 1899, but merely as strong presumptive evidence to that effect. We believe it next to impossible, however, that keen scientific observers like Russell, Gilbert, and others could have traversed this inlet and climbed up over the raised beaches on Haenke Island and elsewhere without seeing the striking evidence of change of level.

Moreover, as already stated (p. 21), the Harriman expedition vessel, *George W. Elder*, sailed twice past the site of the now prominent but then submerged reefs in Disenchantment Bay in June, 1899; and the U. S. S. *Corwin*, with I. C. Russell on board, steamed in 1890 past the site of these reefs "nearly to the ice cliffs of Hubbard Glacier." Sailors are not very likely to fail to report uncharted reefs, and the commander of the *Elder* would undoubtedly have seen and reported these reefs if he had entered the bay after September, 1899.

TESTIMONY OF THE UNITED STATES FISH COMMISSION PARTY.

In July, 1901, a United States Fish Commission party, commanded by Ensign C. R. Miller, sailed up Yakutat and Disenchantment bays and through Russell Fiord. Mr. Miller does not mention the evidences of uplift, which he may not have noticed, not being a trained physiographer, but he does describe other effects of the 1899 earthquakes. He must have climbed over one of the raised beaches on Haenke Island, for one of his photographs, taken from this island in 1901, looks down on part of a rock bench which was elevated 17 to 19 feet in 1899. In this picture[2] the elevated strand is easily recognized.

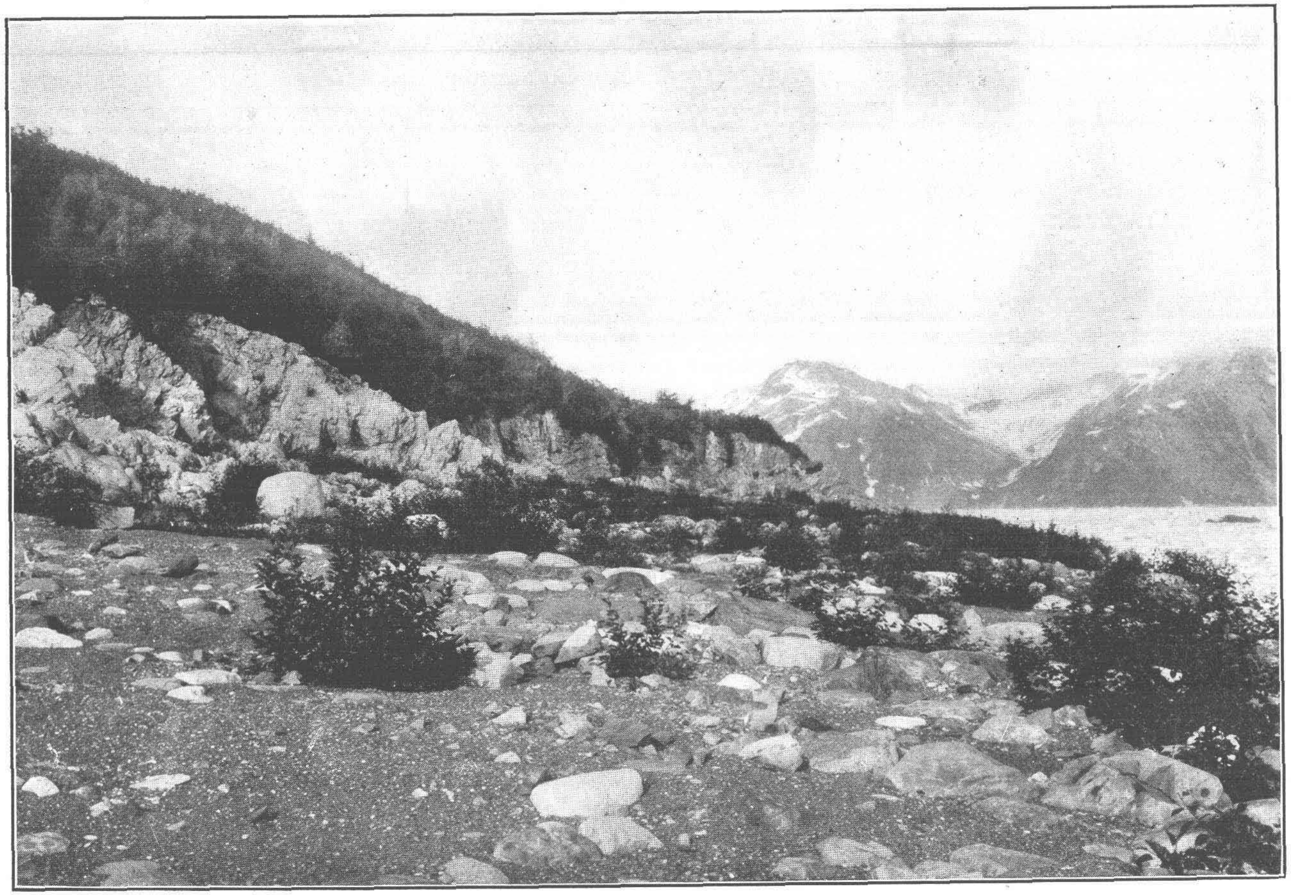
TESTIMONY OF THE NATIVES.

The evidence already cited suggests strongly that no changes of level had taken place in and about Yakutat Bay by 1890–91, by the spring of 1895, or by June, 1899, three months before the series of destructive earthquakes here described, but that the uplift had taken place before July, 1901. The convincing evidence from living plants pushes the date back at least to the spring of 1900. The natives, however, state definitely that the uplifts took place in connection with the earthquakes of the fall of 1899 and that there were no similar recent movements before or since—this last statement being corroborated by our own investigation of all recent earthquakes in this part of Alaska.

Even if other lines of evidence did not so convincingly point to the same conclusion, we feel that there should be no hesitancy in accepting this testimony of the Alaskan natives

[1] Harriman Alaska Expedition, vol. 3, Glaciers, 1904, pp. 45–70.

[2] Bull. U. S. Fish Comm., vol. 21, 1901, Pl. XLIV, opp. p. 392.



ELEVATED BEACH AND SEA CLIFF ON WEST SHORE OF DISENCHANTMENT BAY.

Uplifted 37 feet. Shows encroachment of young alders. Photographed in summer of 1906 by O. D. von Engeln.

as to the date of uplift. There are several reasons for considering it trustworthy. Our questions put to the natives were never in a form to suggest the answer desired. One of our canoemen in 1905, J. P. Henry, a Sitka native long resident at Yakutat, was able to speak, read, and write English well and understood thoroughly the necessity of accurate information. After he knew of our interest in these phenomena he repeatedly indicated to us, before reaching certain places, that uplift had occurred there, and we never found such statements of his as we could verify to be untrue or exaggerated; moreover, he and other natives know the shores of the inlet intimately, for they canoe there every spring in search of seal and would certainly know when such striking changes occurred.

Henry and our other native camp hand, as well as other natives at Yakutat (in statements translated by him), described the great shaking of the earth, the water waves, the fish killed or left stranded by these waves, the appearance of new islands, the uplift of sea caves and beaches (one of these the beach on which the natives camp each year in the sealing season), the formation of the whitened bryozoan film, and the avalanches. They said specifically that all these changes occurred during the earthquakes in the fall of 1899; that they had not taken place in the sealing season of 1899, but were observed in the spring of 1900.

W. H. Thompson, who knows Yakutat Bay well, verifies the testimony of the natives, who are keen observers of changes in nature, especially on this coast, where they hunt seal every spring in small boats. There is also some corroboration of native testimony by other white men, though the prospectors in Disenchantment Bay were too frightened to notice any change of level or saw too much of more spectacular things to report it. Most of the whites were at Yakutat, where they noted little or no change of level, but they do report the submergence of part of a graveyard at Port Mulgrave, opposite Yakutat village, during the earthquake of September 10. It seems probable that most or all of the uplift in Disenchantment Bay occurred during the second shock at noon, September 10, as this was the only quake in connection with which the prospectors noted excessive water waves (see footnote, p. 16); and the only one accompanied by such waves as reported from Yakutat village.

RECENT SUBMERGENCE.

That a small portion of the shore of Yakutat Bay was depressed during the 1899 earthquakes is proved chiefly by the trees that were killed by sand piling up around their bases, waves washing away their foundations, and salt water stopping their growth. Such trees are well shown at several points near the head of Russell Fiord and on the islands and peninsulas on the east side of outer Yakutat Bay.

On the south shore of Knight Island the beach sand extends back into a spruce forest for over a hundred feet, and the rank, sedgy beach grass is growing among the spruce trees far back from the shore (Pl. XIII, *C*). On the present coast the waves have uprooted and thrown down numerous conifers, piling their dead trunks back among the living trees (Pl. XIII, *A*). At several points in the archipelago between Knight Island and Yakutat trees and alder bushes near the water's edge are singed as by a drought, evidently in consequence of the occasional baths of salt water to which they are now subjected as a result of slight subsidence. Near the head of Russell Fiord dead alders rise through a beach, now reached by high tide (Pl. XIII, *B*), where the salt water is encroaching upon the shore strip, making life impossible for its former land flora. At many points at the very head of the bay trees are now reached by salt water; at other points trees stand in lagoons behind barrier beaches. Similar evidence is accepted as proof of submergence along a short strip of coast between Logan Beach and Knight Island.

On Khantaak Island extensive forest areas near the coast have been killed by slight submergence of trees in salt water and the partial burial of trees in beach sand. This is especially well shown at the northeast end of the island, where there are several acres of submerged forest with mature spruces still standing erect (Pl. XV), as well as on the western side of the island and on the mainland between Ankau Slough and Ocean Cape.

Of course physiographic evidences similar to those of the emerged strands are not available at these places, being masked by the deposits of the encroaching shore. It seems certain, however, that there has been an actual downward movement in most of them, for the places of submergence are not exposed points where apparent sinking might be due to recedence of the shore line. Moreover, the dead tree roots are in some places bathed in salt water.

It should be stated that all the areas of submergence are in unconsolidated deposits, most of them in the gravel foreland, and that in a few of them the submergence might be due to a settling of these uncemented strata during the severe shaking. Unconsolidated deposits may also have shifted on the sea bottom because of these shocks; and the violent whirlpools described on page 79 may be due to this cause.

Nevertheless, we feel certain that in most of these places downward movement of the earth's crust has occurred [1]—(*a*) because these places are in narrow belts close to and on the downthrown sides of known fault zones (Pl. XIV, p. 30); (*b*) because the trees are erect, except where undermined and overturned by waves, and are in some places not quite dead, still retaining their needles; and (*c*) because trees elsewhere equally close to the shore and in equally unconsolidated gravels, but away from fault lines, show no evidence of submergence.

COASTS SHOWING SLIGHT OR NO MOVEMENT.

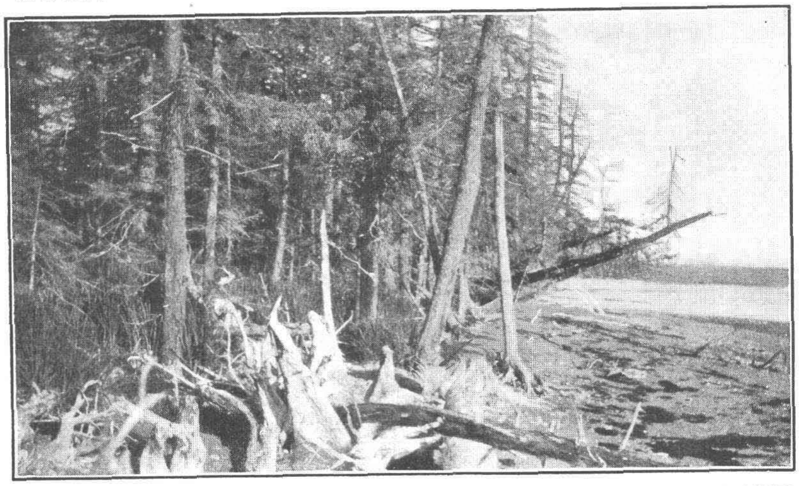
In the 50 miles or more of the coast of Yakutat Bay and its branches where little or no change of level occurred there was some difficulty in determining the conditions. An uplift or a depression of a foot or less would naturally leave faint evidence.

Where we found no dead barnacles, no raised beaches, benches, or deltas, and no vegetation killed by the encroachment of waves or gravel, we concluded that there had been no change of level. Such conditions were found along almost the whole west coast of outer Yakutat Bay, from Kwik River to the Black Glacier; along most of the east coast of outer Yakutat Bay and the islands near the foreland; along parts of lower Russell Fiord within the mountains; and on the shores of a part of the head of the bay within the foreland.

The north side of Nunatak Fiord seemed to have undergone no change of level, but about the other shore, we could not be so certain. The first mile from the Nunatak Glacier front had been uncovered since 1899, as photographs made from exactly the same spot in 1899 and 1905 prove. Here, of course, we found not only no evidence of change of level but no rocky shore bench at present sea level and little marine life. Westward for the succeeding 1½ miles we saw living barnacles, mussels, etc., but no dead barnacles or other marine forms, though in the upper edge of the sea-weed zone the plants were bleached or crisped in 1905, as if deprived of their normal allowance of salt water by slight uplift. We saw such a condition nowhere else, but it is not absolutely certain that these plants would not be revived at the next spring tide. If uplift produced this condition it amounted to not more than a foot. The next 2 or 3 miles of coast has a rock bench, apparently too high for present wave work but not too high to be the work of iceberg waves when the Nunatak Glacier extended farther down the fiord, as we know it did not many years ago. In this stretch of coast a few dead barnacles were seen, but there were also living barnacles at equal heights above present sea level.

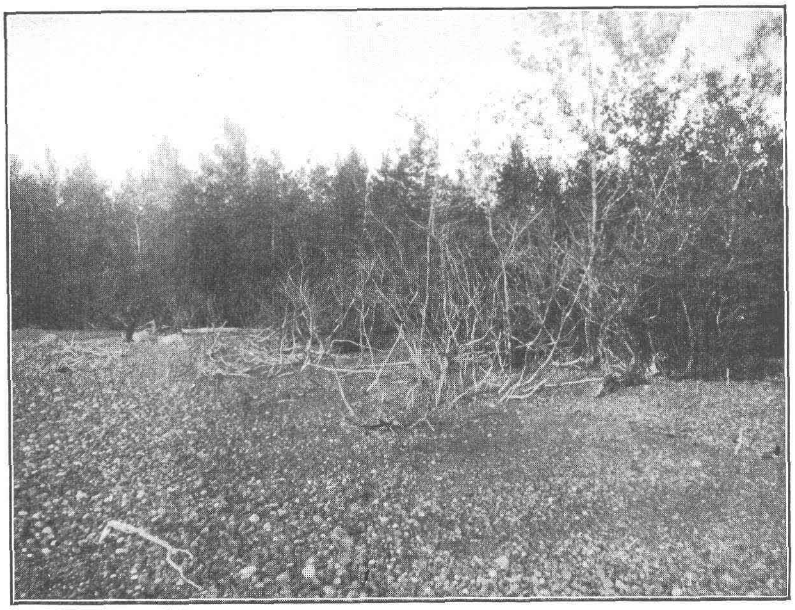
These conditions have been described fully because they are characteristic of the coasts of slight or no movement. In this particular place a slight uplift may have produced the seemingly discordant rock bench upon which some of the upper barnacles had persisted for six years, with an occasional splash of salt water, while other barnacles had died. This assumption is supported by the fact that in several other places we found areas of dead barnacles, killed by uplift, among which one or two individuals were still living a foot or more above reach of the highest tide. On the map (Pl. XIV), however, we have not indicated any change of level. The map, in fact, errs if at all on the side of conservatism, for it does not indicate uplift or depression except where we found conclusive proof of it.

[1] The statement by F. de Montessus de Ballore (Les tremblements de terre, p. 414) in reference to these earthquakes, that the report of the sinking of one part of the coast "merits little credence," is doubtless based on an exaggerated newspaper account seen by him, for the book was published Jan. 15, 1906, and our description of the facts proving sinking of the land was not published till May 25 of the same year.



A. BEACH ENCROACHING ON FOREST NEAR SOUTHWEST POINT OF KNIGHT ISLAND.

Depressed about 5 feet. Beach grass growing among trees. Photographed in summer of 1905.



B. ALDERS NEAR HEAD OF RUSSELL FIORD KILLED BY ENCROACHMENT OF THE SEA.

Depressed 5 feet. Photographed in summer of 1905.

C. ANOTHER VIEW OF BEACH ON KNIGHT ISLAND SHOWN IN *A.*

Photographed in summer of 1905.

MEASUREMENT OF CHANGES OF LEVEL.

The figures showing the amount of emergence or submergence in various parts of the Yakutat Bay region are based on careful determinations made during the summer of 1905. We estimate that over two-thirds of the 150 miles of coast was either uplifted or depressed. Every part of the coast, except a few miles between Hubbard and Turner glaciers, was examined carefully by walking along it or traveling close to shore in a light native canoe and landing frequently. Over a hundred close measurements of the amount of change of level were made.

In measuring uplifts, wherever possible, the vertical distance between the highest living barnacle and the highest dead barnacle attached to the rock was measured with a Locke hand level and a graduated rod, a few of the greater elevations being checked by barometer readings. All the measurements were carefully leveled, for we never depended on barometer determinations alone. This method was as accurate as any other we could have employed with the time and the instruments at our disposal. The error can not be great, for the dead barnacles were nearly everywhere present on the rocky coasts which make up the greater part of the uplifted strands. Moreover, they were so abundant that the places for measurements could be carefully selected, many of the determinations recorded being checked by one or two additional measurements in the same locality.

Barnacles, mussels, and Bryozoa were clinging to the rock in 1909, but not so many as in 1905, when the measurements were made. This evidence of uplift will not be preserved long.

The determinations of amount of uplift may be accepted as minimum measurements for several reasons. In many places the highest living barnacle was living among dozens of dead ones, apparently having survived several inches above the zone of abundant live barnacles for the six years since the uplift, because it was sturdier than its fellows or was so located that the salt water splashed it occasionally when the tide was high. In picking out the highest dead barnacle we often saw above it, in the angles of the rock, loose barnacles fallen from place, or the circular mark left by the calcareous body of a higher dead barnacle which had fallen away. We never measured higher than the highest dead barnacle attached to the rock, although often practically certain that barnacles had formerly grown at a slightly higher level. The correction of this error on both ends might add 6 to 12 inches to some of the uplifts recorded.

Fully four-fifths of the determinations were based on the method of measuring from the highest living to the highest dead barnacle; where it was necessary to use other criteria, barnacles were in most places near by, on one side or the other, to check the determination. Mussels and other marine forms were used in a few places.

On the raised beaches we made a few vertical measurements between parallel lines of driftwood. Two or three measurements were also made between the lower limit of land plants on the raised beaches or deltas and the lowest old bushes and shrubs above, the younger and lower vegetation being nowhere over 5 years old, while the older bushes were 20 years old or more. These measurements may involve an error of a foot or two.

Most of these measurements checked satisfactorily with adjacent barnacle measurements, but along the 4 miles of uplifted coast south of the Turner Glacier, where we found the greatest uplifts in the region, there were absolutely no living barnacles or any other marine forms clinging to the rocks at present sea level, though abundant dead barnacles were present on the raised beaches and uplifted rock headlands. Accordingly along this coast we measured between the high-tide mark of present sea level and the top of the zone of abundant dead barnacles, which was assumed to be close to former high-tide mark on the raised strand. If there was any error at all worth considering in these measurements the uplift along this coast was surely greater rather than less than the amount recorded, for at the front of many of the elevated beaches and deltas there are vertical cliffs as high as the uplift recorded.

For the submerged shore lines it was difficult to get close determinations of the amount of sinking. The best we could do was to measure the vertical distance between the base of the lowest dead tree in place and the base of the highest tree or shrub which had been killed or was being killed by the deposition of gravel and sand about it.

GEOGRAPHIC DISTRIBUTION OF CHANGES OF LEVEL.

CHANGES ON THE SEAWARD SIDE OF THE MOUNTAINS.

Taken as a whole, the foreland and the neighboring islands may be considered as a region of no change of level, though it contains small areas of slight depression, usually too slight for quantitative measurement. On the west side of Yakutat Bay, from a locality opposite Point Latouche to the Kwik Delta, the shore line was studied carefully, but no change in level could be detected. On the southeast side of the bay near the mountains, both on Knight Island and on the mainland, the changes of level, though very irregular, on the whole show uplift. The elevated areas extend but a short distance from the mountain base, and the same is true at the head of Russell Fiord. On these four subparallel coasts (both sides of Yakutat Bay and of Russell Fiord) there is a change from an upraised to a depressed or stationary coast within a short distance—within a few hundred yards southeast of Knight Island and on the southeast shore of the head of Russell Fiord, and within a mile on the other two shores.

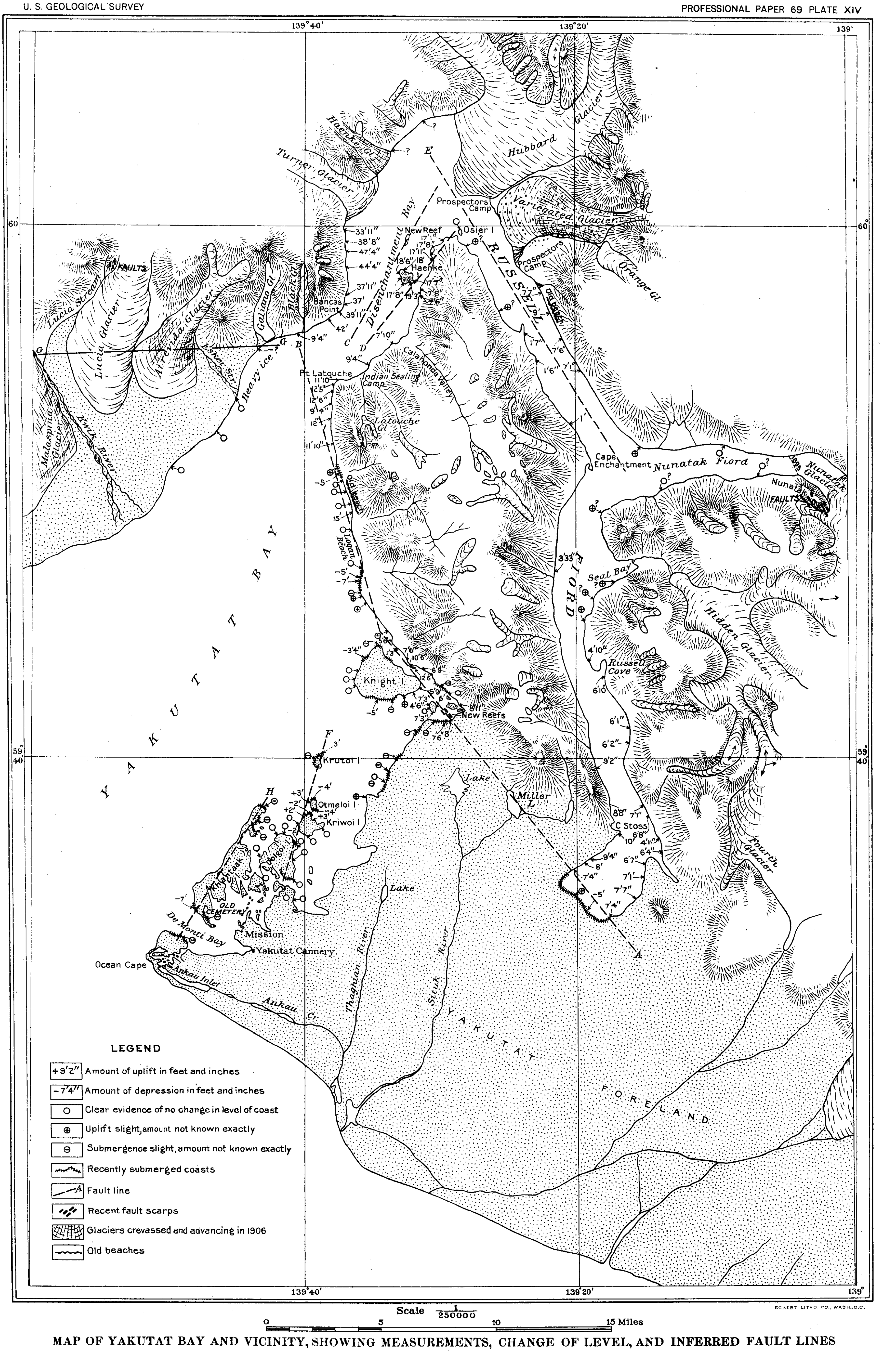
The longest stretch of the foreland coast that we studied lies between Knight Island and Yakutat. Here, both on the shores of the foreland and in the maze of channels between the islands, the usual condition is that of mature forest coming down to the very water's edge and therefore forming an excellent register of change of level. Along most of this coast there has evidently been no change whatever, but at two or three points there has been a very slight uplift, and at a number of places a slight depression, especially among the small islands. There is also evidence of older change of level in two or three places but notably on the northeast end of Krutoi Island, where there is a recent uplift of 3 feet and back of it a beach and wave-cut bluff of much older date carrying a mature forest. This older uplift was between 5 and 10 feet.

At and near Yakutat and in the slough east of Ocean Cape there is no definite evidence of change of level. Whether the partial submergence of the cemetery on Khantaak Island is evidence of depression or was merely due to the sliding of unconsolidated deposits at the time of the earthquake waves was not definitely determined; but just west of this cemetery, on the ocean shore of the island, the forest is encroached upon by present waves, suggesting a depression of about 7 feet. This encroachment might be regarded as the result of wave work alone if the shore affected were not directly in line between an area of depression on the peninsula near Ocean Cape and another at the north end of Khantaak Island (Pl. XV, *B*).

CHANGES ALONG THE MOUNTAINOUS EAST COAST OF YAKUTAT BAY.

The waves sweep in from the open Pacific with so much force along the mountainous east coast of the bay that the new strand is fast cutting back into and destroying the uplifted shore. Nevertheless the evidence of recent change of level is very clear even here, but the amount varies greatly from place to place. Near Knight Island, both on the island and on the mainland, the uplift ranges from 5 to 12½ feet and there are marked variations in short distances. Along the coast north of Knight Island, to a point within 4 or 5 miles of Point Latouche, the general condition is that of either no change of level or else depression; but where the coast turns eastward, both near Knight Island and near Point Latouche, uplifted shores begin abruptly, reaching a maximum height of 12½ feet.

Along most of the straight stretch of coast between these uplifted parts there is a gravel foreland forming a narrow strip between the mountains and the sea. In one part, however, just north of Logan Beach, the mountains come down to the water, and here, for a short distance, there is a recently elevated shore line 15 feet above present sea level; it descends abruptly toward the north, and disappears within less than half a mile. Back of it is an older, spruce-covered upraised beach (p. 42), which also descends northward but is traceable for more than 2 miles. As shown in a later section, these diverse phenomena are believed to be related to a fault line close by the mountain base.



MAP OF YAKUTAT BAY AND VICINITY, SHOWING MEASUREMENTS, CHANGE OF LEVEL, AND INFERRED FAULT LINES

CHANGES IN DISENCHANTMENT BAY.

At Point Latouche the uplifted shores are 11 to 12 feet above present sea level; but they decline perceptibly northward and for most of the distance between Point Latouche and Haenke Island are between 7 and 8 feet above the sea. At Haenke Island, however, the shore lines were raised 17 to 19 feet, and a similar pronounced uplift also appears abruptly on the peninsula northeast of Haenke Island, extends thence nearly to the tip of the peninsula, and then as abruptly declines, so that near Osier Island no evidence whatever remains of any change of level. At the tip of the peninsula a spit, submerged at high tide, connected Osier Island with the mainland in 1905, exactly as Gilbert[1] states that it did in 1899. Within a mile, at the tip of the peninsula, there is a change from no uplift on and near Osier Island to 17 feet 1 inch just southwest of it. It is near this region of pronounced uplift that the new reefs to the north of Haenke Island were uplifted.

On the west shore of Disenchantment Bay the first rock cliff south of Turner Glacier, less than half a mile from the ice front, shows an uplift of 33 feet 11 inches; and within 1½ miles from that point this remarkable uplifted shore line, the most perfect as well as the highest in the region, attains an elevation of 47 feet 4 inches. Just below Bancas Point the elevation is 42 feet; south of that, on the alluvial fan of the Black Glacier stream, it rapidly descends. No accurate quantitative measurements were possible in this region of alluvial-fan deposits, but the uplift evidently extends across the Black Glacier alluvial fan, on the north side of which it is estimated to be about 30 feet, and on the south side, a little over a quarter of a mile away, 9 feet. The Black Glacier stream, which Russell's photographs show flowing on the surface of this fan in 1890, was, in 1905, entrenched in a steep-sided, gorgelike valley from 10 to 15 feet in depth. South of this locality no evidence of uplift was found, but on the coast of the alluvial fan of the Galiano Glacier stream, 1½ miles southwest, there is indication of a slight subsidence. Beyond that, as far as Kwik River, no evidence was found to indicate any change of level.

From these facts it is evident that the shores of Disenchantment Bay have been greatly uplifted and differentially deformed. Although the differences in amount of uplift occur within short distances here, as in other parts of the fiord, they are not traceable to a single sharp break, but are apparently the result of decided change taking place in a narrow zone.

It would be interesting to know what effect the 33-foot uplift had on the shattered and crevassed front of Turner Glacier, for there is evidence of elevation of the coast up to the very edge of the ice (Pl. V, *D*, p. 18). Gilbert suggests that the front of this glacier is floating, and if this is true the uplift would have been more destructive than if the ice rested on the bed of the fiord. We were unable to determine what effect the uplift had; but it is worthy of note that the form of the ice front has been materially changed since Gilbert photographed it in 1899.

CHANGES IN THE NORTHWEST ARM OF RUSSELL FIORD.

The northeast shore of Russell Fiord, from Hubbard Glacier to Nunatak Fiord, shows a uniform uplift of considerable amount. Although satisfactory conditions for accurate measurement were not usually present on the friable slate ledges and extensive beaches which constitute this shore, four good quantitative observations were made. One of them, on the beach, gave 7 feet 7 inches; the other three, made by comparison of barnacles on the rocks, gave measurements of 7 feet 1 inch, 7 feet 6 inches, and 9 feet. Along this coast an older elevated beach, covered with mature alders, was discovered (p. 43).

On the southwest shore of the fiord, although the rocks are very favorable for the preservation of barnacles, we nowhere found evidence, either of a physiographic or a biologic nature, of more than 2 feet of uplift. On most of this coast the evidence was wholly negative, but at four points we found dead barnacles on a slightly elevated bench, from 1 foot to 1 foot 10 inches above the highest living barnacles. At Cape Enchantment a slight uplift has raised the bar that connects the tip of the cape with the mainland, so that the tide now covers it only at the

[1] Harriman Alaska Expedition, vol. 3, Glaciers, p. 69.

very highest stages, if at all. The evidence thus shows that there is a marked difference in the amount of uplift on the two sides of this narrow, straight stretch of Russell Fiord—from 7 to 9 feet on one side and not over 2 feet on the other side.

CHANGES IN NUNATAK FIORD.

Conditions on the southern shore of Nunatak Fiord have already been described (p. 28), and it has been stated that although there is no clear proof of change in level, there is a possibility of an uplift of a foot or less. The northern shore of the fiord likewise gave no proof of change of level; but on the beaches and deltas of this shore a slight uplift might easily be indistinguishable. The difficulty of recognizing an elevated shore line in this part of the fiord is increased by the fact that the recession of Nunatak Glacier has been so recent that vegetation has not yet advanced far up the fiord, and this aid to the detection of uplifted beaches is therefore absent. However, the fact that no evidence of change of level could be discovered in this fiord is believed to demonstrate that if any change occurred it was very slight.

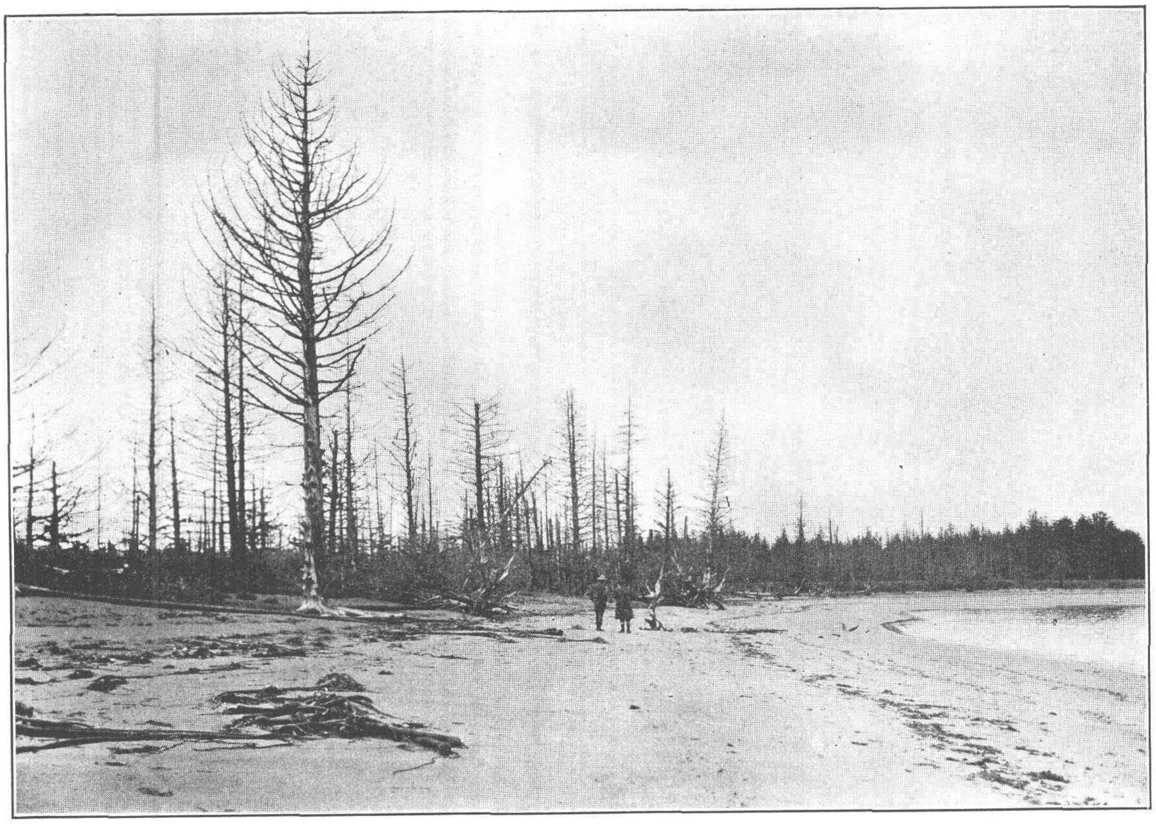
CHANGES IN THE SOUTH ARM OF RUSSELL FIORD.

At Cape Enchantment there is evidently an uplift of less than 2 feet, and several miles south of this, opposite Seal Bay, one of 3 feet 3 inches. Between these points a number of slightly elevated beaches and deltas occur. On the east side of the fiord, however, although a slight uplift—a foot or two—is shown by a low bench just above high-tide level north of Seal Bay, and a greater uplift by elevated deltas at the entrance to Seal Bay, we could get no definite measurement until we reached a point 2 or 3 miles south of Seal Bay. At this point the wave-cut bench rises abruptly and on it we found dead barnacles 4 feet 10 inches above the highest living ones. South of Shelter Cove the bench slowly rises, reaching an elevation of 9 or 10 feet on the west side and 7 or 8 feet on the east side of the fiord.

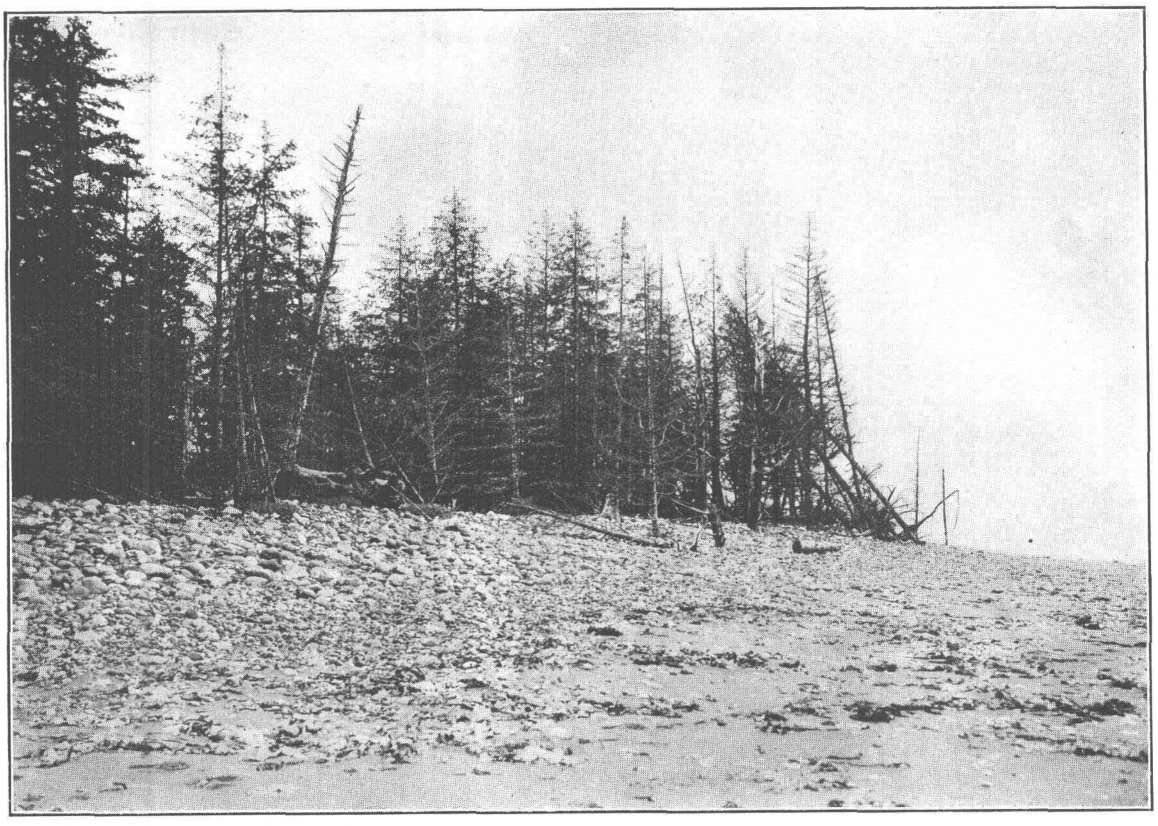
At the very head of the inlet, in the fist-shaped area in the foreland just outside the mountain front, there is a change on both sides of the bay, within a very short distance, from an uplift of 7 feet 4 inches to a submergence.

MAP SHOWING QUANTITATIVE MEASUREMENTS.

The facts stated in the preceding paragraphs in regard to the geographic distribution of changes of level are shown in greater detail on Plate XIV, on which most of the quantitative measurements that we made are given in feet and inches.



A. SUBMERGED COAST ON EAST SHORE OF KHANTAAK ISLAND.
Trees killed by salt water. Photographed in summer of 1909 by O. D. von Engeln.



B. FOREST ON NORTH END OF KHANTAAK ISLAND KILLED BY SUBMERGENCE OF LAND IN 1899.
Trees knocked down by waves. Photographed in summer of 1909 by O. D. von Engeln.

CHAPTER III.

FAULTING.

ABSENCE OF EVIDENCE OF FAULTING AT DISTANT POINTS.

Our observations led to the conclusion that here, in a nonvolcanic region, the land is still rising. Moreover, there is definite evidence that earlier changes of level preceded that of 1899. The widespread effects of the movements of 1899, as indicated by the earthquake observations at many places within a 250-mile radius and at even more distant points, led us to look for reports of changes in shore lines at other places where shocks were reported. We were able to make hasty observations in 1905 at Dundas Bay, near the entrance to Glacier Bay, and at Juneau and Sitka, where we found no change of level.

It was thought probable that in Glacier Bay, over 140 miles southeast of Yakutat, where the Muir Glacier suffered so greatly from the 1899 shocks, a change of level of the shore lines might be found, even though we had ourselves established a point of no movement at Dundas Bay. During the summer of 1906, however, F. E. and C. W. Wright, of the United States Geological Survey, made a careful study of the Glacier Bay region and although they were looking especially for change of level of the shore lines, they found no decisive evidence of it,[1] nor did they find any at Lituya Bay, between Cross Sound and Yakutat Bay. Near Cape Spencer, however, they did find evidence of recent submergence,[1] trees being lowered below high-tide mark.

At the mouth of Alsek River, 70 miles southeast of Disenchantment Bay, Eliot Blackwelder and A. G. Maddren, of the United States Geological Survey, in 1906 failed to find any changes in the level of the Dry Bay shore lines, though they looked for them specifically.

At Cape Yakataga, 100 miles west of Yakutat Bay, there is evidence of a possible change of level in connection with the earthquake of September 3, 1899. (See p. 71.) Mr. S. E. Doverspike, who was at Yakataga during the shocks, makes the following statement[2] in response to an inquiry as to the effects of the earthquake: "Beach raised about 3 feet, noticed by landing place on Yakataga reef; noticed by tide not raising high enough to get over reef." His evidence is independently corroborated by Capt. Ben Durkee, commanding the schooner *Bellingham*, which was anchored off the beach at Yakataga during the earthquake of September 3, who says: "Tide set out from shore and schooner sailed out at end of anchor chains, tide running probably 3 to 4 miles per hour. Tide slow about returning and about one-half proper height according to tide table. Tide returned quietly. Weather perfectly calm."

It seems quite possible that a slight uplift of this shore line in connection with the earthquake may have resulted in an apparently ebbing tide, the failure to rise again not giving the depth at anchorage and the covering of reef previously known. A vessel at anchor during such an uplift would be exactly in a position to prove this. It is hoped that when Yakataga is next visited by scientific observers, it may be determined whether there are raised beaches, barnacles, or other evidences, as in Yakutat Bay, to confirm this reported uplift.

In 1904 the junior author, as a member of a United States Geological Survey party, made many shore traverses at Kayak and Wingham islands and at Katalla, on Controller Bay, 170 miles northwest of Yakutat, and found no evidence of changes of level. He was not then, however, especially on the outlook for such evidence, but in 1906 G. C. Martin, of the United States Geological Survey, examined the coast here with this idea in mind and found no evidence of such changes.

[1] Wright, F. E., letter, Sept. 16, 1908.

[2] Reply to earthquake circular, 1908. This circular was a printed inquiry sent out by the authors in 1907-8. See pp. 62-64.

At Cape Whitshed, near the Copper River delta, H. P. Ritter found in 1899 that there were no changes of level of the land during and after the earthquakes.

In 1904 the junior author made extensive examinations on the coast of Port Valdez, and on Kenai Peninsula near Seward, Seldovia, and Homer, as well as on the Alaska Peninsula in and west of Cook Inlet as far as Unga, in the Shumagin Islands, without finding evidence of recent changes of level at any point northwest of Yakutat within the area of the sensible earthquake shocks in 1899. There are older uplifts on the Alaska Peninsula, however.

From these observations, made immediately southeast and northwest of Yakutat, it appears that changes of level of the coast, with possible exceptions at Cape Spencer and at Yakataga, were confined to Yakutat Bay and its branches. It does not follow, of course, that faulting did not take place in the mountains back of this coast, though in the absence of proof of such faulting it can not be assumed to have occurred. It is our hypothesis, therefore, that the earthquakes, especially that of September 10, were generated by complex faulting which was central in the Yakutat Bay region, but the extent of which along the mountain ranges to the northwest and southeast can not at present be told. Owing to the unreliability of many accounts of the earthquake effects, and the difficulty of collecting even this evidence at so late a day, it seems hardly probable that the full extent of the faulting will ever be definitely known, unless, by future advance of the glaciers, its limits are defined.

INFERRED FAULT LINES IN YAKUTAT BAY.

In the region of our detailed studies the uplift was clearly differential and the movements complex, resulting in a distinct deformation of the coast line and the bordering land, The exact nature of all these differential movements is not certain, though some conclusions regarding them seem well founded. The inferred faults along which there was movement in 1899 are shown on Plate XIV.

MOUNTAIN-FRONT FAULT.

That there is a narrow zone just outside of the mountain base in which uplift is replaced either by depression or by no change of level is clearly shown at four points along a general line (*A*, on Pl. XIV); and along this line the variations in uplift are numerous and abrupt even within short distances.

At the head of Russell Fiord this zone of change from uplift to depression coincides with a change in geologic structure, granitic and other bedrock being found on the side toward the mountains and glacial gravels with no bedrock on the other side. These conditions suggest the presence of a fault line near the mountain base. If such a line is projected it passes exactly through three of the areas where uplift is abruptly replaced by either depression or no change of level, but it would need to be bent slightly to reach the fourth, at the head of Yakutat Bay on the west side. From this evidence a fault line is inferred along the face of the mountains, but just outside their base, from the head of Russell Fiord to Knight Island, at least.

As stated in a later section (p. 44), additional reason for suspecting an older fault here is found in the topography—a straight mountain front with truncated spurs reaching out to nearly the same line. Along this line, northeast of Knight Island, there is also an unusual abundance of avalanche tracks. Moreover, the amount of uplift along this line varies greatly, as it naturally would along a fault whose downthrown side was dragged upward and which was not a single break but a complex of parallel fractures, as seems to have been the case in this region, where the change across the fault line is not one abrupt scarp but occupies a zone of some width. The amount of variation in uplift along this line is shown on Plate XIV. At the head of Russell Fiord there is mainly depression of varying amounts, with one small locality where there was uplift. At Knight Island there was tilting, the side toward the mainland rising and that away from it sinking. A small island just east of Knight Island was tilted in the same direction, and on the mainland marked variations occur in the level of the uplifted shore.

In harmony with the interpretation placed upon the facts in this region is the appearance of the four small islands in Eleanor Cove east of Knight Island, just where the inferred fault is believed to pass; the longer axes of these islands are parallel to the fault line. We do not place this fault line entirely outside of the zone of uplift, because it is believed that some of the upraised coast near and on Knight Island is due to updrag on the downthrown side.

The statement of Ensign Miller[1] that trees were destroyed on the east and west sides of Miller Lake is interesting, as the fault line determined by us on entirely independent evidence passes exactly through this lake.

While it may not have direct bearing on the question as to whether faults *A* and *B* (Pl. XIV) are one curved fault, it is nevertheless of interest to note that the westward extension of this mountain-front fault line (*A*) would carry it past the south base of Amphitheater Knob and along the line between the coal-bearing beds and the rocks of the Yakutat group, which are evidently separated by a profound fault of older date. Fault *B*, however, reaches this coast farther east, between Galiano and Black glaciers.

FAULT ALONG EAST SHORE OF YAKUTAT BAY.

As indicated in the section on fault-block mountains (pp. 44–45), there is clear evidence of a fault line along the mountainous east shore of Yakutat Bay (*B* on Pl. XIV). Here the mountain front is straight and steep and has spurs truncated by triangular facets along a fairly straight line. The mountain face is scarred by numerous avalanches, and in 1899 the shores at its base were washed by the most destructive earthquake water wave recorded in the region. For much more than half its length this shore shows no elevated strands; but they begin where the coast bends away from the straight line, on both the north and the south ends. Near the middle, where the mountain slopes come down close to the sea, there is an upraised ancient beach and, parallel to it, an uplift belonging to the 1899 series. Along this coast, as along the inferred mountain-front fault, there are abrupt and complex changes in level from point to point (fig. 2, p. 42).

We are able to suggest no other explanation for the phenomena recorded here than that of a fault close to the mountain base, uplifting the solid rock of the mountains but not raising all the gravel forelands which skirt most of this straight coast. Behind the broadest part of the narrow gravel foreland, at Logan Beach, there is a valley between the foreland and the mountains, which is easy to understand as a result of former faulting but difficult of explanation in any other way. That the earthquake shocks of 1899 were violent here is proved by the fact that a gold miner's log cabin on the gravel bluff above Logan Beach was partly demolished, unroofed, and thrown partly off its foundation.

We are not absolutely certain whether to correlate this fault (*B*) with the one inferred farther southeast along the mountain front (*A*), which it intersects at a low angle, or to consider it a separate and distinct fault. It is a notable fact that this east-shore fault line, if extended, would strike the west side of the head of Yakutat Bay exactly at the point where the great uplift south of Turner Glacier so rapidly dies out. G. K. Gilbert points out that few if any faults as long as the combination of *A* and *B* (more than 30 miles) are straighter than *A*–*B* considered as one.

POSSIBLE MINOR FAULTS SOUTHWEST OF KNIGHT ISLAND.

Two minor faults (*F* and *H* on Pl. XIV) possibly exist in the archipelago between Knight Island and Yakutat. The evidence is not convincing and consists chiefly in the rather remarkable linear arrangement of uplifted and depressed areas in the midst of a region which, in general, shows no sign of change in level. The fact that in two or three of these areas earlier changes of level are recorded by older uplifted beaches, and that similar shore lines were not discovered elsewhere in the foreland and associated islands, corroborates this evidence, and leads us, with some doubt, to infer two fault lines along the axes of these islands.

[1] Bull. U. S. Fish Comm., vol. 21, 1901, p. 384. Miller says: "On the northern shore is a mountain about 2,500 feet high, and the eastern and western shores are covered with dead spruce and hemlock, caused, it is said, by a subsidence due to an earthquake in September, 1899."

G. K. Gilbert has suggested that the changes here are due to the shaking of the unconsolidated deposits of the Yakutat foreland and are thus a superficial result of the earthquake rather than a consequence of faulting. This explanation, however, seems doubtful to us chiefly because of the linear arrangement of the depressions and uplifts, because of the nonoccurrence of such disturbances except at this single series of localities, and because of associated older elevated beaches.

FAULT ALONG MOUNTAIN FRONT WEST OF YAKUTAT BAY.

Observations by the senior author in 1906 indicate that there was a zone of faulting extending from a point near the head of Yakutat Bay westward along the face of the Floral Hills just west of Lucia Glacier. This inference is based on the fact that both Lucia Stream and upper Kwik River are engaged in cutting away their alluvial-fan deposits at the point where these torrents emerge upon the flat that faces the mountain front—the Kwik on emerging from the Malaspina Glacier and Lucia Stream on emerging from a rock-walled gorge. Each of these streams is forming a series of terraces, the most perfect being along Lucia Stream (Pl. XVI, *A*). The uppermost of the series of recently formed terraces on Lucia Stream supported a scattered growth of alders from five to six years old, showing that the terrace was abandoned by the fan-building stream at least as long ago as 1899 and probably not before. The stream had trenched these gravels to a depth of about 20 feet since the abandonment of the upper terrace.

Uplift here seems very probable, but we have no evidence as to the exact location or direction of the fault line. An inferred fault line, drawn on the map (*G* on Pl. XIV), is made to pass from the lower Lucia Stream terraces eastward, along the line separating the Yakutat group from the Tertiary rocks, to the point where the uplift on the west side of Disenchantment Bay dies out. Such a fault line would account for all the facts observed and would explain the abrupt decrease in elevation on the Black Glacier alluvial fan. Aggradation by glacial streams may have obliterated all other traces of such a line of faulting.

FAULTING ALONG DISENCHANTMENT BAY.

The great uplift (reaching over 47 feet) on the west shore of Disenchantment Bay, the lesser but still great uplift (17 to 19 feet) on Haenke Island and on the shore of the peninsula north of it, and the moderate uplift (7 to 9 feet) along most of the east shore of Disenchantment Bay seem to demand at least two lines of faulting. One of these (*C* on Pl. XIV) is inferred to extend between Haenke Island and the west shore and one (*D* on Pl. XIV) between Haenke Island and the east shore. We have considered the hypothesis of warping or of parallel step faulting similar to that near the Nunatak Glacier, but on the whole the hypothesis of two faults is the simplest explanation of the dislocations observed. No evidence of these inferred faults was discovered other than the remarkable differences in uplift within short distances and the fact that the new reefs north of Haenke Island lie exactly along the line of fault *C*. The steep descent of the elevated shore line, from 17 feet just north of Haenke Island to the point where there is no change of level, at the end of the peninsula near Osier Island, is believed to be related in part to the fault line along the northwest arm of Russell Fiord next to be described. G. K. Gilbert has suggested that structural changes may have been even more complex in the region of the faults *C* and *D*. He suspects compound warping with incidental minor faulting.

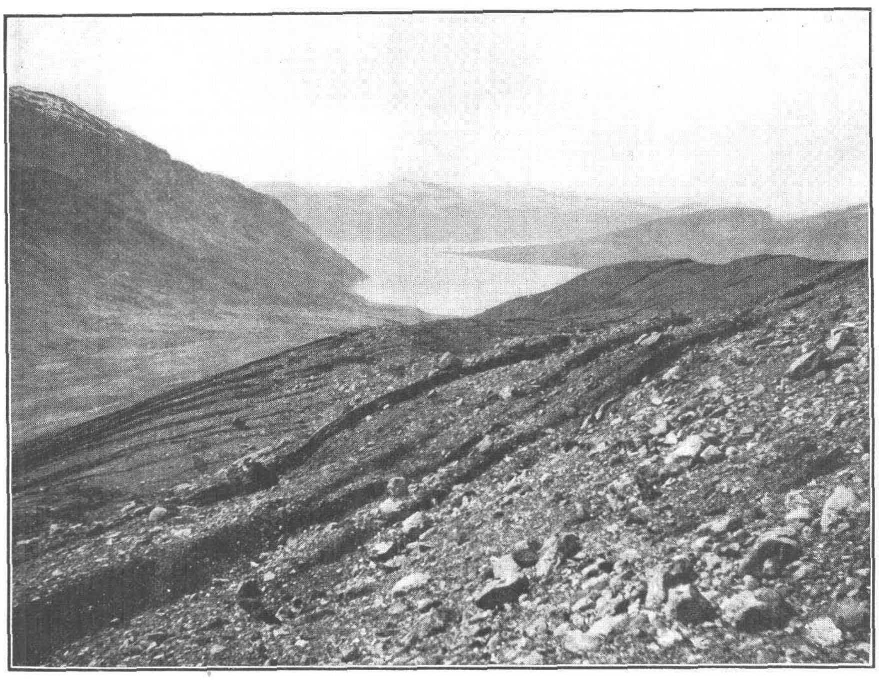
FAULT IN NORTHWEST ARM OF RUSSELL FIORD.

It is elsewhere shown that the geologic structure indicates the existence of an older line of faulting along the straight reach of Russell Fiord (p. 14); that an uplifted beach of older date exists on the northeast shore, whereas none was discovered on the southwest shore (p. 43); and that the uplift of 1899 raised the northeast shore from 7 to 9 feet and the southwest shore nowhere more than 1 foot 10 inches and in most places not at all (pp. 31–32). These facts all point clearly to a fault line (*E* on Pl. XIV) along the axis of this part of the fiord.

Nunatak Fiord furnishes no proof of change of level, though the nunatak at its head is broken by numerous minor faults (p. 37).

A. TERRACE FORMED BY LUCIA STREAM.

Assigned to uplift in 1899. Malaspina Glacier in background. Photographed in summer of 1906.



B. PARALLEL MINOR FAULTS, 2 TO 10 FEET APART, ON NUNATAK AT HEAD OF NUNATAK FIORD.

Photographed in summer of 1905.

SOUTHERN ARM OF RUSSELL FIORD.

From a region of very slight uplift near Cape Enchantment and of probable slight uplift on the opposite shore there is a rise in the elevated shore line on both sides of the south arm of Russell Fiord to a maximum of 10 feet near the head of the fiord. Within a short distance this uplift is abruptly replaced by depression on the foreland, along the line of the inferred mountain-front fault (*A*) already described (p. 34). Near the area of depression lie an ancient submerged forest (p. 41), found by Russell in 1890, and the adjacent buried forests which we discovered in 1905.

There is no evidence of faulting along the axis of the southern arm of Russell Fiord and no proof of an earlier uplift. The varying changes of level observed are readily explained by broad warping and adjustment of the large tilted fault block in which this part of the fiord lies.

MINOR FAULTING AND SHATTERING.

In addition to the major lines of inferred faulting, the approximate positions of which have just been stated, a minor shattering of the crust, referred to in earlier sections, is indicated at several widely scattered points. None of these places are along the lines of inferred major faults, but all such minor faults observed appear to be due to an adjustment of the strains set up in the large tilted blocks—adjustment not by broad warping nor by movement along minute planes but by minor shattering. We are convinced that careful search would show this phenomenon of minor faulting to be more common than our scattered discoveries indicate. Its nature may be inferred from the following description of specific localities.

MINOR FAULTING NEAR NUNATAK GLACIER.

The best visible faults observed in the Yakutat Bay region in 1905 and 1906 are on the rock hill between the tidal and nontidal tongues of Nunatak Glacier. This hill is 1,450 feet high and is composed of steeply dipping gneisses, schists, and slates, with a general northwesterly strike parallel to the main axis of the St. Elias Range.

Of the two summits of this hill (a former nunatak) the lower, or southern, was found to be broken by a series of very perfect parallel faults (Pl. XVI, *B*) whose scarps divide the hilltop and side into a series of parallel steps and treads with a trend of N. 40° W.

There are scores of these faults, most of them along the bedding or schistosity planes of the rock, the number along any transverse line varying from 20 to 40. Their longitudinal extent ranges from only a few feet to several hundred yards. The scarps, which are usually vertical, are of different heights—some an inch or less, some 3 or 4 inches (Pl. XVII, *A*), some a few feet (Pl. XVII, *B*), and one nearly 8 feet. The average is a foot or less. The height of these scarps seems to indicate the amount of throw of the faults, although, as shown in a subsequent section, if the hade was not strictly vertical the movement may in some places have been greater than the height of the vertical step or scarp indicates.

Most of these faults are parallel, but a few of the smaller ones diverge at a low angle and some short cross faults trend at right angles to the main faults which they connect. At the surface there is little crushing or gaping along fault lines, though some fissures were seen, the largest being about 3 feet wide and 9 feet deep. In one or two places a graben block (Pl. XVII, *C*) had dropped down between parallel faults, the narrowest being about 3 feet wide and the widest fully 30 feet.

The faulting seems to have crossed part of Nunatak Glacier, close to which some of the scarps were traced; but if the surface of the glacier was broken in 1899 it had melted down to a smooth surface again by 1905.

There is no very conclusive way of dating this faulting as having surely taken place during the 1899 earthquakes, though glacial striæ extending up to the very edges of the scarps but not over them prove that the faulting occurred since the ice uncovered this nunatak, not many decades ago. The same conclusion is indicated by the displaced veneer of glacial till over some of the faults (Pl. XVII, *A*). The sharp angles at the edges of the scarps (Pl. XVII, *B*) and the smallness or absence of talus slopes at their base (Pl. XVII, *D*) also suggest that the faulting is very recent, for weathering goes on rapidly in this region of abundant precipitation and sharp variations of heat and cold. They could hardly have been exposed for more than six years, and in view of the clear evidence of changes of level only six years before in association with profound faulting, these faults are assigned with some confidence to the period of the earthquakes of September, 1899. The explicit assignment of these faults to a single date (September 15) by F. de Montessus de Ballore, the distinguished French seismologist,[1] is probably an error, although he gives this date at two points in the text and beneath an illustration made from one of our photographs of faults near Nunatak Glacier. We do not feel justified in assigning these faults to any single date, although it seems possible that they were formed on or soon after September 10.

When we revisited these faults on the nunatak in 1909 and 1910 we were impressed by the increase in the weathering of the fault scarps and by the talus accumulation since our first visit, in 1905. Some of the faults were much altered, and tiny talus slopes completely mantled others, furnishing convincing evidence that none of the faults could have existed for more than six years before 1905. These faults, like many other physiographic evidences of earthquakes, are being fast obliterated by the elements.

The following section was measured by B. S. Butler and O. D. von Engeln under the direction of the senior author in 1906. Most of the faults (26) have the upthrow on the southwest side, the three exceptions being of rather large amount (Pl. XVII, *D*). The total upthrow to the southwest is 30½ feet and the total upthrow to the northeast is 12 feet, leaving a total absolute displacement of 18½ feet. The section was measured across the strike of the faults from northeast to southwest in feet and tenths. This section would vary from place to place, the absolute displacement being possibly greater in most places than here, where the large southwest upthrows subtracted so much.

Faults on the nunatak.

[A complete cross section along one line.]

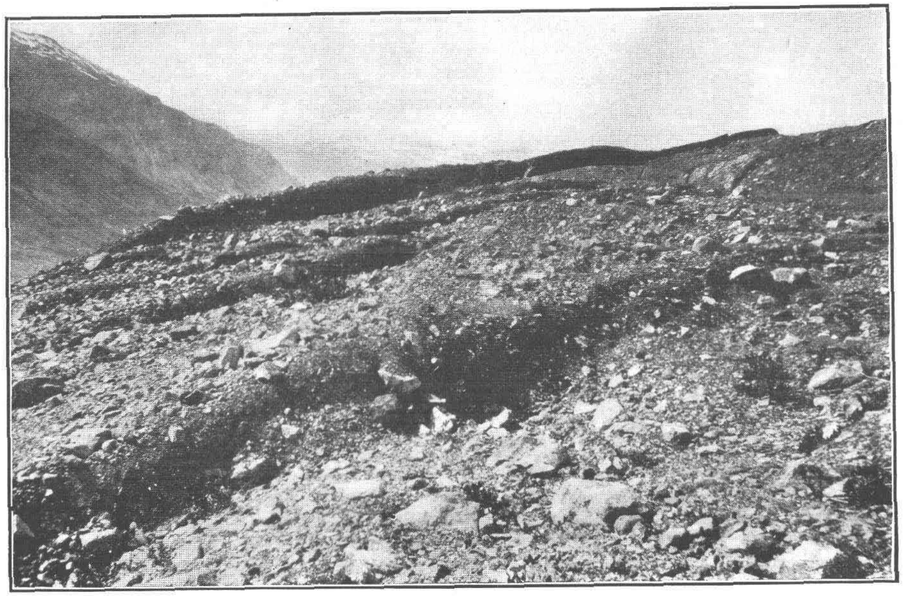
Fault No.	Displacement.	Direction of upthrow.	Fault No.	Displacement.	Direction of upthrow.
	Feet.			*Feet.*	
1	3.2	Northeast.	16	1.0	Southwest.
2	7.9	Do.	17	.6	Do.
3	.8	Southwest.	18	.6	Do.
4	.5	Do.	19	.3	Do.
5	1.0	Do.	20	1.8	Do.
6	.3	Do.	21	3.6	Do.
7	1.6	Do.	22	.5	Do.
8	2.6	Do.	23	1.2	Do.
9	.6	Do.	24	.8	Do.
10	1.9	Do.	25	.7	Do.
11	2.0	Do.	26	.2	Do.
12	.9	Northeast.	27	.4	Do.
13	1.5	Southwest.	28	.6	Do.
14	3.2	Do.	29	.2	Do.
15	2.0	Do.			

MINOR FAULT MOVEMENT PERHAPS NOT VERTICAL BUT OBLIQUE.

An interesting possibility in connection with the minor faulting observed on the nunatak has to do with the direction of movement along the fault planes. It is thought possible that this movement was not vertical but oblique; and the field relations make some such view as this almost necessary. The junior author has discussed this hypothesis,[2] which concerns the minor faults only, especially those upon the rock hill near Nunatak Glacier—the displacements that have just been described.

The rocks concerned are of unequal elasticity, because of their differences in composition, size, attitude, etc., and they form a part of a larger fault block which was jostled and tilted

[1] La science séismologique, Paris, 1907, Pl. VI, fig. 147, and pp. 31, 415.
[2] Martin, Lawrence, Econ. Geology, vol. 2, 1907, pp. 576–579.

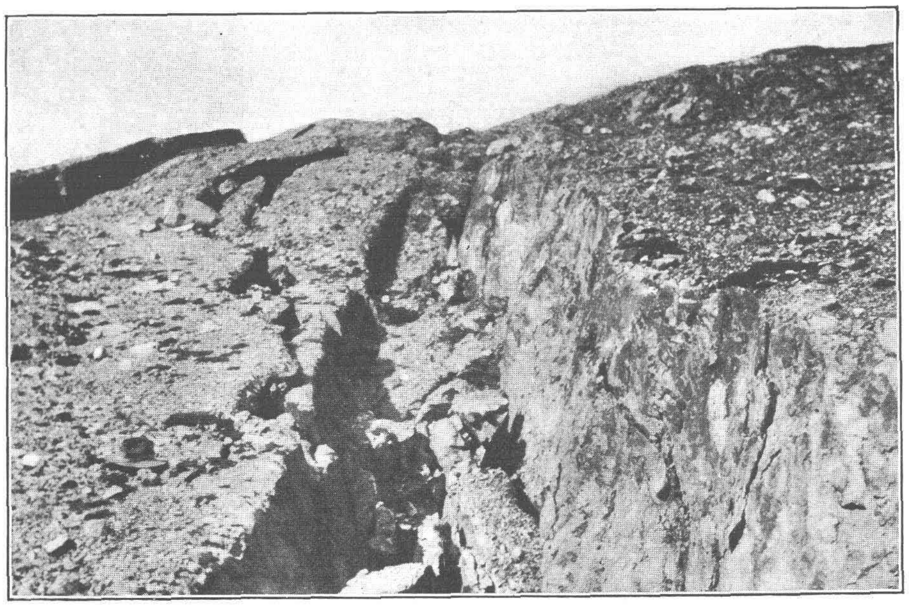


A. PARALLEL MINOR FAULTS ON NUNATAK AT HEAD OF NUNATAK FIORD

Photographed in summer of 1905.

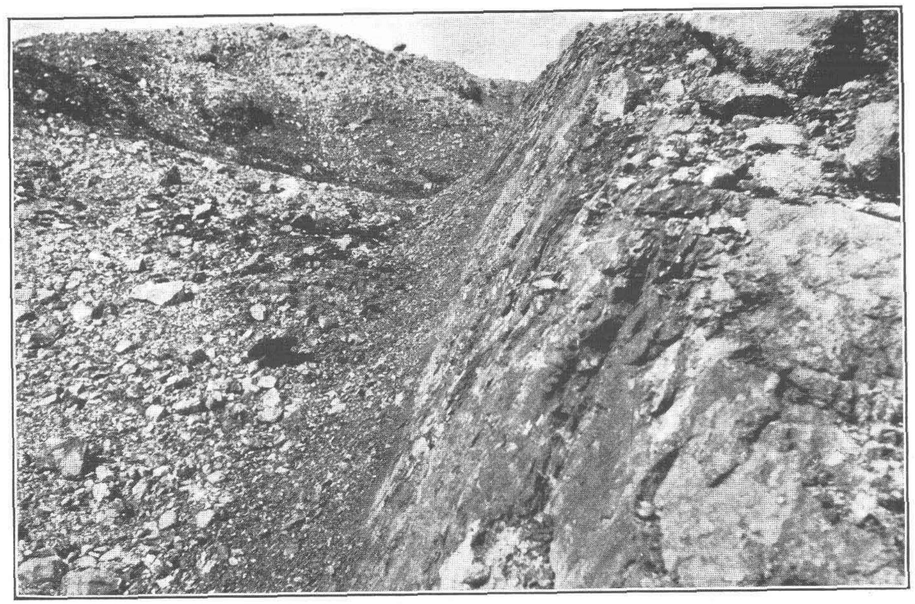
B. FAULT SCARP 4½ FEET HIGH ON NUNATAK AT HEAD OF NUNATAK FIORD.

Possibly made by oblique rather than vertical faulting. Photographed in summer of 1905.



C. GRABEN FAULT ABOUT 30 FEET WIDE ON NUNATAK AT HEAD OF NUNATAK FIORD.

Photographed in summer of 1905.



D. FAULT SCARP 7 FEET 9 INCHES HIGH ON NUNATAK AT HEAD OF NUNATAK FIORD.

Photographed in summer of 1905.

during the changes of level in adjacent parts of Russell Fiord and the neighboring region. When the larger block was tilted by the faulting at its edges, a strain was set up within it and equilibrium could be restored only by minor adjustments. These adjustments would probably not result in any surface changes in some rocks, like the granites which form part of the shores of Nunatak Fiord; and equilibrium in the adjacent bodies of gneiss and conglomerate might also be restored by slipping along minute planes, thus adding or subtracting strain from the adjacent rigid or yielding rock units of the larger block. Slate and schist, however, because of their well-developed cleavage planes (Pl. XVII, *D*), would be more susceptible to visible surface adjustment; and it seems significant that surface faulting was limited to the area of slates and schists. The steep inclination of these beds lends itself to relief by upward movement even if the strain applied was vertical or oblique.

This theory involves no necessity for uplift, and as corroborative evidence it may be stated that no change of the land level was discovered along the coast of this faulted nunatak, although not far from the coast the step faults along one line show a total absolute displacement of 18½ feet. We came to the conclusion that there might have been an uplift of a foot or less along the shore line just to the west, and that on the shores of the nunatak itself there was probably none.[1]

The horizontal movement in the faulting that accompanied the California earthquake of 1906[2] shows that this is a possible state of affairs, as F. L. Ransome[3] and others who have recently discussed the nomenclature of faults have demonstrated.

On the nunatak oblique rather than vertical or horizontal movement seems necessitated by the topographic conditions and the distribution of the fault scarps. The hill has been broken into long, narrow strips, traversing its top and only one side. If there were vertical movement along the fault planes there is no apparent reason why both slopes of the hill should not be faulted alike, and no reason why an 18½-foot uplift on the seacoast of the hill should not accompany the 18½-foot displacement which successive step faulting has made on its slopes.

If there were horizontal movement only, then both slopes of the hill should be faulted and the opposite sides should exhibit an opposite distribution of upthrows; that is, the hill is conceived of as broken into northeast-southwest strips, the smooth slope being disjointed by the southeastward movement of each strip with respect to its northeast neighbor (Pls. XVI, *B*, p. 36; XVII, *A*, p. 38). We should then have a series of seemingly normal faults on one side of the hill with apparent upthrow on the southwest side, so that one going downhill would constantly go up steps. This is what we do find, though there are a few apparent upthrows on the northeast side, where a strip seems to have slipped in the wrong direction, as well as cross faults where the long, narrow strips are broken across.

On the other side of the hill, however, we do not find the opposite distribution of upthrows; we do not go down steps as we go downhill. If this were the case horizontal movement would be demonstrated. Instead of this the opposite slope of the hill is smooth and unfaulted, except for a few scarps which extend just over the crest (Pl. XVII, *B*). Consequently horizontal movement also seems impossible.

It is therefore necessary to consider (*a*) vertical uplift or subsidence of a large block, with differential movement along the layers, or (*b*) oblique movement parallel to the unfaulted slope of the hill. The former theory might explain the existing conditions, the faults dying out within short distances because of readjustments and tilting, if it were not for the lack of change of level along the shores of the fiord just here. That differential strains should have been so naturally balanced as to cause a total displacement of 18½ feet on the hill without a change of level of the coast in this one locality in the whole fiord does not seem reasonable.

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[1] See p. 28, where the bleached and crisped seaweeds that were found here are discussed.

[2] The California earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission. Published by the Carnegie Institution of Washington, vol. 1, 1908, vol. 2, 1910. Gilbert, G. K., The San Francisco earthquake and fire: Bull. U. S. Geol. Survey No. 324, 1907, pp. 4-5.

[3] Econ. Geology, vol. 1, 1906, pp. 777-787.

The theory of oblique faulting at a low angle subparallel to the unfaulted hill slope (fig. 1) has none of these objections. The low angle of emergence would not necessarily involve an appreciable change of level of the land on the seacoast. It would account for the unfaulted hill slope, for the escarpments extending up to and just over the crest of the hill, and for the distribution of steps, or scarps, on the faulted slope, where the strips moved in the relation to each other already outlined. This suggests that a vertical scarp along a fault plane does not always demonstrate vertical movement.

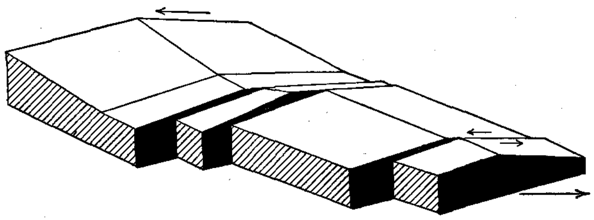

FIGURE 1.—Diagram illustrating oblique faulting, with movement parallel to the hill slope on the right, producing scarps on the opposite side and along the crest. Such movement would result in essentially no change of level in a shore line on the right. (From Martin, Lawrence, Econ. Geology, vol. 2, 1907, fig. 65, p. 79.)

Since writing this discussion in 1907 the junior author revisited the region and made a further examination of these faults to see what facts support or disprove the hypothesis of oblique movement. It was hoped that the faulted surfaces might preserve slickensides that would show the direction of movement conclusively, but weathering had gone so far in 1909 that this could not be determined. The facts observed in the field, however, seem to support the hypothesis of oblique movement as outlined.

POSSIBLE MINOR FAULTING NEAR RUSSELL FIORD.

In the valley of McCarty Glacier, just south of Cape Enchantment, in southern Russell Fiord, a series of fractures was observed in a heavy conglomerate, but these fractures may have been due to sapping near the edge of a cliff recently steepened by ice erosion. The relation of of such faulting or sapping to avalanches is discussed in another place (p. 51). On the nunatak just described there is no possibility that the scarps observed are due to sapping rather than faulting, and it is not altogether probable even in the McCarty Valley.

OTHER AREAS OF MINOR FAULTS.

In several other widely scattered areas minor recent faults were observed in 1905, though nowhere in such profusion or perfection as in the area near Nunatak Glacier. No major fault scarps were seen, the faults occasioning the greater changes of level nowhere extending to the surface where studied and most of them following older fault lines beneath the waters of the deep fiord. Minor surface faulting was seen on many of the mountain slopes traversed in 1905 where such evidence would be preserved.

On the southwest slopes of Mount Tebenkof recent faults strike N. 50° W. and N. 65° W. On the ridge east of Point Latouche, 1,900 feet above sea level, faults strike N. 85° W. Several in a moraine have a throw of 3 feet, but some of the scarps are only a few inches high. These faults can not possibly be due to sapping or landslides, for they cross a valley and extend up the middle of a broad ridge where there are no steep slopes within several hundred yards. On the nunatak in Lucia Glacier and on the spur south of Floral Pass, on the west side of Floral Hills, similar faults were observed. On Haenke Island and the mainland opposite there was a suggestion of surface faults, but it was inconclusive and may have been due to fissuring long before 1899.

FOLDING VERSUS FAULTING.

Both in the field and since our return we have attempted to interpret the phenomena of deformation here described by a theory of folding or warping, but without success. Opposed to the hypothesis of folding are four significant facts, which seem to eliminate it. In the first place, the lines of deformation extend in too many directions. In the second place, the zones of gradation between areas of different degrees of deformation are exceedingly narrow and the intervening areas of uplift are very broad; warping, if present, would necessarily be very complicated. In the third place, the minor faulting proves actual dislocation in parts of the region. Finally, profound faulting is proved by the series of severe earthquakes and their destructive avalanches and water waves.

NATURE OF THE DEFORMATION.

Briefly summarizing the conclusions which the facts seem to warrant, we find that in 1899 there was a renewal of mountain growth, uplifting that part of the mountain front which borders the Yakutat Bay inlet by amounts ranging from 7 to 10 feet on the southeast side of the bay and 40 to 47 feet on the northwest side. This uplift all occurred within a little less than four weeks, the major movement probably taking place in a single day (September 10) and possibly in connection with a single faulting movement—that which caused the last heavy shock on that day. This uplift was complicated by movement along secondary fault lines which produced at least three and perhaps more distinct major blocks with roughly parallel sides, as follows: (*a*) The area between fault lines *A*, *B*, *C*, and *E* (Pl. XIV), including all the peninsula and a part of the mountains east of the south arm of Russell Fiord, to an unknown distance toward the southeast; (*b*) a block west of fault line *C*, extending westward an unknown distance from the west shore of Disenchantment Bay and bounded toward the south by the mountain-front fault (*G*); (*c*) a block extending for an unknown distance northeastward from the northeast shore of the northwest arm of Russell Fiord. The first and, so far as our evidence shows, the largest of these blocks—that including the peninsula—is apparently tilted upward toward the south and west.

Accompanying this faulting was a minor fracturing, apparently due to local adjustments in the tilted blocks. Doubtless this minor fracturing was much more widespread than our observations indicate, for it was discovered in more than half of our expeditions into the interior, whenever we went out of the valleys away from the seacoast. Moreover, it would be expected as a common result of the sudden movement of a great block of the earth's crust composed at the surface of tilted beds, many of which were thin bedded and fissile. It is highly probable that some of the differences in the amount of uplift in contiguous areas are due to such minor differential adjustment.

From such great and complex crustal movements as are so clearly proved in this region, it is easy to understand the earthquake phenomena observed. That such movements should produce world-shaking earthquakes follows almost of necessity;[1] and that the number of minor shocks should be numbered by the hundreds is likewise a necessary result of so complex a shattering of the earth's crust. While it is possible that some of the shaking had its source outside of the Yakutat Bay region, the phenomena in that region seem by themselves amply sufficient to account for it all.

OLDER CHANGES OF LEVEL.

That the fault movements of 1899 were merely the latest of a series is clearly indicated by the facts observed in our field studies. There are two distinct features that give evidence of older changes of level in the Yakutat Bay inlet—the submerged forests and the older elevated beaches.

SUBMERGED FORESTS.

One of the submerged forests was discovered in 1891 by Russell,[2] who briefly describes the occurrence as follows:

> A fragment of the history of the region at the head of Disenchantment Bay[3] is recorded in the buried forest just below the level of high tide, at the head of a cove southwest of Cape Stoss. The heavy deposits of gravel in which the beach lines about the head of the bay have been excavated are more recent than this forest.

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[1] Milne says of these shocks (in a communication signed J. M., in Nature, vol. 75, 1907, p. 224): "We do not know the magnitude of the masses involved, but from measurements like those made by Messrs. Tarr and Martin we may estimate them as being represented by one or two million cubic miles of rocky material."

[2] Second expedition to Mount St. Elias: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 89.

[3] Head of Russell Fiord according to more recent usage.

On our visit we found buried forests at four points in the region mentioned by Russell. There are hundreds of trees in place, some fully 2 to 3 feet in diameter and all broken off near their roots. In addition there were some recumbent logs and others embedded in the overlying gravels. The roots of the trees were in a clay, in some places more than 3 feet below normal high tide. We could not determine whether these forests antedate the expansion of glaciers, as a result of which the Yakutat foreland was formed, or whether they are of later date, growing on the margin of the fiord and being destroyed by the relatively recent formation of the glacially dammed lake under whose gravels they are now partly buried. In any event these trees, below high-tide level, demonstrate a subsidence of this region at no very remote period.

A second locality in which a submerged forest occurs is at the north end of Logan Beach. Here, in an area of several hundred square yards, there are fully 50 upright tree stumps (Pl. XVIII, *A*), the lowest one visible being about 10 feet below the high-tide mark. Back of this locality a forest-covered gravel bluff rises to a height of about 100 feet, the stumps of the old forest extending almost up to its base. Although it is not absolutely certain, the evidence indicates that this forest is even now being uncovered by the removal of the gravels. The trees are far too numerous and too upright for their presence to be explained by downsliding from the crest of the neighboring gravel terrace. The nature of the soil in which these trees grew was not ascertained, but the abundance of great bowlders found in close association with them suggests that they were growing on a morainic surface when they were buried by the gravels.

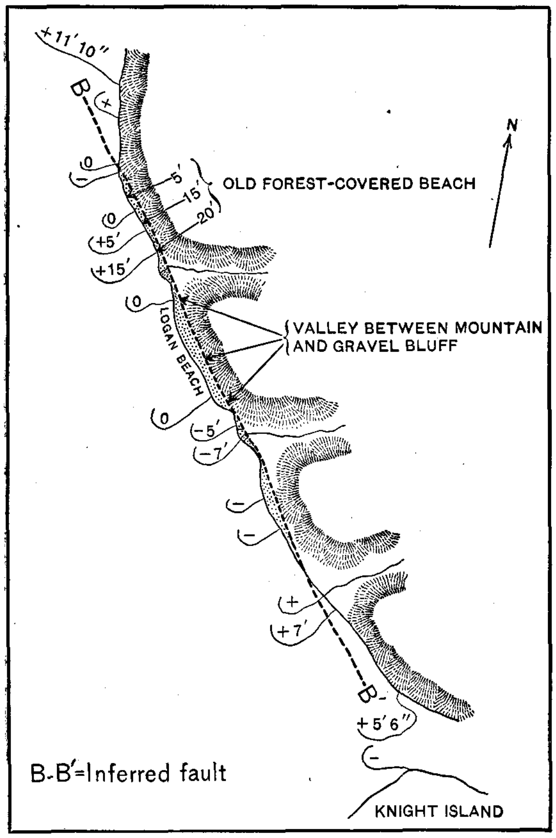


FIGURE 2.—Sketch map of east coast of Yakutat Bay, illustrating the conditions associated with the inferred fault line along this coast. (From Tarr, R. S., and Martin, Lawrence, Bull. Geol. Soc. America, vol. 17, 1906, p. 53.)

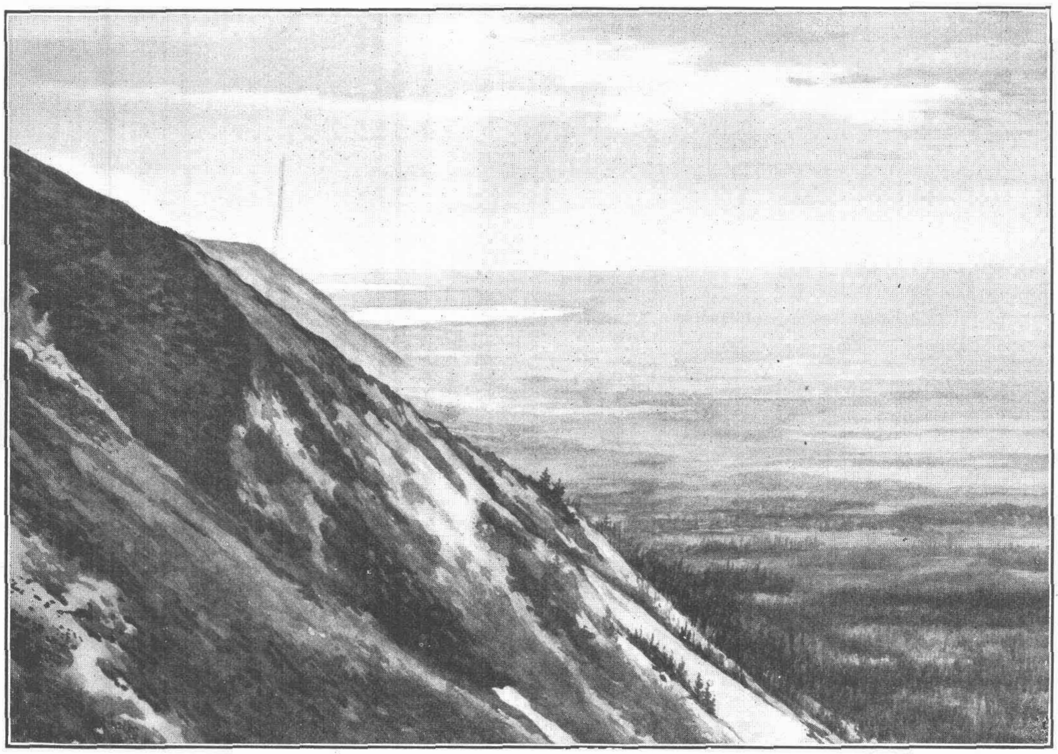
OLDER ELEVATED BEACHES.

Older elevated beaches were found at three points in the inlet. One of these is on the northeast or lee side of Krutoi Island. Here, back of the storm beach and of a still higher beach uplifted in 1899, there is a narrow terrace of beach gravels, backed by an old wave-cut bluff whose base is 8 or 10 feet above present sea level. Spruce trees more than a century old are now growing on both the older beach gravels and the bluff. This older elevated beach is close by one of our inferred fault lines and is associated with a beach uplifted in 1899 in a part of the bay where there was in general little or no change of level.

The second ancient elevated beach is just north of Logan Beach, north of the submerged forest mentioned above and also along one of our inferred fault lines. (See fig. 2.) Logan Beach itself lies outside of the fault line, on the downthrown side of the fault, and shows no evidence of change of level except that furnished by the older submerged forest described. Immediately north of Logan Beach, however, there was an uplift of about 15 feet in 1899, and just back of this lies the older elevated beach. At its south end this older elevated beach starts in a wave-cut rock cliff of ancient date, at an elevation of about 5 feet above the beach uplifted in 1899, or 20 feet above present sea level. The upraised beach of 1899 extends northward about half a mile, rapidly decreasing in elevation from 15 feet to the point where it dies out.

A. STUMPS OF OLDER SUBMERGED FOREST AT LOGAN BEACH, EAST SHORE OF YAKUTAT BAY.

Photographed at midtide in summer of 1905.



B. TRUNCATED SPURS OF MOUNTAIN FRONT, RISING ABOVE YAKUTAT FORELAND.

Looking southeastward. An inferred older fault line passes along the base of the escarpment, which is followed also by fault line A of 1899. Miller Lake and head of Russell Fiord in background. Photographed in summer of 1905 from an elevation of 1,590 feet.

The older beach also descends northward, having at a distance of half a mile an elevation of 15 feet above the present storm beach crest, then descending toward the north, and disappearing about 2¼ miles from the rock cliff in which it starts. Throughout most of this distance the elevated beach is backed by a steep, forest-covered, wave-cut gravel bluff. The earthquake wave generated in 1899 swept the forest from a part of this older elevated beach and wave-cut bluff. (See Pl. XIX, *A*.) The broken trees are all mature, and in one of them we were able to count 75 rings, proving the ancient elevated beach to be at least 75 years old.

A third ancient elevated beach was seen in the northwest arm of Russell Fiord, nearly opposite Marble Point. Here an old wave-cut cliff in the slate rock rises from 20 to 40 feet above a narrow gravel terrace (fig. 3). Both the gravel terrace and the rock bluff are covered by a dense mature alder thicket with bushes apparently as old as those on the hill slope above the bluff, which are estimated to be not less than 25 years of age. An uplift of about 7 feet took place on this coast in 1899, but the older uplift was not more than half as great. A number of other possible ancient sea cliffs of varied character were found, but none that we felt certain enough about to assign definitely to this origin.

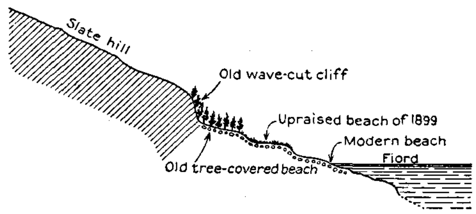


FIGURE 3.—Cross section of northeastern part of Russell Fiord opposite Marble Point, illustrating the two uplifts recorded there. (From Tarr, R. S., and Martin, Lawrence, Bull. Geol. Soc. America, vol. 17, 1906, p. 52.)

EARLIER FAULTING.

Besides the evidence of former movements of the mountains in the Yakutat Bay region furnished by the older elevated beaches and the submerged forests, there is clear evidence of former fault movement in the relation of the strata themselves. This has been briefly stated in a previous section (p. 14), and is more fully treated by Tarr and Butler in their general discussion of the physiography and geology of the Yakutat region.[1] Innumerable faults are visible in the outcrops; and at least two grand faults separate the different rock systems—one between the Yakutat group and the younger Tertiary beds along the mountain front west of Yakutat Bay, and the other between the Yakutat group and the older crystalline rocks along the axis of the northwest arm of Russell Fiord.

The presence of these fault lines, the evidence of the topography, and the existence of proof of former changes of level show clearly that the mountains of the Yakutat Bay region, whose trend is approximately parallel to that of the older faults (along some of which there was renewed movement in 1899), owe at least a part of their present form and elevation to faulting. The incompleteness of the evidence of profound recent faulting, prior to 1899, is doubtless due to the fact that glaciers have so recently occupied a large part of the region. Bearing on this general question of the formation of the mountains and furnishing far more specific and extensive proof of their present growth by movement along fault lines is the evidence furnished by the shore lines which were deformed in September, 1899, as already described.

TOPOGRAPHIC SIGNIFICANCE OF FAULTING.

THE FIORDS.

That the fault movements of 1899 may be a part of an important process by which the main lineaments of topography in this region were developed is evident. (Pls. I, p. 12; XIV, p. 30.) The straight mountain front, the straight mountainous east shore of Yakutat Bay, and the straight northwest arm of Russell Fiord all bear evidence of faulting during this most recent period of uplift; and the evidence seems to demand the presence of two fault lines within Disenchantment Bay. How far this process of faulting can be applied in explanation of the initial outlining of the fiords is not certain from any facts we could gather, but of one thing we are certain: In spite of the parallelism of the fault lines to several reaches of the fiord, and in spite

[1] Tarr, R. S., and Butler, B. S., Prof. Paper U. S. Geol. Survey No. 64, 1909, pp. 163-164.

of their possible importance in initially determining the main lineaments of the major valleys, the present depth and form of the fiords are assignable not to faulting but to glacial erosion, as has been demonstrated elsewhere.[1]

FAULT-BLOCK MOUNTAINS.

The evidence of profound faulting in the rocks of the Yakutat Bay region is most striking.[2] In places the beds are literally crushed and kneaded; a score of minor faults may appear in a single small outcrop of the sandstones, shales, etc., of the Yakutat group, the older and younger formations being less faulted in detail.

THE MOUNTAIN FRONT.

Russell[3] assigned to faulting a very important part in the evolution of the topography of the region. He called attention to the fact that the mountain front, which rises above the Yakutat foreland and above the plateau of Malaspina Glacier, consists of a series of steeply rising truncated mountain spurs (Pl. XVIII, *B*) possessing remarkable alignment, which he explained as a gigantic fault scarp, the gravels of the foreland having accumulated on the depressed orographic block. He further stated that there had been movement along this fault line in very recent time, basing his conclusion on a prominent gravel terrace near Knight Island (which, however, we interpret as a moraine terrace, although agreeing with his conclusion on other evidence).

An alternate hypothesis to account for these truncated mountain spurs is that they were worn away by marine erosion during the period antedating the deposit of the coastal-plain gravels of the Yakutat foreland, giving rise to enormous sea cliffs rising fully 1,500 feet.

It is an important question whether faulting or marine erosion has been most potent in shaping the scarp of the mountain front. As seen from Cape Stoss and elsewhere at the head of Russell Fiord, in the summer of 1905, a certain mountain spur to the southeast (see Pl. XXII, p. 54) presented a strikingly level top, with abrupt front and back scarps, suggesting the possibility of wave-planed benches and sea cliffs. Eliot Blackwelder,[4] who visited the region in 1906, presents some facts in support of the hypothesis that the upper bench, with the scarp at its back, is a wave-cut terrace and is part of a larger system of terraces traced eastward along the coast. The lower scarp he is inclined to interpret as a sea cliff associated with the wave-planed rock bench of the gravel-covered foreland, assigning to the whole mountain face southeast of Russell Fiord an origin by marine erosion rather than by faulting.

Both views as to the origin of this mountain face might possibly be brought into harmony by supposing the upper, possibly wave-planed bench southeast of Russell Fiord, with its sea cliff, to be the correlative of the low-lying, planated bedrock headlands outside of the mountain base near the head of Russell Fiord, between Cape Stoss and the fault line, beyond which rock in place was not found. Low-lying outcrops of this same date are also seen in the foreland to the southeast; but none occur on the shores of Yakutat Bay, to the west of the Russell Fiord outcrops. The lower scarp southeast of Russell Fiord may be a fault scarp, like that between Russell Fiord and Yakutat Bay extending northwestward to Point Latouche, differential faulting having located these wave-cut surfaces at far different levels at the present time. Faulting is regarded as of far greater recent topographic significance here than in the glaciated fiords, as already stated.

Although we are able to contribute little to the discussion of these rival hypotheses, such facts as we discovered support Russell's explanation rather than the theory of marine erosion. A depression of a part of the foreland prior to 1899 is clearly indicated by the presence of sub-

[1] Tarr, R. S., and Martin, Lawrence, Bull. Am. Geog. Soc., vol. 38, 1906, pp. 158–160. Tarr, R. S., and Butler, B. S., Prof. Paper U. S. Geol. Survey No. 64, 1909, pp. 107–119. Tarr, R. S., Glacial erosion in Alaska: Pop. Sci. Monthly, vol. 70, 1907, pp. 99–119.

[2] Tarr, R. S., and Butler, B. S., Prof. Paper U. S. Geol. Survey No. 64, 1909, pp. 145–164.

[3] Nat. Geog. Mag., vol. 3, 1891, p. 57.

[4] Oral communication.

merged forests beneath the gravels at the head of Russell Fiord (p. 41). Moreover, during the changes of level in 1899 the land was in places depressed on the foreland side and raised on the mountain side of Russell's supposed fault line; and one of the fault lines which we infer from our study of the 1899 changes of level coincides closely with that postulated by Russell.

EAST SHORE OF YAKUTAT BAY.

Russell also assigns to faulting the similar topographic features of the steep mountain face of the peninsula that forms the east side of Yakutat Bay north of the foreland. This, he says,[1] "bears evidence of being the upheaved side of a fault of quite recent origin. The steep inclination and shattered condition of the rocks along this line are evidently due to the crushing which accompanied the displacement." The conditions here are closely like those existing where the mountain front rises above the foreland; but at this locality the hypothesis of marine erosion seems even less applicable. Some of these cliffs rise to heights of 1,500 feet, with the spur ends cut off in triangular facets and the intermediate valleys hanging. A part and possibly most of this topography may be explained by glacial erosion quite as well as by faulting; but it is noteworthy that one of our inferred 1899 fault lines runs at the very base of these cliffs and, further, that there is definite evidence of a recent uplift along this line antedating that of 1899 (p. 42).

REGION WEST OF YAKUTAT BAY.

Russell points out that the geologic structure west of Yakutat Bay is more complex, with long mountain spurs projecting into the ice plateau. To the topography of this region also he assigns fault origin as a major factor. Besides great faults extending northwest and southeast along the mountain front, he infers several cross faults. Some of the evidence on which Russell assumes faulting here, especially that for the cross faults, would harmonize better with the interpretation of glacial erosion; and it is quite probable that had he studied this region with the present-day views concerning glacial phenomena, he would in some instances have applied this explanation rather than faulting.

Russell also states[2] that the southern face of Mount St. Elias is a fault scarp, and from his study of the bedrock geology he infers that the St. Elias Range is young, having apparently been formed since the close of the Tertiary period. He believes that the breaking and upheaval of the rocks are so recent "that erosion has scarcely modified the forms which the mountains had at their birth. The formation of glaciers followed the elevation of the region so quickly that there was no opportunity for streams to act. The ice drainage [see Pl. I, p. 12] is consequent upon the geologic structure and has made but slight changes in the topography due to that structure."

Russell found rocks containing fossils of existing species of marine animals like the mussel, as well as leaves of modern plants like the willow, at Pinnacle Pass, 25 miles west of Yakutat Bay, between Seward and Malaspina glaciers.[3] These rocks are 5,000 feet above sea level and prove uplift of at least that amount in Pliocene or Pleistocene time.

As our observations did not extend through the entire region studied by Russell, we will not discuss this phase of the question further than to state that the evidence of marked faulting in 1899 lends strong support to his interpretation. At the same time we feel obliged to add that, even with this support, we are hardly able to accept as final his judgment as to the extreme youthfulness of the St. Elias chain or to assign to faulting as great importance as he did.[4]

[1] Nat. Geog. Mag., vol. 3, 1891, p. 83.
[2] Idem, pp. 131, 170–173, 199–200.
[3] Idem, pp. 174–175.
[4] I. V. Novarese, of the Royal Geological Office at Rome, has recently (Filippi, F. de, The ascent of Mount St. Elias, Appendix E, pp. 232–234), on a rather incomplete basis of fact (reading Russell's reports and examining the specimens brought home by the Duke of the Abruzzi's party), cast some doubt on Russell's explanation of the origin of Mount St. Elias.

CHAPTER IV.

SURFICIAL EFFECTS OF THE SHOCK.

EARTHQUAKE WATER WAVES.[1]

Descriptions of the water waves in Disenchantment Bay and at Yakutat village during the earthquake of September 10, 1899, have already been given (pp. 16 and 35). The slight water waves, none of them at all destructive, observed at greater distances—in the fiord at Valdez (p. 80), in Lynn Canal near Skagway (p. 74), on the Yukon (p. 81), on a branch of the Kuskokwim (p. 74), and on the Koyukuk (p. 75), seem certainly to have been caused by these same earthquakes. The records (marigrams) of the automatic tidal gages at San Francisco, Cal., and near the mouth of the Yukon at St. Michael, Alaska, show no variations attributable to seismic disturbances in September, 1899. There were no tidal gages nearer Yakutat Bay, and as there were practically no changes of level of the coast outside of the Yakutat Bay region it is not surprising that destructive water waves should not be reported elsewhere.

In 1905 we found clear evidence at several points in Yakutat Bay of the destructive force of the earthquake water waves, or tsunami. The effects were not everywhere shown, because the destructive waves were not everywhere generated and because the amount of destruction wrought depended on the nature of the coast. Rock coasts would manifestly show no evidence after a lapse of six years. Forested coasts might preserve clear evidence; but little of the coast of inner Yakutat Bay is forested, and not all of this was washed by great waves. On the shores of Knight Island and parts of the Yakutat foreland, for instance, undisturbed forests extend clear to the water's edge, contrasting strongly with the adjacent littoral forest near Logan Beach, where a devastating wave rushed high upon the shore.

The effects at Logan Beach are typical of the destructive action of tsunami, to which the name tidal waves is often erroneously applied. The beach and the zone back of it were totally wrecked by the waves (Pl. XIX, *B*). The present beach is littered with trunks and limbs of trees; the elevated beach hoisted in 1899 is covered with similar débris; and the older elevated beach, on which mature trees were growing up to 1899, presents a wild, almost impenetrable tangle of uprooted, broken, twisted, and shattered trunks mingled with leaning trees. All vegetation was killed up to 40 feet vertically above sea level, and the receding wave scattered the débris along the lower stretches of coast in indescribable confusion (Pl. XIX, *A*). The violence of this wave is proved by the fact that it broke a sound tree 75 years of age.

It seems likely that preliminary shaking of the gravelly soil prepared these trees for easy overturning and uprooting by the water waves, as the stretch of coast where the destruction was greatest is almost exactly along a fault line.

On the west side of Yakutat Bay, near Disenchantment Bay, along a fault line and just west of the place where the shore line was uplifted 42 feet, the water waves were also tremendously destructive, rushing back at least a quarter of a mile, to a height of 30 feet vertically above the present coast, and uprooting part of a cottonwood grove along whose edges the dead trunks are now piled in confusion.

Between this windrow of dead trunks and the present coast are many mature willows which were killed and had their branches and shoots bent southward, toward the open ocean, by the receding water wave. The wave also eroded the bark and piled driftwood at the base and on the north side of a dead cottonwood tree, still standing between the sea and the windrow of dead trunks at the forest's edge, proving the latter not to be on an uplifted shore line.

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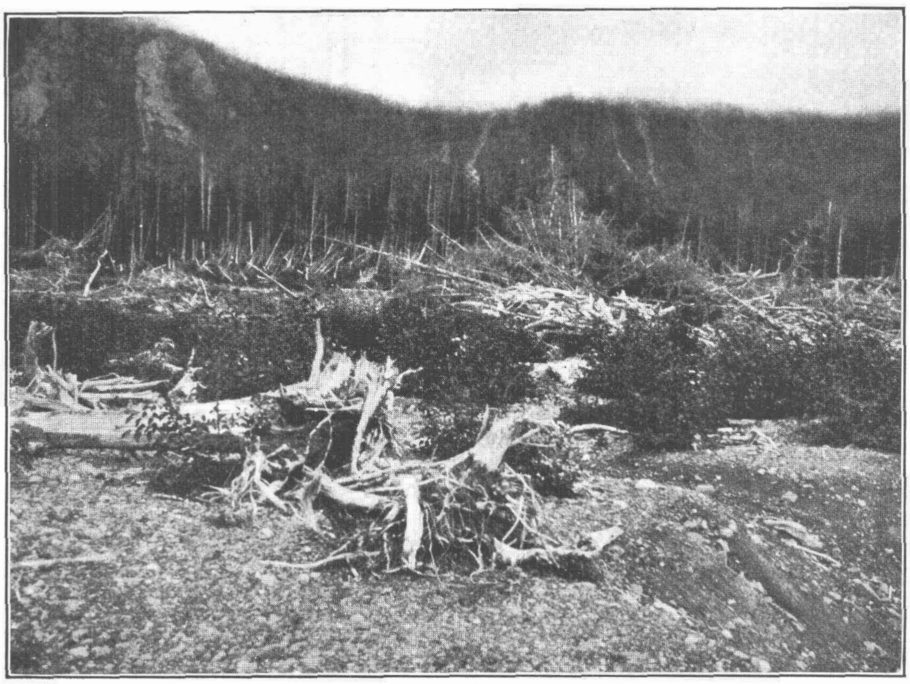
[1] G. K. Gilbert has suggested that these be called by the Japanese name, tsunami.

A. FOREST ON EAST SHORE OF YAKUTAT BAY DESTROYED TO HEIGHT OF 40 FEET ABOVE PRESENT SEA LEVEL BY EARTHQUAKE WATER WAVE IN 1899.

View along fault line B. Photographed in summer of 1905.



B. ANOTHER VIEW OF WAVE-DESTROYED FOREST SHOWN IN *A*.

Avalanche scar visible on the mountain slope. Photographed in summer of 1905.

At Cape Stoss, in southern Russell Fiord, a water wave passed across the sandy peninsula which connects the rocky island with the mainland, leaving large quantities of driftwood at higher levels than the elevated beach and wrapping a tangle of driftwood about a very large bowlder several hundred yards from the beach.

Here and elsewhere the extensive beds of wild strawberries on the sandy beaches were destroyed by the earthquake waves; and in 1905 the natives said that many of the beds had not yet developed their former productivity.

Definite evidence of the passage of an earthquake water wave was found in 1906 on Strawberry Island, at the mouth of Kwik River. At this point there is a low barrier beach against which the waves now beat; back of it is a lagoon, on the inner side of which, a quarter of a mile from the present barrier beach, rises a narrow sand and gravel bar. This bar, known as Strawberry Island, is an old barrier beach, now abandoned because of the seaward advance of the coast. On it mature cottonwoods grow, and wrapped around their bases, at an elevation of about 15 feet, much driftwood was found, and stranded among them a number of large drifted logs. Evidently the earthquake wave swept over the present barrier beach, across the lagoon, and over the top of Strawberry Island, but not with sufficient violence to throw down the forest.

Between this point and the entrance to Disenchantment Bay much driftwood lies far above the reach of the highest waves of the present day. This we infer was drifted in by the earthquake wave. Elsewhere in the inlet less definite evidence of the recent presence of a water wave was found.

The entire Yakutat Bay inlet was thus swept by at least one great earthquake water wave. That this wave rushed through the inlet on September 10, 1899, is evident from the testimony of the prospectors that during or immediately after the most violent shocks of that day there were one or more waves in Disenchantment Bay, and of the residents at Yakutat that pronounced waves were observed in the harbor there at the same time. On both the west and east sides of Yakutat Bay (at the mouth of Kwik River, and just north of Logan Beach), at the entrance to Disenchantment Bay, and at Cape Stoss, near the head of Russell Fiord, clear proof of the occurrence of such a wave persists even to this day.

This wave evidently varied in height and in destructiveness, but the observed facts are not sufficient for a thorough discussion of the variations. It is clear, however, that the wave reached nearly three times as high on the east side of Yakutat Bay, near Logan Beach, as on the west side, at the mouth of Kwik River. It is also certain that, while in the former place it threw down a forest in wild confusion, in the latter it was incapable of overthrowing cottonwood trees rooted in beach sand and gravel. Furthermore, the wave that destroyed the forest north of Logan Beach was unable to throw down trees at Knight Island, 4 or 5 miles distant.

As to direction, the wave was certainly from the north at the entrance to Disenchantment Bay and at Cape Stoss. Elsewhere we have no evidence of its direction; but all the facts observed would harmonize with the hypothesis that it was generated in Disenchantment Bay and Russell Fiord, and, on moving out into the broadening inlet, rapidly decreased in size and vigor. Local conditions may have caused it to strike with especial force on the coast north of Logan Beach. Such a water wave could hardly have come from the ocean without making a record on distant tide gages. Moreover, the cause for such a wave was clearly present in the inner portions of Yakutat Bay, where the land was upraised, and, so far as we can tell from the evidence obtained, was not present along the ocean coast.

A possible later consequence of these 1899 earthquakes is referred to in the Juneau Record for December 9, 1907, which says, in a description of the damage done at Yakutat by a storm on November 18, 1907:

> Neither Indians nor whites had ever seen the ocean surge roll in on Yakutat Harbor to the extent it did on that day. On November 18 at high tide the swell beat in on the doorsteps of the Indian houses, and the foundation of one building was so damaged that the house will soon fall into the bay. * * * The increase of the ocean swell on the Yakutat Harbor year by year was caused by the earthquake of 1899.

This increase in the ocean swell is presumed to have been made possible by the enlargement of the harbor entrance, either through erosion by the earthquake water waves or through a slight sinking of the land on the point opposite Yakutat village during the earthquakes of 1899.

SAND VENTS AND FURROWS.

Sand vents, or craterlets, and furrows such as are developed during earthquakes in unconsolidated materials are reported from the Yakutat Bay region.

At Ocean Cape, opposite Yakutat village, C. E. Hill [1] examined a series of these furrows on September 11, 1899, the day after their formation, and made a rough sketch map of them. An area of about 10 acres was traversed at about 4-foot intervals by great furrows, which he thinks may originally have been 20 feet deep and 5 feet wide, but which had caved before he saw them, leaving them only 4 or 5 feet deep.

The prospectors report the formation of jagged cracks near their camp in Disenchantment Bay during the several shocks on September 10. This camp was on a gravel outwash plain.

Hans Hansen [2] states that in a journey eastward from Yakutat, in 1900, he saw, on Blacksand Island, near Situk River, a crack in the ground about 10 inches wide on top and 18 inches deep, running north and south for about 400 feet. He also noticed smaller cracks, running in the same direction, about 10 miles west of Dry Bay. Evidently these are similar to the furrows described by Mr. Hill. Similar furrows are also said to have been formed in incoherent sand flats in the Lynn Canal region, which is more than 150 miles southeast of Yakutat Bay.

Near Ocean Cape, opposite Yakutat village, Mr. Hill also observed what were apparently sand vents. He describes holes 4 or 5 feet in depth, around which the sand was scattered 6 inches deep over several acres. These he ascribes to waterspouts, though it seems more likely that these craterlets were true sand vents. R. W. Beasley [3] has stated that during the severe shock at noon on September 10 "craters were caused that threw out water and sand."

The writers did not visit the site of these sand vents, not knowing of Mr. Hill's observations at the time (1905), but it seems improbable that such evanescent forms would have been preserved for six years. On numerous other plains of unconsolidated sand and gravel in and about Yakutat Bay, where furrows and craterlets may have been formed during the earthquakes, none were left in 1905 or 1906. In each place, however, any such forms would have been speedily destroyed by wave action on beaches or by aggradation on glacial outwash plains. For instance, at the time of our visit the streams from the eastern margin of Hubbard Glacier and from Variegated Glacier had healed the jagged cracks which the prospectors describe (p. 16) as having been formed during the heavy shock on September 10, 1899, on the outwash plain near their camp in Disenchantment Bay.

EARTHQUAKE AVALANCHES.

All vigorous earthquakes affecting mountainous regions are accompanied by avalanches of rock or snow, or both. Naturally a region shaken again and again by shocks of great magnitude would be expected to furnish abundant evidence of such avalanches. Because of the remarkable after-effects of the avalanches thrown down by the earthquakes of 1899 in causing a spasmodic advance of several glaciers, we have taken special pains to gather information as to their extent. In the following sections it is shown that the downfall of rock and snow during the first half of September, 1899, was enormous in amount and spread over a wide area.

IN AND NEAR YAKUTAT BAY.

Avalanche tracks are far more abundant in the Yakutat Bay region than in any part of the thousand-mile mountainous "inside passage" from Seattle to Sitka. This abundance is not due to a steepness of slope greater than elsewhere in the coastal ranges nor to any unusual condition

[1] San Francisco Examiner, dispatch dated Seattle, Sept. 21, 1899, date of clipping not ascertained. Reply to earthquake circular, 1907.
[2] Reply to earthquake circular, 1907.
[3] Sitka Alaskan, Sept. 16, 1899. Reply to earthquake circular, 1907.

of the rock that makes it specially prone to landslides. Rather significantly the most abundant avalanche tracks are near main fault lines—that is, along the mountain front near Knight Island, on the east side of outer Yakutat Bay, and thence northward along the mountainous face of the east side of Yakutat Bay to Point Latouche. Here we saw the mountains scarred by innumerable landslides, which had carried down thousands of trees and tens of thousands or perhaps millions of tons of rock. The natives state that "the mountain face was here entirely changed in 1899." (See Pl. XIX, *B*, p. 46.)

Within Disenchantment Bay, where fault lines are also close to steep mountain slopes, there are numerous avalanche tracks, but they do not show so clearly in this locality because there is no forest here. On the west side of Yakutat Bay avalanches were numerous, the track of one through the forest on the south side of Amphitheater Knob, west of Galiano Glacier, being very striking. Farther west evidence of abundant avalanches was discovered in 1906 all the way to Blossom Island and up all the valleys that pierce the mountains.

A photograph of the Galiano Glacier taken by Russell in 1890 and another from the same site in 1905 show that in the interval numerous large hanging glaciers and snow patches in the cirque at the head and along the sides of Galiano Glacier had totally disappeared. These are believed to have fallen during the earthquakes of 1899, one of whose major fault lines runs close to the mouth of the Galiano Valley.

Just east of this place two similar photographs of the Black Glacier, taken in 1890 and in 1905, show remarkable changes which could not possibly be ascribed to normal weathering during this brief period. Large patches that were covered by alder shrubs and by grass in 1890 had totally disappeared in 1905, bare rock taking their place. The mountain face was so scarred and the talus slopes so enlarged as to attract attention in 1905, the authors marking the changes on Russell's 1890 photograph while standing on the site from which it was taken.

It is worth noting that here, close to an inferred fault line and near the place where a raised beach 42 feet above tide gives place to no change of level, the avalanches were very numerous, though a mile or two away, where the coast was raised from 33 to 47 feet, but not along a fault line, photographs prove that none of a series of hanging glaciers, precariously poised on the mountain side 1,000 feet above sea level, were shaken down in 1899. How delicately these glaciers were poised, however, is proved by the falling of one of them on July 4, 1905, just 24 hours after we had photographed it. There was no earthquake at the time, but possibly preparation for the final dislodgment of this glacier was made by the earth shaking in 1899. This fact shows the difference in the effect of the disturbance at different distances from the actual fault lines.

The prospectors have told us of the abundant avalanches in Disenchantment Bay during and after the earthquakes of September 10. They call especial attention to them as one of the appalling features accompanying the earthquake (pp. 16–17).

DISTANT AVALANCHES.

It is evident that the effect of the earthquakes in producing avalanches was widespread. In the Yakutat Bay region itself a considerable development of avalanches in the snow fields of Variegated, Haenke, Galiano, Atrevida, and Marvine glaciers seems essential to account for the pronounced advance of these glaciers (pp. 53–58). Photographic proof of such avalanching at the head of Galiano Glacier has just been referred to. In the longer of these glaciers the avalanching occurred among the mountains at a distance from Yakutat Bay, and it is probable that similar avalanches occurred among the still more distant sources of other glaciers whose fronts have not yet felt the impulse of the forward movement that has caused the remarkable advance in the glaciers mentioned.

Many avalanches occurred far outside of the Yakutat Bay region, notably in the region near Yakataga and Kayak, in the Chugach Mountains, in the upper Copper River valley, in the Wrangell Mountains, near the headwaters of White River and the upper Alsek, and in the

Birch Creek, Atlin, and Berners Bay districts. The areas named below are among those in which notable avalanches occurred during the earthquakes of September, 1899.

Capt. Durkee, whose schooner was anchored off the coast at Yakataga, states[1] that during the earthquake of September 3 he "could plainly see the dust from the breaking of the tops of the mountains, beginning at Dry Bay [probably mouth of Yahtse River], 40 miles east, to Cape Suckling, 70 miles west, consuming from five to six minutes, as near as I can remember." This no doubt refers to the progressive fall of avalanches of rock and snow along the St. Elias Range, the east-to-west progression supporting the idea that Yakutat Bay was near the center of disturbance rather than merely a point in a long linear stretch of synchronous disturbances.

Near Kayak, on Controller Bay, C. W. Chamberlin saw avalanches, with great clouds of dust, due to the earthquake shocks. In the Chugach Mountains Lieut. Babcock heard eight muffled reports, like gunshots, after the earthquake on the morning of September 3, and one just before the light shock which he observed in the evening of the same day. He also refers to similar noises after the heavy shock of September 10. These are interpreted as probably caused by falling avalanches, due to the earth shaking. Mr. Rice heard similar sounds in the Copper River valley at the same time.

Oscar Rohn reports that in the Wrangell Mountains "in the high mountain country the roaring and crashing of avalanches was an hourly occurrence. * * * We very frequently saw the avalanches rush down the mountain, and often saw the dust and snow rising from them." Mr. Rohn had not associated these avalanches with the earthquakes and was not on the north side of the mountains before the earthquakes, so we do not know surely whether avalanches occurred there only during and after the earthquakes, though that seems probable.

A. H. Brooks notes that the noises which a member of his party, Edward Brown, heard near the headwaters of Tanana and Nabesna rivers, some distance north of Mr. Rohn's position, were limited to August 27 and that none had been noted before, though for six weeks they had been traveling close to the snow ranges. These he attributes to an earthquake before September 3. On September 3 he and his party heard similar noises on the upper Tanana River "resembling the sound of blasting." Several prospectors also reported similar noises near the headwaters of White River about August 27, describing the sounds as "like a mountain splitting in two." Avalanches might cause such sounds, and they may have been started by preliminary shocks not felt at Yakutat Bay itself.

At Dalton House, 90 miles east of Yakutat, the "heavy noises resembling far-away explosions or rumbling of thunder" were thought by Sergt. Acland[1] to be "caused by the shifting of glaciers in the Alsek Valley." They may have been due to landslides as well as glacier and snow avalanches. In the Birch Creek district, south of Fort Yukon and about 430 miles northwest of Yakutat Bay, an avalanche is said to have been caused by the earthquake of September 10. Along the Yukon near the mouth of Nordenskiold River, 180 miles northeast of Yakutat, J. J. McArthur heard "an irregular succession of detonations like the booming of cannon," probably due to avalanches in the mountains to the southwest. These booming noises were also heard near Five Fingers, on the Yukon. Distinct rumblings were also heard along Hootalinqua River, 200 miles northeast of Yakutat.

In the Atlin district, near Surprise Lake, British Columbia, John Bimms saw what he calls smoke coming from hitherto smokeless mountains during the week of the heaviest earthquakes (Sept. 3–10), and attributed it to a new volcano. As he did not visit the supposedly smoking mountain, seen by him from a distance, and as no volcano is known to exist in that district, it seems more likely that what he saw was the dust from great avalanches, caused by the earthquakes. In the Berners Bay district, 60 miles north of Juneau, H. W. Mellen noted that bowlders were started rolling down the mountain by the shocks on September 10, 1899.

These accounts of what were apparently avalanches during or immediately preceding the earthquake shocks give good basis for the belief that the expectable thing happened—that

[1] Reply to earthquake circular, 1907.

great landslides and snowslides resulted from the disturbance of equilibrium over a wide area, as well as in the Yakutat Bay region itself, where abnormally great numbers of recent avalanche tracks still scar the mountain slopes.

That the vigorous fault movements accompanying earthquakes are of peculiar importance in causing erosion is patent in this connection. In the Yakutat Bay region alone tens of thousands of tons of rock were thrown down as avalanches and the mountains were shattered by secondary faults and by fissures, admitting the water into the ground and, in favorable places, making beginnings for landslides of the future. Even after six years the work of the avalanches is still clearly visible and their effects will continue for years, probably increasing the rate of erosion.

EFFECT OF THE EARTHQUAKES ON GLACIERS.

OLDER VARIATIONS IN GLACIERS.

Most of the Alaskan glaciers studied show distinct evidence of recent recession. Recession has been clearly proved by Reid and others for Muir Glacier; by Russell, Gilbert, and the authors for the Yakutat Bay glaciers; and by Gilbert and others for glaciers in other parts of Alaska. In the Yakutat Bay region the recession was in progress up to 1905,[1] there having been pronounced retreat in the interval between Gilbert's studies early in the summer of 1899 and ours in the summer of 1905 (Pl. XXII, p. 54).

There is clear evidence in the Yakutat Bay region of at least two periods of advance prior to this period of recession. The earliest occurred centuries ago, when the glaciers occupied the entire inlet and built the foreland beyond the mountain face. A mature forest now grows on the deposits laid down by this early maximum advance. A much later advance caused the glaciers to again push far down into Disenchantment Bay, to fill almost if not quite all of the northwest arm of Russell Fiord, and to fill Nunatak Fiord and advance up the south arm of Russell Fiord more than halfway to its head. The evidence of this advance is in the form of overridden gravels; and its recency is attested by the immaturity of the vegetation growing on these gravels. The recession from this advance was still in progress in 1905, not having yet reached the limit of retreat that had been attained prior to the advance, for some of the glaciers still rested on overridden gravels of earlier origin. The period between the two advances was long enough for forests to occupy the region over which the second advance extended, for wood from trees of this interglacial time is incorporated in the débris brought down by the second advance. We have no record of other oscillations, though this is not proof that there were no others.

An advance similar to that of the Yakutat Bay glaciers has been shown by Reid and others to have affected Muir Glacier,[2] and, so far as can be inferred from the evidence, it seems probably to have been contemporaneous with that of the glaciers of Yakutat Bay.

There is no proof that either of the glacier advances referred to bears any relation to former periods of earthquake activity; but in the light of the remarkable changes in the glaciers of the Yakutat Bay region which resulted from the earthquake of 1899, it is by no means improbable that the second advance was related to the influence of earlier earthquakes. The question as to what effect earthquakes have on glaciers is a new one, and in view of the fact that the Yakutat Bay earthquakes throw much light on this question the evidence is presented with some fullness.

SHATTERING OF GLACIERS AND DISCHARGE OF ICEBERGS IN 1899.

Doubtless all the glaciers in the region most disturbed by the earthquakes suffered more or less breaking which was accompanied by the discharge of icebergs from tidal ice tongues. There is first-hand evidence of such damage in the Wrangell Mountains,[3] in the Disenchant-

[1] See Tarr, R. S., and Martin, Lawrence, Glaciers and glaciation of Yakutat Bay, Alaska: Bull. Am. Geog. Soc., vol. 38, 1906, pp. 145–167; Position of Hubbard Glacier front in 1792 and 1794: Idem, vol. 39, 1907, pp. 129–136; Tarr, R. S., The Yakutat Bay region, Alaska: Prof. Paper U. S. Geol. Survey No. 64, 1909, pp. 35–89.

[2] Reid, H. F., Studies of the Muir Glacier, Alaska: Nat. Geog. Mag., vol. 4, 1892, pp. 19–84; Glacier Bay and its glaciers: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 421–461.

[3] Copper River Exploring Expedition, 1900 p. 123.

ment Bay district,[1] in the Lynn Canal region,[2] and in the Surprise Lake district near Atlin, British Columbia.[3] Much ice was discharged into Lynn Canal,[4] Taku Inlet,[5] and Disenchantment Bay, to the temporary detriment of navigation. The steamship *Rosalie* was damaged by collision with the floating ice. The effects seem to have been temporary only, and further information concerning them is lacking, except that in 1905 Taku Glacier[6] appeared to be recovering from the losses it sustained in 1899.

SHATTERING OF MUIR GLACIER.

In contrast with other glaciers those of Glacier Bay, especially the popularly known Muir Glacier, are reported to have suffered a more permanent loss. It has been commonly believed that the earthquakes so shattered the front of Muir Glacier that they indirectly caused notable recession (Pl. XX), and the icebergs have certainly so clogged the inlet as to render it inaccessible to steamships until 1907. Mr. Buschmann[7] has testified that this condition began in the fall of 1899, immediately after the earthquakes, the floating ice interfering with his small cannery steamers. The breaking of Muir Glacier and the increase of icebergs is alluded to in the newspapers of the time.[8] H. F. Reid[9] has called attention to these phenomena, which had been referred to in some of the early newspaper accounts already cited. C. L. Andrews[10] and W. H. Case, who visited Glacier Bay in 1903, determined the retreat of the ice front of Muir Glacier as between 2½ and 3 miles, and attributed it to the earthquakes of 1899. The same cause was assigned by G. K. Gilbert,[11] who visited the bay in the summer of 1899, with other members of the Harriman Alaska Expedition, and was the last scientific observer to see the glacier before the earthquakes. Gilbert[12] has also inquired into the visits of steamers to Glacier Bay in 1900, 1901, and 1902, and the floating ice which turned them back, as observed by O. H. Tittmann, of the United States Coast and Geodetic Survey, and the commanders of several tourist steamers.

In the summer of 1906 F. E. and C. W. Wright, of the United States Geological Survey, visited and resurveyed the ice fronts of Glacier Bay, including Muir Glacier itself, and have called attention to the changes which had taken place in it since 1899.[13] They believe that the great recession of Muir and adjacent glaciers may not be solely the direct result of the earthquakes but may be largely due to increased exposure to melting and iceberg discharge, as a result of the rapid retreat, by which the extent of ice cliff exposed to the waves was greatly increased (from approximately 17,000 feet in 1892 to 40,000 feet in 1906).

In 1907 Glacier Bay was visited by Otto Klotz, of the Canadian Boundary Commission, and by Fremont Morse, in charge of a United States Coast and Geodetic Survey party, who mapped the fronts of the tidal glaciers there from bench marks established by the Canadian surveyors who had mapped the Alaskan boundary region in 1894. Each of these men published a brief account of the changes.[14] The maps by Netland, accompanying Morse's paper, show the retreat of Muir, Grand Pacific, Johns Hopkins, and other glaciers between 1894 and 1907. In the interval of 13 years the total retreat of Muir Glacier was 8½ miles and of the Grand Pacific 8 miles. (See Pl. XX.) Klotz suggests the relation of this retreat to earthquakes; Morse definitely correlates it with the earthquake of 1899 and contrasts the present and the past condition

1 Seattle Daily Times, Sept. 28, 1899, reprinted in Weekly Times, Oct. 4, 1899. Sitka Alaskan, Oct. 14, 1899.

2 Seattle Daily Times, Sept. 21, 1899, reprinted in Weekly Times, Sept. 27. San Francisco Chronicle, Sept. 22, 1899. A clipping dated Sept. 21, 1899; paper and date not known.

3 San Francisco Chronicle, Oct. 5, 1899.

4 Victoria Semi-Weekly Colonist, Sept. 25, 1899. Seattle Daily Times, Sept. 22, 1899, reprinted in Weekly Times, Sept. 27.

5 Victoria Semi-Weekly Colonist, Oct. 12, 1899.

6 Jour. Geology, vol. 13, 1905, p. 317.

7 Reply to earthquake circular, 1907.

8 Victoria Semi-Weekly Colonist, Oct. 2 and Oct. 12, 1899.

9 Variations of glaciers: Jour. Geology, vol. 9, 1901, p. 253; vol. 10, 1902, p. 317; vol. 11, 1903, p. 276; vol. 12, 1904, pp. 258-260.

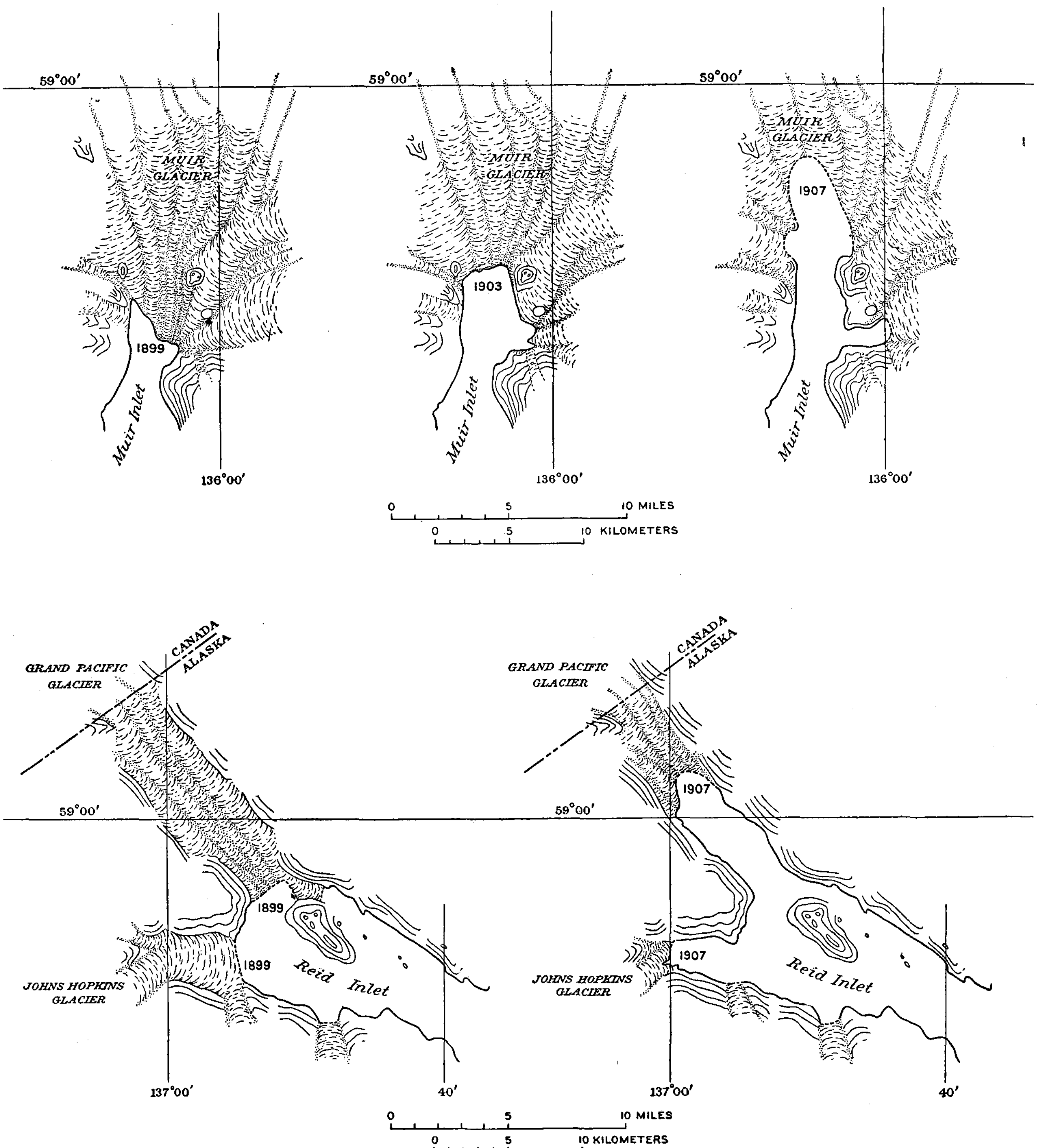
10 Nat. Geog. Mag., vol. 14, 1903, pp. 441-444.

11 Idem, p. 445.

12 Harriman Alaska Expedition, vol. 3, Glaciers, pp. 23-25.

13 Recent changes in the glaciers of Glacier Bay, Alaska; an abstract of paper presented at winter meeting Geol. Soc. America, New York City, 1906; summary in Jour. Geology, vol. 16, 1908, pp. 52-53.

14 Klotz, Otto, Geog. Jour., vol. 30, 1907, pp. 419-421. Morse, Fremont, Nat. Geog. Mag., vol. 19, 1908, pp. 76-78.



MAPS SHOWING MUIR GLACIER IN 1899, 1903, AND 1907, AND GRAND PACIFIC AND JOHNS HOPKINS GLACIERS IN 1899 AND 1907.

After G. K. Gilbert, C. L. Andrews, and Fremont Morse.

of Muir Glacier in a way that will bring regret to many travelers who have known this great ice tongue in the years before the earthquake, as follows:

> Formerly the Muir presented a perpendicular front at least 200 feet in height, from which huge bergs were detached at frequent intervals. The sight and sound of these vast masses falling from the cliff or suddenly appearing from the submarine ice foot was something which once witnessed was not to be forgotten. It was grand and impressive beyond description.
>
> Unfortunately the recent changes in the Muir have not increased its impressiveness from a scenic standpoint. Instead of the imposing cliff of ice, the front is sloping, and seems to be far less active than formerly. Its shape is entirely changed. It is now divided into two branches formed by what were formerly two "nunataks" in the body of the glacier. The eastern arm discharges but little and appears to be nearly dead. The front of the western arm is in the shape of an elongated basin and, as above stated, slopes gently. It is badly crevassed; a point of rock juts out at the water's edge on the west side of the basin. This is apparently the prolongation of a ridge which outcrops through the ice field farther back and which will soon, if the glacier continues to retreat at its present rate, make two arms of the present western one. It is from this western arm that the bulk of the ice is now discharged.

Morse states that in 1907 the excursion boats were, for the first time since 1899, able to approach Muir Glacier closely, the *Spokane*, commanded by Capt. James Carroll, getting within a mile of the ice front on one trip that year.

E. R. Martin,[1] of the Alaskan Boundary Survey, also attributes the changes in the ice tongues of Glacier Bay to the earthquakes of 1899. Mr. Martin has published some beautiful pictures of icebergs near the Muir Glacier.

We visited Glacier Bay in 1911 for the National Geographic Society, finding still further retreat of Muir, Grand Pacific, Johns Hopkins, and other glaciers. Muir Glacier no longer touches tide water except in a short cliff, and we were able to walk over a moraine accumulation at several points where there was tidal ice front in 1907. From our studies of the glaciers of the Glacier Bay region in 1911 we have reached the conclusion that the importance of the effect of the earthquakes of 1899 on the retreat of these glaciers may have been somewhat exaggerated.[2]

ADVANCE OF YAKUTAT BAY GLACIERS.

Such changes in Muir Glacier as are due directly or indirectly to the earthquakes of 1899 are noteworthy because of the fact that they have occurred at a distance of 150 miles from the Yakutat Bay region, where the shocks appear to have been central. In marked contrast is the condition of the Yakutat Bay glaciers, which presumably suffered a greater shattering, but which speedily recovered from it only to undergo a slower and more profound alteration, which culminated in a notable advance.

THE SNOW SUPPLY.

The evidence of the prospectors in Disenchantment Bay (p. 16) and of other observers in the region about Yakutat Bay (p. 49), as well as our own studies, clearly shows that the mountains were so profoundly shaken by the earthquakes that great avalanches of snow and rock were thrown down on every hand. This probably happened not merely once but again and again during September, 1899.

It is to be noted also that the St. Elias, Fairweather, and other ranges in this part of Alaska are peculiarly suited to shed an enormous amount of snow under the influence of such a shaking as they must have received during the earthquakes. This is the region of the heaviest precipitation in North America outside of the Torrid Zone. The annual rainfall at Yakutat is not known, but 170 miles distant, at Katalla, on Controller Bay, where the mountains are much lower, a record kept in 1907 showed a precipitation of 101 inches for eight months [3]—a rate of about 150 inches a year. This rate, however, is based on only a part of one year's record. At Orca (west of the mouth of Copper River and 215 miles west of Yakutat Bay), the nearest station where a record is kept, the annual precipitation is 149 inches; at Sitka, 250 miles to the southeast, it is 88 inches; and at Nuchek, 240 miles west of Yakutat, it is 190

[1] Nat. Geog. Mag., vol. 19, 1908, pp. 183-184.
[2] As our studies in 1911 were made after this paper had been put in type the reasons for this conclusion must be stated in another paper.
[3] Quoted by Martin, G. C., Bull. U. S. Geol. Survey No. 335, 1908, p. 17.

inches. These are average figures, the precipitation reaching 198 inches at Nuchek in a single year. Among the mountains of the Yakutat Bay region the precipitation would probably be even more. We have no means of telling the amount that falls on the mountain slopes, but as the warm, damp winds blow from the ocean with much steadiness against the lofty, unbroken mountain wall that rises from sea level to heights of 15,000 to 19,000 feet, the precipitation must of necessity be very heavy; and above the snow line, which lies at an elevation of 2,000 or 3,000 feet, practically all of it falls as snow. After every storm, even in summer, the mountains above the snow line are whitened by a heavy coat of freshly fallen snow, which is so deep that it masks the scars caused by avalanches that have bared the rock faces in the interval of pleasant weather.

In such a region as this the snow mantles all slopes to which it can possibly cling, and the excess is shed into the valleys. The descriptions and photographs by Russell, the narrative of the Abruzzi expedition to Mount St. Elias, and the reports of the Boundary Commission parties, all tell vividly of both the heavy snow cap (Pl. XXI) and the frequent snow avalanches occurring under even normal conditions. It is this normal, everyday supply that has filled the mountain valleys with rivers of ice (Pls. I, p. 12; XXII), making this the region of the greatest glaciers in the temperate zone outside of southern Greenland.

Of the conditions among these mountains Russell gives a vivid word picture.[1] As he looked down from Russell Col, near the summit of Mount St. Elias, he saw—

a vast snow-covered region, limitless in expanse, through which hundreds and perhaps thousands of barren, angular mountain peaks projected. There was not a stream, not a lake, and not a vestige of vegetation of any kind in sight. A more desolate or utterly lifeless land one never beheld. Vast smooth snow surfaces, without crevasses, stretched away to limitless distances, broken only by jagged and angular mountain peaks. * * * The view to the north called to mind the picture given by Arctic explorers of the borders of the great Greenland ice sheet, where rocky islands, known as nunataks, alone break the monotony of the boundless sea of ice. The region before me was a land of nunataks.

This was the region most vigorously shaken during the earthquakes of September, 1899. Under such shaking its valleys must of necessity have received sudden and vast accessions of snow, ice, and rock, for even under ordinary conditions these materials are constantly being supplied in great quantities by the influence of gravity alone. Glacialists reasonably explain ordinary oscillations of valley glaciers as the result of variations in snow supply to the glacier reservoirs. An increase in precipitation of a few inches a year, for a period of years, is believed to be competent to cause a notable advance in the glacier, after the lapse of sufficient time; and a deficiency in precipitation is believed to be followed by a corresponding recession.

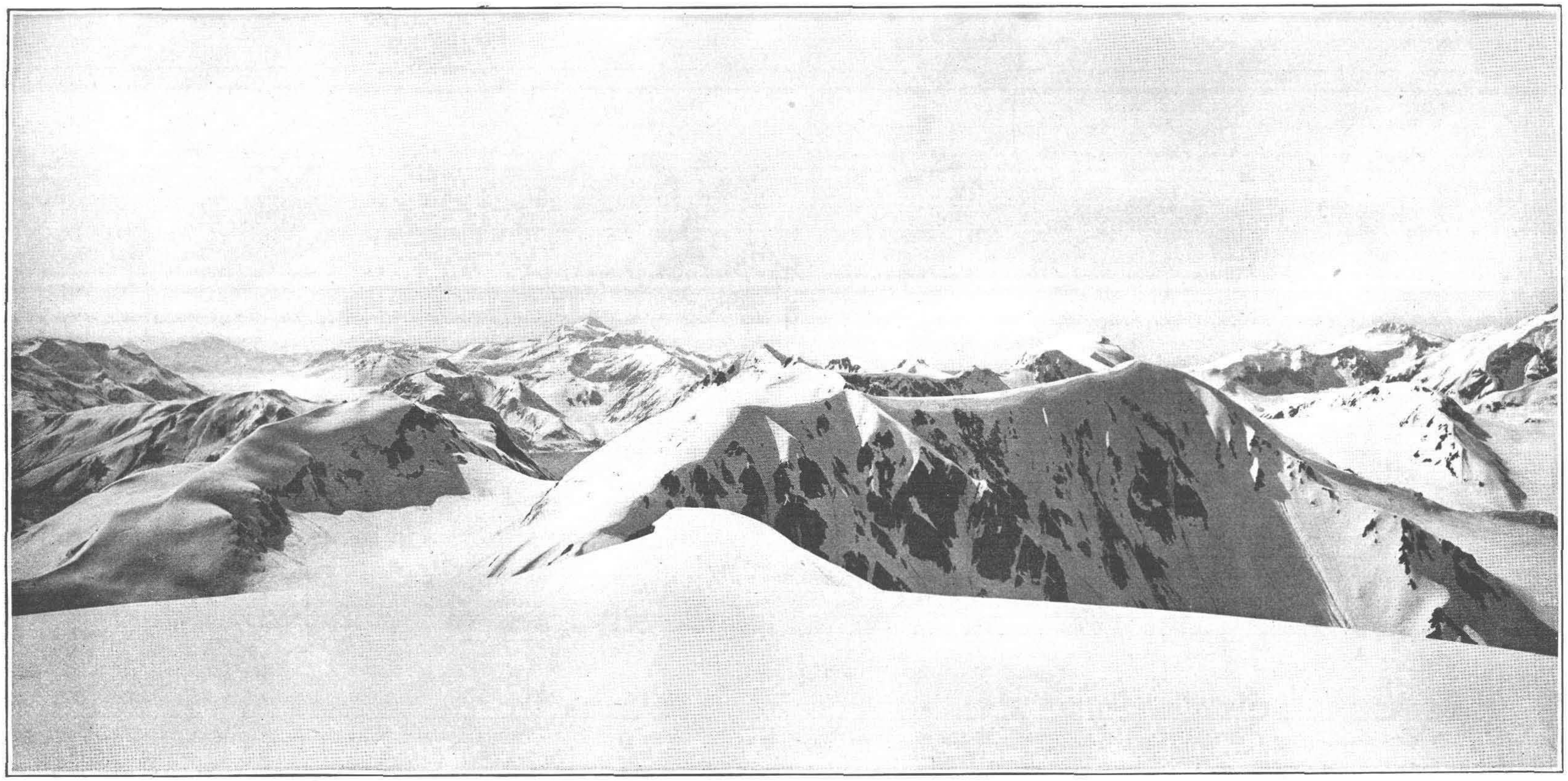
What, then, would happen after so sudden and so great an increase in snow supply as that which was thrown into the head reservoirs of these glaciers in the autumn of 1899? This is a question which can not be answered from direct observation in other regions, and it is not certain how many glacialists would have given in advance the answer which now seems necessary to explain the phenomena that have been observed in Yakutat Bay since 1899. If a slow and slight advance in glaciers is caused by a moderate addition to their reservoirs, it follows that a sudden and great advance must result from the addition of an enormous amount to the reservoirs in a brief interval of time. As a river rises in flood after an unusually heavy fall of rain, so a glacier flood results from the sudden accession of vast amounts of snow. This seems a reasonable proposition; it becomes a necessary conclusion from the facts revealed by the comparative study of the Yakutat Bay glaciers in 1905 and 1906.[2]

THE ADVANCING GLACIERS.

In the summer of 1905 we studied the glaciers of Yakutat Bay and found them all in a state of recession. With the single exception of Galiano Glacier, none of them showed clear proof of a recent advance, though it is quite possible that some of the smaller valley glaciers

[1] Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1893, p. 47.

[2] For a fuller statement see Tarr, R. S., Recent advance of glaciers in the Yakutat Bay region, Alaska: Bull. Geol. Soc. America, vol. 18, 1907, pp. 257-286; The Yakutat Bay region, Alaska: Prof. Paper U. S. Geol. Survey No. 64, 1909, pp. 90-95; The theory of advance of glaciers in response to earthquake shaking: Zeitsch. für Gletscherkunde, Bd. 5, 1910, pp. 1-35.



SNOW-COVERED MOUNTAIN TOPS IN YAKUTAT BAY REGION.

In left background are snow-covered slopes adjacent to Hidden Glacier, which advanced 2 miles between 1906 and 1909 as a result of earthquake avalanching in 1899. Photographed by Brabazon, Canadian Boundary Commission, from an elevation of about 4,000 feet.

had advanced since 1899 and were again receding. There was clear evidence in 1905 [1] that Galiano Glacier had made a great advance since Russell's visit in 1890 and the visit of the Canadian topographers in 1895. A forest that was growing on it in 1890, which Russell both described and photographed and which is shown clearly in a photograph by Brabazon, taken from the hill back of Point Latouche in 1895, had been destroyed. In 1905 we found that a stagnant extension of the glacier beneath an alluvial fan had been pushed up through the fan, destroying it. Russell's photographs clearly show the fan, but it was not there in 1905. The neighboring, somewhat larger Atrevida Glacier on one side and the smaller Black Glacier on the other side of the Galiano had not changed in position or character since Russell saw them. We were puzzled greatly by this phenomenon and could account for it only as a result of the 1899 earthquake, though by a process which we could not then understand.

In 1906 the senior author returned to the region and found a most astonishing change. Some of the glaciers were in no notable respect different from their condition in 1905; these included some of the largest, such as Hubbard, Turner, Nunatak, and Hidden glaciers. Others, on the contrary, were utterly transformed (Pl. XXIII).

For example, Variegated Glacier, which lies just east of the Hubbard, descends through a mountain valley in a serpentine course, extends beyond the mountain face, and there expands into a piedmont bulb of stagnant ice covered with morainic débris. All parts of the piedmont portion of this glacier were easily traversed in 1905, and for a distance of 6 miles we ascended with ease the part that lies within the mountain valley. The ice surface was smooth and almost unbroken and we did not even find it necessary to rope the party together.

Ten months later, in June, 1906, the entire glacier within its mountain valley was a sea of crevasses, utterly impassable. The breaking of the ice had extended far out into the moraine-covered bulb, so that it was no longer possible to walk over the surface. The moraine that had accumulated through long wasting during a period of stagnation had largely disappeared in the newly formed crevasses; the previously stagnant bulb had been pushed forward several hundred yards, covering an old rock gorge that in 1905 was plainly visible in front of it; the ice in the piedmont bulb had become thickened, its surface being 100 to 200 feet higher in 1906 than in 1905; and the subglacial streams of 1906 emerged from a portion of the ice front far removed from the drainage channels of the previous year. Thus, in the short interval of 10 months there had been pronounced advance, noticeable thickening, and profound crevassing throughout at least 6 or 7 miles of glacier.

Between Turner and Hubbard glaciers two small, hitherto unnamed valley glaciers descend from the mountains. We photographed them in 1905 and compared them in the field with photographs taken in previous years, without being able to detect any change in the interval; but we did not go out on them. They were practically stagnant and were covered with black morainic débris. In 1906 the one nearest Turner Glacier, which we have named Haenke Glacier, had, like the Variegated Glacier, been transected by a network of crevasses. It had also thickened and had advanced greatly, far more than the Variegated Glacier. In 1905 it ended on the land and was faced by a broad alluvial fan; in 1906 its front was in the sea at least a mile farther out, and it was united with Turner Glacier. A photograph taken for the United States Fish Commission in 1901 furnishes clear evidence that in that year the other of these two glaciers was in a state of advance, but by 1905 it had become so smoothed by ablation that we saw no proof of recent transformation, and therefore can not now state how great a change was in progress in 1901.

It was the plan of the expedition of 1906 to go westward over Malaspina Glacier, starting from a point near Galiano Glacier and crossing Atrevida, Lucia, Hayden, and Marvine glaciers in succession. This was the route that Russell easily followed in 1890; and in 1905 we made sure that the route was feasible, first by a day's expedition on Atrevida Glacier, and second by a reconnaissance (by the junior author and Mr. Butler) across Atrevida and Lucia glaciers to the west side of the Floral Hills, where Hayden, Marvine, and Malaspina glaciers were

[1] Tarr, R. S., and Martin, Lawrence, Glaciers and glaciation of Yakutat Bay, Alaska: Bull. Am. Geog. Soc., vol. 38, 1906, pp. 152-153.

clearly visible. In each of these expeditions no special difficulties of ice travel were encountered. It was possible to go anywhere on Atrevida, Lucia, and Hayden glaciers, and from the views obtained on the west side of the Floral Hills it seemed as feasible to traverse Marvine and Malaspina glaciers as it was in 1890 when Russell crossed them.

Only one small area of notable crevassing was found on Atrevida Glacier (Pl. XXIII, *A*), and both its surface and margin were, so far as we could see, in essentially the same condition as in 1890. Although we did not then so interpret it, we are now convinced that this area of crevassing was the first stage in the change that caused such a marvelous transformation in the next few months.

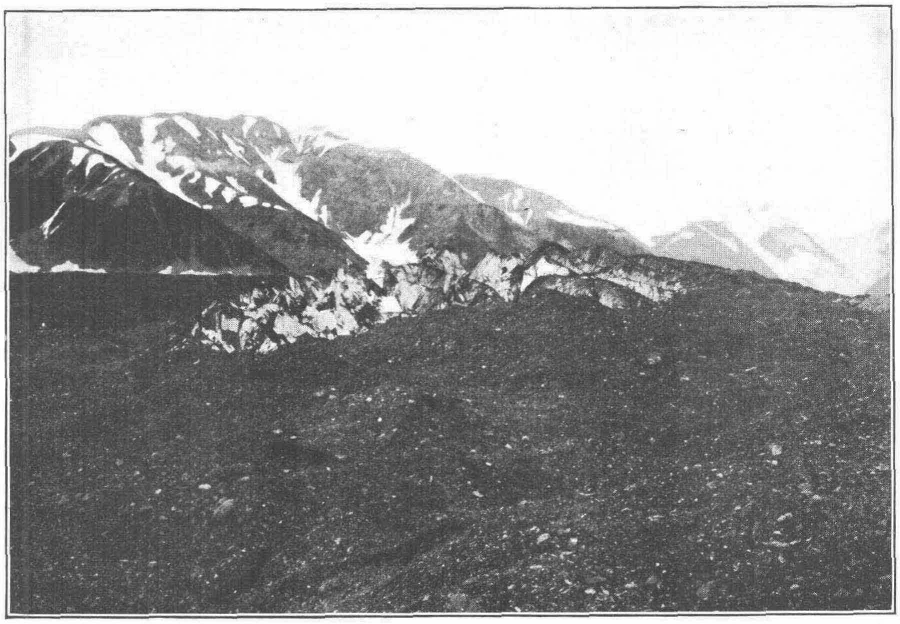
In June, 1906, Atrevida Glacier was utterly changed. Its surface was a labyrinth of crevasses (Pl. XXIII, *B*), and to cross it was wholly out of the question. The crevassing extended from a point near the head of the mountain valley out beyond the mountain front into the stagnant piedmont bulb, destroying an alder thicket and spruce forest growing in the moraine that ablation had caused to accumulate on this lower, expanded portion of the glacier. The newly formed crevasses broke the glacier for a distance of 8 or 10 miles, and the moraine and alder bushes were being swallowed up in them. As in the other glaciers, the ice had advanced notably, fully 100 yards on the east side and several hundred yards on the west side, there overriding a camp site occupied in 1905 by the junior author.

The forward movement of Atrevida Glacier was in progress during our visit. We could hear the ice break, and passage along the margin of the glacier was rendered perilous by the huge blocks of ice and the stones that now and then came crashing down from the broken ice wall. The glacier was then advancing into and destroying the spruce forest that grows up to its margin. Such an absolute change in conditions in so short a period seemed almost incredible. In 1905 we could ascend the gentle slope of the margin of Atrevida Glacier at almost any point. Ten months later to ascend its broken, jagged, precipitous side required the cutting of steps in the ice, with the ever-present danger of the falling of overhanging ice blocks. In 1905 we could walk care-free over all parts of the surface of the glacier; in 1906 yawning crevasses barred progress in every direction.

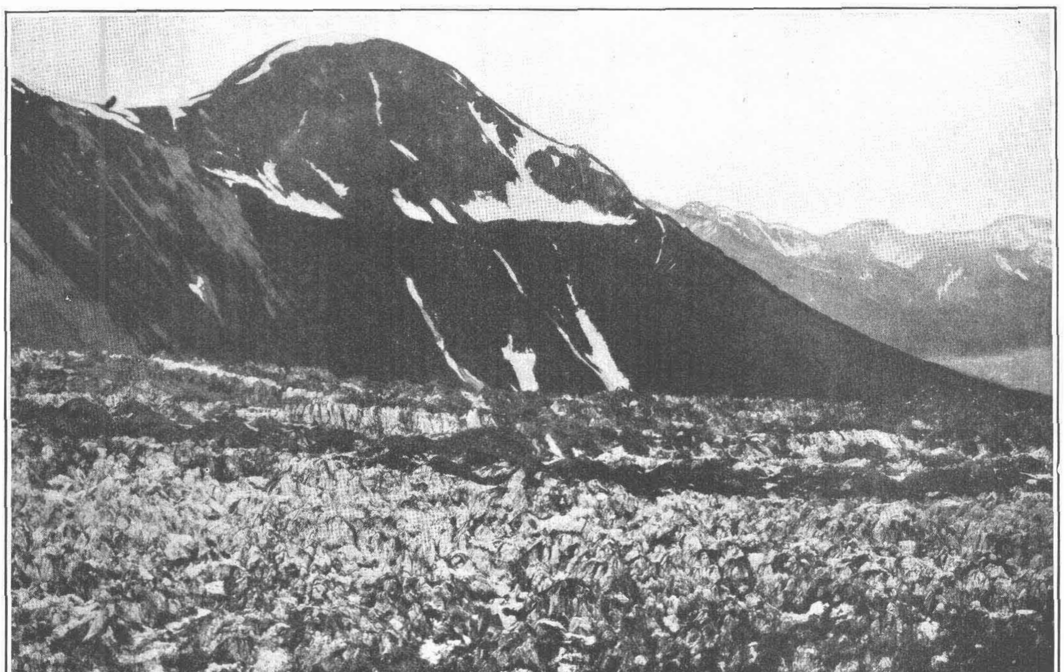
Hoping still to get out on Malaspina Glacier, we began exploring its eastern margin, where Russell had easily crossed it during his retreat in 1891, but we found it impassably crevassed under the influence of the forward thrust of its tributary, Marvine Glacier. We crossed Hayden Glacier, which was unchanged, and made an excursion eastward across Lucia Glacier, which was also unbroken, to the western margin of the crevassed Atrevida Glacier. On returning across Lucia and Hayden glaciers we found our progress westward barred by Marvine Glacier, whose margin we followed up to the point where it emerges from its mountain valley northwest of Blossom Island. Later we found that the crevassing caused by the thrust from Marvine Glacier affected the entire eastern portion of Malaspina Glacier, so that entrance upon it from Yakutat Bay was no longer possible, although it was crossed by Russell in 1891 and by the Abruzzi and Bryant parties in 1897. The newly crevassed area, which has a linear extent of over 15 miles, is 3 or 4 miles wide where Marvine Glacier emerges from its mountain valley, but expands to a width of over 10 miles near the sea; and through this entire area the glacier, formerly an excellent highway for travel, is now impassable. (Pls. I, p. 12; XXII, p. 54.)

As we passed along the margin of Malaspina and Marvine glaciers we had abundant proof that, like Atrevida Glacier, the Marvine was even then rapidly advancing; but, having made no studies here in 1905, we are unable to tell how great an advance had taken place. As we walked along the ice cliff or camped at its base we heard the ice breaking and saw the huge ice blocks tumble down its broken side.

Prior to 1906 a part of the eastern margin of Malaspina Glacier had so long been stagnant that a deep morainic soil had accumulated on it, and in this soil was growing a forest fully half a century old. The trees had all leaved out in the spring of this last year of their life, when the thrust of the ice which lay beneath their roots opened up crevasses that swallowed up some of the soil and many of the trees themselves. The great gashes thus formed exposed the long-buried ice to rapid melting, and thus more of the soil disappeared; streams of liquid



A. MORAINE-COVERED SURFACE OF CENTRAL PART OF ATREVIDA GLACIER AS IT APPEARED AUGUST 20, 1905.



B. CENTRAL PART OF ATREVIDA GLACIER, CREVASSED BY SUDDEN AND VIOLENT ADVANCE AFTER PHOTOGRAPH FOR *A* WAS TAKEN.

Looking in opposite direction from direction of view in A. Photographed August 2, 1906, by O. D. von Engeln.

mud descended from the ice margin; and the trees came crashing down the ice slope. Almost constantly there was a sound of avalanches of mud and stones, or the falling of ice blocks, or the crashing of trees as they slid from their unstable positions. The ice margin, formerly a gently sloping, forest-covered bluff, was now a jagged ice cliff (Pl. XXIV), resembling a frost-riven granite precipice, the resemblance being increased by the muddy stain which discolored the broken and piled-up ice blocks.

We returned to Yakutat Bay in 1909,[1] when we found the advancing glaciers of 1906 so healed that travel over their surfaces was again possible, but far less easy than in 1905. The spasmodic advance had evidently quickly run its course and had been succeeded by stagnation. But in the interval between 1906 and 1909 Hidden Glacier had advanced about 2 miles, and, near the place where the front stood in 1905, one of our photographic sites had become buried beneath 1,100 feet of ice. The advance had been rapid and it had quickly subsided, for by 1909 we could walk over the glacier surface, though it was greatly roughened by the partially healed system of crevasses. Hubbard Glacier was also advancing, but it had pushed forward only slightly, and its advance had ceased in 1910, when the junior author again visited Yakutat Bay.[2] In 1909, Lucia Glacier was advancing and was so broken that it could not be crossed, though it was easily crossed in 1906. We are informed that a Canadian boundary survey party under the charge of Mr. Ogilvie crossed this glacier in the summer of 1911 and proceeded westward across Hayden and Marvine glaciers. The junior author in 1910 found that Nunatak Glacier had advanced 700 to 1,000 feet between the summers of 1909 and 1910.[2]

Nunatak Glacier is the ninth of the series of glaciers to advance, as is shown in the following table:

Advance of glaciers at Yakutat Bay.

Glacier.	Date of advance.	Length of glacier.
Galiano	After 1895 and before 1905	2 or 3 miles.
Unnamed glacier[1]	1901	3 or 4 miles.
Haenke	1905–6	6 or 7 miles.
Atrevida	1905–6	8 miles.
Variegated	1905–6	10 miles.
Marvine	1905–6	[2] 10 miles.
Hidden	1906 or 1907	16 or 17 miles.
Lucia	1909	17 or 18 miles.
Nunatak	1910	20 miles.

[1] Between Haenke and Hubbard glaciers. [2] Excluding expanded lobe in Malaspina.

The first glaciers to advance were the shortest. The longest of the Yakutat Bay glaciers have not yet responded to the earthquake shaking. The advance was alike in several respects in all the glaciers—it was abrupt and spasmodic, it caused profound transformation of the glacier surface, and it resulted in thickening at the termini—and all the glaciers quickly subsided and returned in a few months to a stagnant state after the effects of the rapid forward movement were spent.

NATURE AND CAUSE OF THE ADVANCE.

The conditions in the Yakutat region show accurately what happens when the impulse of a glacier flood passes down a rigid ice stream to its terminus. The glaciers, which once pushed forward slowly, advance with a spasmodic rush. At Yakutat Bay they moved forward hundreds of yards in not more than 10 months and perhaps in much less time; and at the same time they became greatly thickened, not merely in parts that had previously been active, but also in parts that had long been stagnant. Scores of square miles of ice, hitherto either stationary or else moving so tranquilly that the surface was smooth and practically uncrevassed, were suddenly transformed into a wilderness of pinnacles and crevasses—the troubled surface of a glacier flood.

[1] Tarr, R. S., and Martin, Lawrence, The National Geographic Society Alaskan Expedition of 1909: Nat. Geog. Mag., vol. 21, 1910, pp. 1-54.

[2] Martin, Lawrence, The National Geographic Society researches in Alaska: Nat. Geog. Mag., vol. 22, 1911, pp. 537-560.

No one has so far been ingenious enough even to suggest a reasonable alternate hypothesis to that of the glacier flood to account for these phenomena. Nor has any serious objection been urged to the explanation proposed, unless, indeed, it is to the rapidity of the passage of the flood from the gathering ground to the glacier terminus. Less than seven years was required for the transmission of the impulse from the reservoir to the end of Marvine Glacier—a distance of at least 15 or 20 miles; and the period was even shorter for Galiano Glacier. If the resemblance of the glacier flood to a river flood were exact in all respects, such rapid transmission would, of course, be out of the question, for manifestly it would have been impossible for the snow that was avalanched down upon the glacier reservoir in 1899 to reach the end of the glacier, say 5 or 10 miles distant, in a period of six or seven years. It is conceived, however, that the actual condition is that of a thrust transmitted from the overloaded reservoir through the lower layers of the glacier, causing a flowage of the more plastic basal ice and a breaking of the rigid upper ice into a choppy sea of séracs, pinnacles, and crevasses.

That all the glaciers in the region should not have responded to the impulse of the unusual supply of snow shaken down during the earthquakes of 1899 is not unexpected. Among the reasons why some of the glaciers have not advanced two suggest themselves with greatest force—variation from place to place in the amount of snow thrown down and variation in the distance through which the thrust must pass from reservoir to glacier end. Some glaciers may have already responded to the impulse, as the short Galiano Glacier had done before 1905 and as others were doing in 1906; others may never notably respond, and still others may yet reach the flood stage. It is hardly to be supposed that the year 1906 was the only one to witness the effect of the 1899 earthquakes on the glaciers of the Yakutat Bay region.[1]

SIGNIFICANCE OF THE PHENOMENA.

It is too early to state fully the significance of the glacier floods that vigorous earthquake shaking may generate. As yet we know of but this single instance, and of this we have the comparative records of but four seasons; we can only speculate as to the changes yet to come in this region as a result of the 1899 earthquakes. How long the glaciers at present advancing will continue to do so is wholly unknown.[2] Nor can we tell what glaciers will next receive the impulse, nor for how long a time, nor with what result.

If Hubbard, Turner, Nunatak, and Hidden glaciers should all advance at the same time, and if their advance should be equal, in proportion to their size, to the advance of the Haenke Glacier, their fronts might well push out as far as the positions recorded by their last notable advance (p. 51). It is at least a rational hypothesis that this last advance was the result of glacier floods, due to the downshaking of snow among the glacier supply grounds during one or a series of vigorous earthquakes of former dates.

If it is too early to understand fully the true significance of the phenomenon of earthquake-caused advance in the region of its occurrence, it is certainly too early to attempt to apply the lessons from it to other regions. Yet it may not be unprofitable to speculate briefly on this matter also. We believe it to be beyond doubt that in the Yakutat Bay region vigorous earth shaking has caused a glacier advance of flood proportions as a result of the avalanching of vast quantities of snow, ice, and rock among the mountains in the zone of supply. If this is true, surely similar phenomena must have occurred here and elsewhere in the past. May they not even have occurred frequently and with notable results not hitherto recognized? May there not be small floods resulting from moderate shaking, as well as great floods due to vigorous shaking? To us the answer to both these questions seems clearly affirmative. We believe it probable that such floods have been and, indeed, are even now in progress. We make the suggestion, however, not with the intention of attempting to prove it at present, but merely to record it, in the hope that glacialists will test the explanation in regions other than Yakutat Bay.

[1] This statement, written at the close of the season of 1906, has since received confirmation by the subsequent advance of larger glaciers observed in 1909 and 1910, as briefly described above (p. 57).

[2] Subsequent study, in 1909 and 1910, proves the advance to be brief.

CREVASSED ICE CLIFF ON EASTERN MARGIN OF ADVANCING MALASPINA GLACIER.

Blocks of *dirt-stained ice*, looking like rock, were protruded through the morainic soil and had overturned trees since they leaved out in the summer. Photographed August 11, 1906, by O. D. von Engeln.

The termini of glaciers fluctuate, sometimes with puzzling irregularity. Naturally the hypothesis of climatic variations is the one that first suggests itself to the investigator, and doubtless this is a correct explanation for many glacier oscillations. But here is an alternate cause which is certainly in progress in at least one region. Why not, then, in others? High mountains, the supply ground of glaciers, are notably unstable and liable to earthquakes, great and small. Every time an earthquake, even though of moderate vigor, affects such a region unusual accessions to the glacier reservoirs are likely to be made. Surely then, in due time, the glacier must be affected and its terminus must respond to the impulse from this addition to its supply—as surely as a stream responds to a light rain or a glacier to the moderate increase in snow supply due to a series of unusual seasons of snowfall. If a great earthquake visits the region, so much more must the glacier in due time respond to the impulse from the unusual supply. This impulse must be of unusual intensity, for it is due to the snowfall of years, which, clinging in unstable position on the mountain sides, is abruptly tumbled down upon the glacier reservoirs. It is conceivable that a glacier might thus receive more snow, ice, and rock in a few moments than would normally fall upon it in several years.

To many it has seemed difficult to account for notable fluctuations in glaciers as the result of mere variations in snowfall through climatic changes of which we have little evidence. Moreover, known climatic variations are slow and moderate and seem quite inadequate to produce great fluctuations in glaciers. Although there are variations in snowfall in Alaska, and perhaps even periods of unusual increase and decrease in snow supply sufficient to account for considerable variations in glaciers, we wish nevertheless to point out that the effect of earthquake avalanching is a possible cause for such variations. It is, moreover, normal and natural and presents no serious difficulties. How far it explains variations in glaciers, past and present, we are not in a position to state; but it seems more than probable that this process has been widely effective.

Taku Glacier, for example, is reported [1] as having had a marked advance, proved by photographs, between 1890 and 1905. The adjacent Norris Glacier was advancing and destroying forests when photographed by F. E. and C. W. Wright on May 29, 1904. As these glaciers are within the region that was vigorously shaken by the earthquakes of 1899 the hypothesis may be entertained that their activity was due to earthquake avalanching.

Valdez Glacier, in Prince William Sound, was retreating when the junior author visited it in 1904 and seems to have still been doing so when its front was visited in 1905 by U. S. Grant, of Northwestern University, in charge of a United States Geological Survey party. But between the summer of 1905 and the summer of 1908 it markedly advanced, the monuments set up by Grant in 1905 being destroyed by the advancing ice tongue before his visit in 1908. The glacier has subsequently retreated slightly and it is not definitely known whether the advance was accompanied by crevassing, as in the Yakutat Bay glaciers.

Inasmuch as (*a*) some Alaskan glaciers are advancing and others in the earthquake-shaken region are retreating; as (*b*) there is no suggestion of climatic variations to account for these oscillations and especially no reasonable climatic explanation of such selective oscillation; as (*c*) the mountain slopes on which these glaciers head are known to have been vigorously shaken during the earthquakes of September, 1899 (see Pl. XXXIII, in pocket), as well as in 1896, 1900, and 1908; and as (*d*) the avalanching known to have accompanied certain of these earthquakes would account for selective, delayed, and progressive oscillations of these ice fronts—the hypothesis is proposed that the temporary advance of other Alaskan glaciers may be explained by earthquake avalanching.

Had the Alaskan glaciers been studied with the same care as those of the Alps, for a century or more, it would doubtless be more easy to state exactly the nature of the effect of earthquake avalanching on glaciers in general. Unfortunately, lofty mountains liable to vigorous earthquakes and carrying heavy snow cover and consequent great glaciers are, in the main, located in regions still remote and little studied. It was only by a most favorable combination of cir-

[1] Reid H. F., Variations of glaciers: Jour. Geology, vol. 14, 1906, p. 408.

cumstances that the Yakutat Bay advances came to the attention of a scientific party. There may be, even now, a hundred or more large glaciers in Alaska which are presenting clear evidence of the flood stage, due to the earthquake of 1899, but about which the world will forever remain in ignorance.

Other Alaskan glaciers within the area vigorously shaken in September, 1899, which have subsequently had short vigorous periods of activity, accompanied by severe crevassing and advance. interrupting a period of stagnation or slighter activity, are tabulated below

Glaciers advancing between 1899 and 1911.

Glacier.	Distance and direction from Yakutat Bay.	Year of activity.	Amount of advance.	Described by—
Norris	225 miles southeast	1904		F. E. and C. W. Wright.
Taku	do	Between 1890 and 1905		H. F. Reid.
In Lituya Bay	120 miles southeast	Between 1894 and 1906	½ mile	F. E. and C. W. Wright.
Childs	190 miles west	1905–1906		Lawrence Martin.
Valdez	240 miles northwest	Between 1905 and 1908	250 to 350 feet	U. S. Grant.
Miles	190 miles west	Between 1908 and 1910	1,800 to 4,000 feet	Lawrence Martin.
Shoup	250 miles northwest	About 1900 or 1901		U. S. Grant.
Alsek	75 miles southeast	Between 1906 and 1908		Fremont Morse.
In Alsek Valley	55 miles east	1908		Do.
Near Frederika Glacier.	150 miles northwest	do		S. R. Capps.
Russell	145 miles northwest	Between 1891 and 1908		Do.
Nizina	155 miles northwest	Between 1899 and 1908		Do.
In Alsek Valley	70 miles southeast	1909		Tarr and Martin.
Rendu	120 miles southeast	Between 1907 and 1911	Over 1½ miles	Do.
Adjacent cascading glacier.	do	do	¼ mile	Do.
La Perouse	130 miles southeast	1910	Over ¼ mile	Lawrence Martin.
Childs	190 miles west	1910–1911	2,000 feet	Do.
Grinnell	do	do		Do.
Rainy Hollow	120 miles east	Between June and September, 1910	2,000 feet	Webster Brown.
Chitistone	135 miles northwest	1911	½ mile	R. F. McClellan.
Heney	190 miles west	do		Tarr and Martin.

It is not known whether these advances were climatic or were due to earthquake avalanching. That the two sorts of advances may be distinguished when observations are made at the right time is indicated by the fact that a general advance of the glaciers of Prince William Sound, which began with the 1,600 to 1,700 foot advance of Columbia Glacier in 1908 (lasting until 1911 or later) and was continued in 1910 by the advance of 14 other glaciers, seems to be climatic rather than a result of the earthquakes of 1899 or that of October, 1900 (p. 94), or some later seismic disturbance.[1] The 15 Prince William Sound ice tongues (Columbia, Meares, Yale, Harvard, Radcliffe, Smith, Bryn Mawr, Vassar, Wellesley, Barnard, Baker, Cataract, Roaring, Harriman, and Blackstone) which were advancing synchronously in 1910, are of variable lengths and sizes, and the Columbia has not advanced in three years as much as the Childs, possibly under the earthquake impulse, advanced in less than one year, nor is its crevassing so severe. Its rate of motion increased from nine-tenths of a foot a day, in 1908, to $2\frac{1}{10}$ feet a day in 1910. Of those listed above as advancing between 1899 and 1911 the Childs and La Perouse, and probably the Rendu and Rainy Hollow glaciers, became suddenly crevassed, advanced great distances, and as suddenly ceased their activity, in these respects strongly resembling the nine Yakutat Bay advances (p. 57). Childs Glacier increased its rate of motion from about 6 feet a day in 1909 to 40 feet a day in 1910, and as suddenly slowed down again. We realize that all the features of earthquake-generated advances are not yet known; but we do feel that when full information is available such advances will be readily distinguished from climatic oscillations, that many or all of the advances listed above are of the earthquake-avalanche type, and that future advances may be expected in such of the longer ice tongues in the severely shaken portions of the St. Elias, Fairweather, Coast Range, Chugach, Wrangell, and Alaska ranges as have steep slopes for avalanches and other conditions favorable for the earthquake-avalanche type of advance.

[1] Martin, Lawrence, Two glaciers in Alaska: Bull. Geol. Soc., America, vol. 22, 1911, p. 731; The National Geographic Society researches in Alaska: Nat. Geog. Mag., vol. 22, 1911, pp. 548–553; corrected list quoted in H. F. Reid's variations of glaciers: Jour. of Geology, vol. 19, 1911, p. 458, and in Zeitschr. für Gletscherkunde, vol. 6, 1911, pp. 101–102.

Still other Alaskan glaciers, in portions of the territory frequently shaken by severe earthquakes, have had earlier periods of unusual activity, with crevassing and advance, within historic times.[1] Some of these are listed below and there are doubtless many others. For each of these the hypothesis may be considered that earthquake avalanching during one or another of the great periods of seismic disturbance listed in Chapter VI may have caused the advance, or that some may have been due to climatic variations and others to earthquakes. The list shows clearly that the series of great glacial advances in the Yakutat Bay region since 1899 is not exceptional, and suggests that the relationship of earthquakes to variations of glaciers may be common in Alaska, as, indeed, it may be elsewhere in the world.

Glacial advances before 1899.

Glacier.	Year of activity.	Amount of advance.	Described by—
In Lituya Bay	Between 1786 and 1894	2½ miles	Otto Klotz.
In Lituya Bay	Between 1786 and 1894	3 miles	Do.
Brady	Between 1794 and 1894	5 miles	John Muir.
Portage	Between 1794 and 1880	1 to 3 miles	Lawrence Martin.
Baker	Before 1800		Do.
Serpentine	Before 1817		Do.
Toboggan	Before 1840		Do.
Western Malaspina	Between 1837 and 1880	About 20 miles	Do.
Serpentine	Before 1882		Do.
Western Malaspina	1886		H. W. Seton Karr.
Nellie Juan	Probably before 1887		U. S. Grant.
Toboggan	Before 1889		Lawrence Martin.
Baker	Before 1891		Do.
Eastern Malaspina	Before 1891	Over 1,500 feet	I. C. Russell.
Muir	Between 1890 and 1892	300 yards	H. F. Reid.
Fredericka	1891		C. W. Hayes.
Patterson	1891		H. F. Reid.
Columbia	About 1892		G. K. Gilbert.
La Perouse	1895		Do.
Columbia	About 1897 or 1898		Do.
Barry	1898		Lawrence Martin.

[1] Martin, Lawrence, The National Geographic Society researches in Alaska: Nat. Geog. Mag., vol. 22, 1911, pp. 553–557.

CHAPTER V.

OBSERVATIONS OF THE EARTHQUAKE.

NATURE AND SCOPE OF THE EVIDENCE.

SOURCES OF INFORMATION.

CLASSIFICATION.

The records of the earth shaking of September, 1899, which we have been able to gather may be divided into four kinds—(1) the testimony of the men who were in Disenchantment Bay, where the disturbances were apparently central; (2) the testimony of those who were at Yakutat village, 30 miles distant, during the shocks; (3) the evidence from those who felt the shocks at other points within a radius of 250 to 480 miles; (4) the distant seismograph records. As these records differ in value, it seems best, first of all, to indicate which ones have been used and how much dependence has been placed on each of them. A briefer statement of the facts regarding the earthquake of 1899, given in this and the following chapters, has been published by the junior author.[1]

CONTEMPORARY ACCOUNTS.

The authors have been surprised at the number and variety of contemporary accounts of an earthquake occurring in a region so remote and so little visited. A popular account appeared in the Scientific American [2] and was reprinted in Current Literature.[3] There was a note on the earthquakes in the National Geographic Magazine.[4] An examination of a few of the newspapers [5] to which the junior author had access has revealed over 50 accounts of these earthquakes in newspapers published in places so widely separated as Sitka, Tokyo, and London.

Nevertheless, aside from the single fact that Muir Glacier had been made inaccessible by damage done to its front during an earthquake shock in September, 1899, almost nothing was known up to 1905 of the remarkable physical changes effected by these earthquakes. The Yakutat natives knew that there had been changes in the shore lines of Disenchantment Bay, where they hunt seal each year; but they knew nothing more. The whites who were in Disenchantment Bay during the earthquakes had never gone back to see what changes had taken place, and, with a single exception, those who lived at Yakutat, engaged in fishing or lumbering, concerned themselves little with the wonderful fiord at their doors. We ourselves had seen but one newspaper account of the earthquake and were totally unprepared for the remarkable phenomena which we found in Yakutat Bay during the summer of 1905.

REPLIES TO EARTHQUAKE CIRCULARS.

After the manuscript of the preceding pages of this report was essentially ready for publication, it was decided that it might be worth while to send out an earthquake circular containing a series of questions and requests for information in order that the area of the sensible shock might be more carefully determined and that additional contemporary accounts of the phenomena might be procured and existing information verified.

[1] Martin, Lawrence, Alaskan earthquakes of 1899: Bull. Geol. Soc. America, vol. 21, 1910, pp. 339-406.

[2] Vol. 81, No. 26, Dec. 23, 1899, pp. 405-406.

[3] Vol. 27, Feb., 1900, p. 123.

[4] Vol. 10, No. 10, Oct., 1899, p. 421.

[5] These include such daily or weekly papers published in Sitka, Alaska; Victoria, B. C.; Seattle, Wash.; Portland, Oreg.; San Francisco, Cal.; Chicago, Ill.; Toronto, Canada; New York City; and London, England, as are available in the Wisconsin State Historical Library at Madison, and a few others from which clippings had been made by Prof. H. F. Reid, of Johns Hopkins University, and by Mr. H. P. Ritter, of the United States Coast and Geodetic Survey.

Accordingly, about 600 copies of the circular reproduced below were sent out, with franked and addressed return penalty envelopes inclosed for reply. They were sent to individuals in Alaska and elsewhere who were known to the writers or who were suggested by members of the United States Geological Survey, the United States Coast and Geodetic Survey, the United States Fish Commission (Bureau of Fisheries), the United States Revenue-Cutter Service, the Alaska Commercial Co., and others, or by persons to whom circulars or letters of inquiry had been sent; to all United States officials in Alaska, including all regular and voluntary United States Weather Bureau observers, postmasters, deputy collectors and inspectors of customs, commissioners and marshals, commanders of military posts, and teachers of Government schools; to all ministers and missionaries of all churches, and to managers of all canneries, salteries, etc., in Alaska; to the secretary of each Alaskan Brotherhood Lodge; to the editors of all daily and weekly newspapers published in Alaska and to several in Yukon Territory, British Columbia, and the western United States; to all Canadian inspectors and collectors of customs in towns within the possible field of the earthquake; to post commanders of the Royal Northwest Mounted Police; to agents of the Hudson's Bay Co. in Canada; and to others.

The sending out of this circular has amply repaid the labor, expense, and delay. From the 600, some of which were sent out as late as June, 1908, over 200 replies of various sorts were received. Twenty-four were returned blank, but the greater number of these had been sent to places from which only negative evidence could have been expected; 40 were returned by the postal authorities because the office addressed had been discontinued, the mission had been removed, the newspaper had gone out of business, the cannery had not been reopened, or the individual had left for parts unknown; 36 contained specific statements either that no earthquakes had been felt by the writer, or else that he had come to the place too recently to know and could find no one in the place who could supply reliable information on the subject; the remainder, numbering over 100, contained valuable information, either specifying places where we had not previously known certainly that the shocks were felt, or verifying information already at hand, or correcting mistakes printed in sensational contemporary newspaper reports, or referring to still other persons who had valuable information. The 140-odd replies in the two divisions last mentioned have been invaluable in determining the boundaries of the region where the shock was sensible to persons and in verifying, correcting, and rewriting many sections of the text, a few of the better replies being quoted in full. Those who filled out and returned the printed circular or showed it to others who did so have conferred a real favor upon all interested in the advancement of knowledge concerning earthquakes. We are, however, nearly as much indebted to those who merely said that no shocks were felt at their homes as to those who were able to supply full data concerning the effects of the earthquakes at points nearer the center of activity. In footnotes, citing replies to this circular, the date given is that of the reply.

A copy of the circular follows.

EARTHQUAKES IN ALASKA IN SEPTEMBER, 1899.

Messrs. R. S. Tarr and Lawrence Martin, of the United States Geological Survey, are investigating the series of earthquakes that occurred in Alaska in September, 1899. These shocks were widely felt, notably at Yakutat, but also as far northwest as Valdez and as far southeast as Skagway, Juneau, and Sitka.

It is important that a complete list be made not only of the places where these shocks were felt, but of the near-by localities where no shocks were felt, of the times of observation of shocks, their duration and intensity, and the changes made by them in buildings, etc., and in nature.

It is requested that all persons having reliable information on this subject forward it to this office, and that persons seeing this letter and not knowing about the earthquake personally shall mention or present the letter to those who do. Notes made at the time, newspaper clippings, letters, or other descriptions written in 1899 may be of great value, and we should like to obtain verbatim copies of them. Failing this, we should value description, based on memory, of your personal observations, or of observations made by others and thought reasonably true by you, in reply to the specific questions following. It is requested that you send some reply, even if it be that you know nothing of the matter.

Information required.

1. *Name of observer*..........
2. *Present address of observer*..........
3. *Occupation of observer*..........
4. *Date or dates of observation*..........
5. *Place of observations.*—Make answer as exact as possible. If shocks were felt on more than one date, answer the following questions independently for each date. ....
6. *Time of earthquake.*—State accuracy of timepiece, when last regulated, and whether local (sun) time, Juneau time, Valdez, or other time was kept. If several shocks were felt, list independently. ....
7. *Length (duration) of shock.*—If not observed by a watch with a second hand, a desirable form of answer is: "Long enough to run out of doors," "Long enough to get out of bed and light a candle," or similar answer. ....
8. *Intensity of shock*..........
9. *Effects of earthquake.*—Damage to buildings; damage to wharves, etc.; opening cracks in ground; causing landslides or avalanches; affecting springs, etc.; causing pits or small craters; sending out water or sand; damaging glaciers; changing shore lines by uplift or depression; causing waves on bays, inlets, lakes, or rivers; killing fish; causing tops of trees or flagpoles to vibrate, lamps to swing in houses, doors or windows to slam, etc. ....
10. *Personal sensations.*—Difficulty in standing up; difficulty in walking; nausea or dizziness; different sensations on others than on yourself. Did you know it was an earthquake at the time? Was there any appearance of waves in the ground? Was there a hard shaking or a gradual movement? If at night, was it enough to wake one up? ....
11. *Direction of earthquake.*—Did it seem to come from any one direction or directions? How was the direction determined? Did others agree as to this direction? ....
12. *Noises accompanying shocks.*—State nature, loudness, duration, etc., as fully as possible. Did the loudest noise come before, after, or during the hardest shock? ....
13. *Nearest place where shock was felt.*—If you were in Alaska, British Columbia, or Yukon Territory during the period between September 3 and September 29, 1899, and did *not* feel any shocks or effects of shocks, please state where you were, etc. This negative evidence is of the greatest value in determining the boundaries of the disturbed area. State the nearest place to you where shocks were felt or damage was done by the earthquakes. ....
14. *Published accounts.*—If you have access to files of newspapers or other periodicals that give accounts of these earthquakes (especially Alaskan newspapers), will you please give specific reference to dates of articles and nature of description? If you can give us clippings on this subject, they will be greatly appreciated, or clippings loaned to us will be promptly returned. ....
15. *Other observers.*—If you know other observers of these earthquakes, will you kindly send us their names and addresses, that we may get into correspondence with them? ....
16. *Other earthquakes.*—If you have experienced other earthquake shocks in Alaska, will you please inform us of the date, place, and nature of observation? ....

REPORTS OF OBSERVERS.

REPORTS FROM POINTS NEAR CENTER OF DISTURBANCE.

Disenchantment Bay.—There were eight men in inner Yakutat Bay near the junction of Disenchantment Bay and Russell Fiord (Pl. XIV) during the earthquakes of September 3 and September 10. Their story, quoted on pages 15–17 of this report, shows the experience of the nearest eyewitnesses of the earthquakes, though it contributes little of scientific interest.

Yakutat Village.—Several persons have described the phenomena at Yakutat village, notably C. E. Hill,[1] a civil engineer, now in Seattle; R. W. Beasley,[2] the storekeeper at Yakutat, with whom we also talked in 1905; Rev. Albin Johnson,[3] of the Swedish Evangelical Mission Covenant Church at Yakutat; and W. M. Rock,[4] employed in 1905 at the Yakutat sawmil.

The steamship *Dora* put into Yakutat September 12, and it was her crew and passengers [5] who brought out the first news of the earthquakes, though telegraphic dispatches had previously told of seismic disturbances felt in Skagway.

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[1] (*a*) Seattle Post-Intelligencer, Sept. 23, 1899. (*b*) San Francisco Examiner, clipping dated Sept. 21, 1899, specific date of clipping not known. (The lack of specific identification of certain clippings from San Francisco papers and the absence of reference to the logs of several vessels and the journals of certain Alaska Commercial Co. posts, etc., is due to the destruction of these important records in the fire which followed the San Francisco earthquake of 1906.) Part of this was also published in the Toronto World, Sept. 25, 1899, and quoted by English seismologists in Rept. British Assoc. Adv. Sci., 1900, p. 83; idem, 1902, p. 62. (*c*) Reply to earthquake circular, 1907.

[2] Sitka Alaskan, Sept. 16, 1899 (the first printed account of these earthquakes); reply to earthquake circular, 1907.

[3] Rept. Comm. Education for 1898–99, vol. 2, p. 1402; reply to earthquake circular, 1907.

[4] Victoria Semi-Weekly Colonist, Oct. 12, 1899.

[5] Sitka Alaskan, Sept. 16, 1899. San Francisco Examiner? (dated Juneau, Sept. 14, 1899; specific date of clipping not known). San Francisco Chronicle (dated Seattle, Sept. 20; specific date of clipping not known). Seattle Daily Times, Thursday, Sept. 21, 1899, reprinted in Weekly Times, Sept. 27, 1899. Butte Weekly Miner, Sept. 21, 1899. New York Evening Post, Sept. 21, 1899. New York Daily Tribune, Sept. 21, 1899. Toronto Mail and Empire, Sept. 22, 1899.

On September 17 the United States revenue cutter *McCulloch* entered Yakutat Bay, and Gov. Brady and others went ashore, where they learned of the earthquakes. By this time the eight prospectors had made their way out from Disenchantment Bay, and more was known of the earthquakes than when the *Dora* was in port, so that the *McCulloch* carried away a much fuller account of the catastrophe. Descriptions by members of her crew and the passengers, so far as found by us, are as follows: The commander of the vessel, Capt. W. C. Coulson, refers briefly to the shocks and to changes in Point Turner.[1] The Seattle newspapers printed interviews with some members of the crew.[2] Gov. Brady alludes to the earthquakes in his annual reports for 1899 and 1900.[3] Two of the passengers gathered specific information concerning the earthquakes, and to them the newspapers of the country were indebted for the most widely published descriptions of the shocks and their results. One of these was W. J. Lampton,[4] a well-known newspaper and magazine writer. The other was the late Dr. Sheldon Jackson, then Government agent in Alaska, whose rather exaggerated account[5] has appeared in a great many publications in more or less abridged form. Probably these two men's descriptions of the Yakutat earthquakes were read by more people than any others, for they were widely copied in the newspapers and doubtless appeared in many others besides the few cited. They are not so reliable, however, as the first-hand accounts by Cox and Fults (pp. 15–17), who were in Disenchantment Bay, or those by Hill and Beasley (pp. 70–71, 77 and 79–80), who were at Yakutat village during the shocks.

REPORTS FROM DISTANT POINTS.

West and northwest of Yakutat Bay important observations were made of the earthquakes, especially by parties of the United States Coast and Geodetic Survey and the United States War Department. To the southeast observations were made at the chief Alaska coast towns, and in the wilderness to the north and east a few observations were made by persons in camps or settlements along the trails. Most of these places are within a radius of 250 miles of Yakutat Bay, though a few are more distant. (See Pls. II, p. 14, and XXXIII, in pocket, for location of these places.)

Mouth of Copper River.—Just west of the Copper River delta, at Cape Whitshed, about 12 miles from Orca (220 miles from Yakutat), a Coast Survey party in charge of H. P. Ritter made detailed observations of the earthquakes felt between September 3 and September 29, 1899,[6] recording 35 shocks. As Ritter's observations were made at a point whose exact latitude and longitude are known and as they were timed with a good and well-rated chronometer, giving mean local time, they are of the utmost value. They constitute the most important record, except that of distant seismographs, which the investigation of the contemporary account of these earthquakes has revealed, giving an accurate basis for computation as to the times of origin of the shocks at Yakutat, about 220 miles distant, as well as for comparison with distant seismograph records. The basis for computing the times of origin is about as good as Dr. Oldham had for the great Indian earthquake of 1897, the nearest accurate time record to which was made at Calcutta, 255 miles distant, although of course he had many other time records as well. Mr. Ritter's record is given on pages 71–72.

Yakataga.—At Cape Yakataga, 100 miles west of Yakutat, the captain of a vessel which was just offshore September 3 and one man who was on shore noted the earthquake and have furnished interesting records.

[1] Log of the U. S. Revenue-Cutter Service vessel *McCulloch*.

[2] Seattle Daily Times, Sept. 28, 1899; reprinted in Weekly Times, Oct. 4, 1899.

[3] Department of the Interior, Misc. Repts., pt. 2, H. Doc. 5, 56th Cong., 1st sess., p. 29; H. Doc. 5, 56th Cong., 2d sess., pt. 2, p. 25.

[4] New York Sun, Oct. 1, 1899.

[5] Sitka Alaskan, Sept. 23, 1899. San Francisco Examiner, Sept. 25, 1899. London Times, Sept. 25, 1899; reprinted in weekly edition, Sept. 29, 1899. Victoria Semi-Weekly Colonist, Sept. 28, 1899. Portland Weekly Oregonian, Sept. 29, 1899. Introduction of domestic reindeer into Alaska, Ninth Ann. Rept., for 1899, 1900, p. 50. Japan Times, Tokyo, Oct. 31, 1899. Pubs. Earthquake Investigation Committee in Foreign Languages, Tokyo, No. 6, 1901, pp. 47-48. An abridged Italian translation appears in an appendix to the Boll. Soc. sismologica italiana, vol. 6, 1900, p. 178.

[6] Abstract in Ann. Rept. Coast and Geodetic Survey, 1901, pp. 78, 206; also supplied to us in full in manuscript not previously published.

Controller Bay.—At Katalla, near Kayak Island, 170 miles west of Yakutat, just east of the Copper River delta, and at Cordova and Orca, just west of Copper River, notable earthquake phenomena were observed by Messrs. Shepard, White, Williams, and others.[1] Great avalanches[2] are said to have been caused by the earthquakes.

Chugach Mountains.—During the summer of 1899 a War Department party under Capt. W. R. Abercrombie was engaged in building a military trail from Valdez, on Prince William Sound, into the Copper River valley. One section of the party, under Lieut. W. C. Babcock,[3] was in the Chugach Mountains northeast of Valdez, about 240 miles northwest of Yakutat, and noted the earthquakes of September 3 and 10, making detailed observations as to time and notable features. Captain Abercrombie himself felt the shock of September 3 in the Tsina Valley, west of Copper River, only 210 miles northwest of Yakutat Bay.

Copper River Valley.—Other members of the Abercrombie expedition noted the earthquakes of September 3 in localities at least 250 miles from Yakutat. These were John F. Rice,[4] a quartermaster's clerk, who was at Copper Center; A. N. Powell,[5] a guide, who was between Copper Center and the mouth of Tazlina River; and another scout and guide,[6] who were at the junction of Klutina and Copper rivers.

Wrangell Mountains.—Oscar Rohn,[7] geologist of the Copper River exploring expedition, who was near the divide of Nizina and Chisana (formerly called Tanana) glaciers, in the Wrangell (Skolai) Mountains southeast of Mount Wrangell and 170 miles northwest of Yakutat Bay, also felt the earthquake of September 3, being nauseated by the swaying motion.

Nutzotin Mountains.—Near Mentasta Pass, in the Nutzotin Mountains, what was probably this shock of September 3 was observed by G. B. Rorer, a prospector.

Tanana River.—A. H. Brooks,[8] of the United States Geological Survey, who was north of the Nutzotin Mountains, near the junction of Tanana and Nabesna rivers, 240 miles northwest of Yakutat Bay, heard the sound of avalanches in the mountains on the afternoon of September 3 at the exact time of these earthquakes.

Valdez.—At Valdez, a seaport on an arm of Prince William Sound, one of the earthquakes was so strong that men were made dizzy and could not stand,[9] houses and forests were disturbed, and there were earthquake water waves in Port Valdez.[10]

Latouche Island.—On Latouche Island, in Prince William Sound, Lieut. E. F. Glenn,[11] of the United States Army, observed the shocks on September 3.

Unga.—There are a number of references to earthquakes felt at Unga, in the Shumagin Islands, at about this time;[12] but as the voluntary Weather Bureau observer[13] recorded no seismic disturbance on the days of the heavier shocks (Sept. 3, 10, 15, 23, and 26), some doubt is felt about correlating these with the Yakutat disturbance. Most shocks at Unga are doubtless volcanic. The Yakutat shock was tectonic, and there is no reason for believing that it was sensible to a few persons but not to the Weather Bureau observer at Unga, 850 miles to the southwest, when it was not felt at so great a distance in any other direction.

Dry Bay.—At the native village at Dry Bay, 75 miles east of Yakutat Bay, severe earthquakes were felt by the natives.

At sea, west of Yakutat.—Three different vessels report severe storms or other exceptional conditions at sea on September 3, 1899,[14] in the region west of Yakutat, near Kodiak Island and at other places.

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1 Replies to earthquake circulars, 1907-8.

2 Chamberlain, C. W., Seattle Daily Times, Sept. 21, 1899; reprinted in Weekly Times, Sept 27, 1899.

3 Copper River exploring expedition: S. Doc. 306, 56th Cong., 1st sess., 1900, pp. 73-74.

4 Idem, p. 102.

5 Idem, p. 132.

6 Reply to earthquake circular, 1908.

7 Copper River exploring expedition: S. Doc. 306, 56th Cong., 1st sess., 1900, p. 123.

8 Journal, 1899, and personal communication.

9 Camicia, L. S., and Glesener, Philip, reply to earthquake circular, 1908.

10 Seattle Daily Times, Sept. 21 and 29, 1899, reprinted in Weekly Times, Sept. 27 and Oct. 4, 1899. A San Francisco paper, 1899; exact date of clipping unknown.

11 Explorations in and about Cook Inlet, 1899: Rept. 1023, 56th Cong., 1st sess., 1900, p. 715.

12 Sitka Alaskan, Nov. 4, 1899.

13 Record of H. S. Tibbey, submitted to the authors.

14 New York Evening Post, Sept. 26, 1899. Seattle Weekly Times, Oct. 4, 1899.

On the day of the second heavy earthquake (September 10) the United States revenue cutter *McCulloch* [1] was "off Unga Island and experienced quite a hard southeast storm with heavy cross swells. Capt. Coulson would not say that the storm was attributable to the shock, as such storms were customary at this time of year."

Andrew Brown,[2] of Seattle, was on the steamer *Alliance* between Kodiak and Sitka during this earthquake, and reports the worst storm he had experienced in 25 years in the north Pacific Ocean.

It seems probable that all these heavy storms, on this rather stormy coast and at a stormy time of the year (near the autumn equinox), have a purely accidental relationship to the seismic activity. They are mentioned because they have been commonly associated in the press and in the popular mind with these earthquakes. There is no reason for such association.

Glacier Bay.—In the region near Muir Glacier the earthquakes were severely felt, according to Mr. Buschmann, the cannery superintendent at Bartlett Bay, in 1899. Unfortunately, no direct observation of the effects of the shocks upon the glaciers was made; but the observations by competent glaciologists before the shocks, and by other observers since 1899, afford definite information as to the results. A number of people have referred to the effect of these shocks on the glaciers, notably John Burroughs,[3] H. F. Reid,[4] who ascribed the changes to the earthquake of September 3, 1899; C. L. Andrews,[5] who first visited Muir Glacier after the changes had taken place; and G. K. Gilbert,[6] who was on the last scientific expedition which visited Muir Glacier, as well as the Yakutat Bay glaciers, before the earthquakes. Gilbert ascribed the changes to a series of severe earthquakes on September 12, 1899, and later; but in a letter dated March 12, 1907. he states that he probably obtained this erroneous date from newspaper reports.

Southeastern Alaska, British Columbia, and Yukon Territory.—The earthquakes of September 3, September 10, and later dates were felt at Sitka,[7] at Juneau,[8] at Haines,[9] in Taku Inlet,[10] and at other places not already named.

Skagway, especially, suffered from the whole series of shocks, which were felt also at Dyea, Pyramid Harbor, Bennett (British Columbia), Caribou Crossing (Yukon Territory), White Horse, and near Atlin (British Columbia). Because these places, notably Skagway, are settlements of considerable size or are along traveled routes reached by the steamers or on a telegraph line, the shocks in this general area have been reported much more fully from them than from less favorably located places, such as Yakutat and the wilderness to the north and northwest, where the shocks were probably even more severe. The accounts [11] vary in merit and probability and are cited here because many of them tell the places where the different shocks were felt and the dates of their occurrence.

The earthquake shocks of September 3 and 10 were also reported [12] from several points along Yukon River and on the trails between Lake Bennett and the Klondike district. We have specific information [2] of earthquake shocks on both September 3 and September 10 at Carmacks, the headquarters of the Tantalus detachment of the Royal Northwest Mounted Police, 190 miles northeast of Yakutat Bay, near the mouth of Nordenskiold River; at Dalton House, 90 miles east of Yakutat Bay; at White Horse, 170 miles northeast of Yakutat; on

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[1] Seattle Daily Times, Sept. 28, 1899, reprinted in Weekly Times, Oct. 4, 1899.
[2] Reply to earthquake circular, 1907.
[3] Harriman Alaska Expedition, vol. 1, p. 89.
[4] Variations of glaciers: Jour. Geology, vol. 9, 1901, p. 253; vol. 10, 1902, p. 317; vol. 11, 1903, p. 287; vol. 12, 1904, pp. 258–260.
[5] Nat. Geog. Mag., vol. 14, 1903, pp. 441–444; with a note by G. K. Gilbert, p. 445.
[6] Harriman Alaska Expedition, vol. 3, Glaciers, pp. 23–25.
[7] Sitka Alaskan, Sept. 16, 1899. Seattle Daily Times, Sept. 28, 1899; reprinted in Weekly Times, Oct. 4, 1899.
[8] A San Francisco paper, 1899; exact date of clipping not known. Seattle Daily Times, Sept. 20, 1899; reprinted in Weekly Times, Sept. 27, 1899
[9] Seattle Daily Times, Sept. 21, 1899; reprinted in Weekly Times, Sept. 27, 1899. San Francisco Chronicle, Sept. 22, 1899.
[10] Seattle Daily Times, Sept. 22, 1899; reprinted in Weekly Times, Sept. 27, 1899. Jour. Geology, vol. 13, 1905, p. 317.
[11] San Francisco Chronicle (dated Tacoma, Sept. 9, 1899; exact date of clipping not ascertained); same, Oct. 5, 1899. Seattle Weekly Times, Sept. 27, 1899 (dated Skagway, Sept. 11); same, Oct. 4, 1899. Seattle Daily Times, Oct. 2, 1899; reprinted in Weekly Times, Oct. 4. Chicago Daily Tribune, Sept. 12 and 23, 1899. New York Daily Tribune, Sept. 12, 1899. Sitka Alaskan, Oct. 7, 1899. Victoria Semi-Weekly Colonist. Sept. 21 and 25, 1899. Gwillim, J. C., Ann. Rept. Geol. Survey, Canada, vol. 12, Summary Rept. for 1899, p. 62A.
[12] Victoria Semi-Weekly Colonist, Sept. 25, 1899. Seattle Weekly Times, Oct. 4, 1899.

the Hootalinqua River, 200 miles northeast of Yakutat Bay; at Tagish and Five Fingers, all in Yukon Territory; and at White Pass, Alaska.

On the Yukon, at the mouth of Stewart River, 60 miles south of Dawson and 240 miles north of Yakutat Bay, very light shocks were felt during the first 10 days of September, 1899. One shock is said to have been felt at Fort Selkirk, 215 miles northeast of Yakutat Bay.[1] This area, like the Sitka-Juneau-Skagway region and the Prince William Sound and Copper River valley region, falls in the zone between the 150 and 250 mile radii from Yakutat, where severe shaking should have been expected; but because of lack of specific information in many accounts as to places of observation, other than "along the trail" or "on the Yukon," these places can not be exactly located on the map.

Places more than 250 miles distant.—At Sumdum, 275 miles southeast of Yakutat Bay, R. V. Rowe,[1] on an unrecorded date in September, 1899, was "helping to build a hotel * * * and was fitting the window frame in the gable when the shock came." He "had to catch hold of the studding to keep from being thrown out."

On Wade Creek, in the Fortymile district, 290 miles north-northwest of Yakutat Bay, a heavy shock was felt, presumably on September 10.

At Eagle, Alaska, about 340 miles a little west of north from Yakutat Bay, well-authenticated earthquake shocks, on September 10 and 26, were reported by a United States Weather Bureau observer.

On Etolin Island, Alexander Archipelago, in McHenry Inlet, about 375 miles southeast of Yakutat Bay, Fred Patching,[1] a cannery foreman, reports a sharp earthquake about 6.30 a. m. on a Sunday in September, 1899 (exact date not known), in connection with which some great landslides occurred. It seems rather doubtful whether this shock may be safely correlated with the Yakutat Bay earthquakes, because it was not observed anywhere else in the vicinity nor at several places much nearer Yakutat.

Approximately 380 miles west of Yakutat Bay, near Kenai Lake, an earthquake was felt "in the fall of 1899," no date being recorded. It is said [2] to have caused lamps to swing, goods to roll from shelves, and the ground to sway so as to cause dizziness.

About 390 miles a little north of west from Yakutat Bay the earthquake of September 3 was noted by Rev. F. R. Falconer at Susitna station, just north of Cook Inlet. It was also felt at Tyonek, on Cook Inlet, and near by at Ladds and the shocks of September 3 and 10 were felt at Homer, on Cook Inlet, 420 miles west of Yakutat, by George Jammé.

About 430 miles northwest of Yakutat Bay, in the Birch Creek district, the earthquake of September 10 was observed by J. E. Kinnaley.

About 480 miles northwest of Yakutat Bay, beyond Mount McKinley, Lieut. J. S. Herron felt the shock of September 3; and 670 miles northwest of Yakutat, near Treat Island, on Koyukuk River, north of the Yukon, F. C. Schrader and a United States Geological Survey party encountered phenomena which we believe were associated with the same shock.

At the Russian mission, Ikogmut, on Yukon River, 730 miles west-northwest of Yakutat and 315 miles from Schrader's place of observation, what is presumed to be this same earthquake was felt by the Russian missionaries at about the same time in the afternoon.

On Lake Chelan, in the State of Washington, nearly 1,200 miles from Yakutat Bay, a series of water waves observed on September 10, the day of the most severe earthquakes, were possibly caused by these seismic disturbances.

From a number of other places in various parts of Alaska, British Columbia, and Yukon Territory specific information has been received that no earthquakes were felt in 1899. These include towns or other white settlements or camps in every inhabited region in this part of North America. Nevertheless the boundaries between the area of the sensible shocks and the undisturbed areas (see Pl. XXXIII, in pocket) can not be drawn with any great confidence,

[1] Reply to earthquake circular, 1907.

[2] Lennox, W. E., reply to earthquake circular, 1907.

because so much of the area probably shaken was then and is still an uninhabited wilderness. A few of the scattered outlying places, where local conditions were favorable for observation and where observers were present and have furnished information, are noted above.

DISTANT SEISMOGRAPH RECORDS.

The seismograph records of the Yakutat earthquakes are mentioned in several newspapers,[1] referring chiefly to records made by a seismograph in Victoria, British Columbia (see Pl. XXVIII, p.102), the nearest instrument at that time.

The seismographs throughout the world also recorded the major shocks, clearly showing the times at which the earth waves set in motion by the faulting arrived at places as far distant as Toronto, Canada; Mexico City, Mexico; Cordoba, Argentina; Kew and Shide, England; Uccle, Belgium; Grenoble, France; San Fernando, Spain; Strassburg, Hamburg, and Göttingen, Germany; Rome and Florence, Italy; Trieste and Kremsmünster, Austria-Hungary; Nicolajew, Russia; Bombay, India; Tokyo, Japan; Batavia, Java; Mauritius, in the Indian Ocean; and Cape Town, South Africa.

These evidences that the Yakutat Bay disturbances were world-shaking earthquakes were studied by experienced seismologists, like John Milne,[2] F. Omori,[3] R. D. Oldham,[4] and others,[5] even before we visited Yakutat Bay; and the times of occurrence and place of origin of the earthquakes were determined by some of these seismologists from the seismograph records alone. A description of the Italian records of these earthquakes was compiled by A. Cancani [6] from observations by Agamennone, Grablovitz, Riccò, Bastogi, Stiattesi, Oddone, Belar, and others. Cancani gives an Italian translation of part of one of the exaggerated newspaper accounts of these earthquakes and reproduces the detailed record of the seismographs in the observatories of Italy. Other seismograph records of these earthquakes are printed and briefly discussed by E. Lagrange,[7] by F. P. Schwab,[8] and by R. D. M. Verbeek.[9]

We were, however, unaware of these studies until after our return from Alaska in 1905, and indeed until after the publication of our preliminary report.

CHRONOLOGY OF THE SHOCKS.

THE EARTHQUAKE OF SEPTEMBER 3, 1899.

POINTS OF OBSERVATION.

With one possible exception,[10] the earthquake of September 3 was the first disturbance felt in Alaska during the autumn of 1899. It occurred at 3.03½ p. m. September 3 ($3^h\ 03^m\ 28\frac{1}{3}^s$ p. m. computed mean local time at Yakutat; or $0^h\ 21^m\ 40\frac{1}{3}^s$ a. m. September 4, when reduced to

[1] Victoria Semi-Weekly Colonist, Sept. 21 and 28, 1899. New York Daily Tribune, Sept. 25, 1899. Chicago Times-Herald, Sept. 25, 1899. San Francisco Examiner, Sept. 25, 1899.

[2] Rept. British Assoc. Adv. Sci., 1900, pp. 64 et seq.; 1902, pp. 62–64.

[3] Publ. Earthquake Investigation Committee in Foreign Languages, No. 5, Tokyo, 1901, pp. 47, 62, 63, etc.; No. 6, 1901, pp. 47–48, 49–50, 50–51, 52–53; No. 13, 1903, pp. 96–99, etc.; No. 21, 1905, pp. 45–49, et al.

[4] Quart. Jour. Geol. Soc., vol. 62, 1906, pp. 459, 461, 471.

[5] Stupart, R. F., Proc. and Trans. Roy. Soc. Canada, 2d ser., vol. 9, 1903, p. 70. Kortazzi, J., Gerland's Beiträge zur Geophysik, vol. 4, 1900, pp. 404–405. Van der Stok, J. P., Proc. Sec. Sci. Koninkl. Akad. Wetenschappen Amsterdam, vol. 2, 1900, pp. 244–246.

[6] Notizie sui terremoti osservati in Italia durante l'anno 1899: Boll. Soc. sismol. ital., vol. 6, Appendice, 1900–1901, pp. 178–190, 194–198, 199–208, 223–229, 231–234.

[7] Les mouvements sismiques en Belgique en 1899: Bull. Soc. belge d'astronomie, vol. 5, No. 2, 1901.

[8] Berichte über Erdbebenbeobachtungen in Kremsmünster, 1899: Mitt. Erdbeben-Comm. Kaiserl. Akad. Wiss. Wien, vol. 15, 1900, pp. 42–45.

[9] Observations made at the Royal Magnetic and Meteorological Observatory at Batavia, vol. 22, 1899, pt. 1.

[10] Alfred H. Brooks, of the United States Geological Survey, reports that Ed. Brown, one of his party, heard roaring noises near the headwater region of Tanana and Nabesna rivers, 225 miles north-northwest of Yakutat Bay, on Aug. 27, 1899, at about 8 p. m. These noises, which sounded like distant volleys of musketry or artillery, lasted several days and were attributed to avalanches and, as no avalanches had been heard before, to avalanches set off by an earthquake. An independent report of the same sort comes from a party of prospectors near the head of White River the last week in August, 1899. One of the men in this party says (Victoria Semi-Weekly Colonist, Sept. 25, 1899; and Seattle Weekly Times, Oct. 4, 1899; clippings dated Vancouver, Sept. 22, 1899): "It [the shock] was accompanied by the noise of what sounded most like the splitting of a mountain. First it was like the sound of field battery, and later it came in a tremendous shock as if whole armies were engaged in battle. There were volleys, each lasting about a minute." Although the definite association of these avalanches with an earlier earthquake is not absolutely established, it is possible that there may have been an earthquake before Sept. 3, felt chiefly on the north side of the St. Elias Range.

Greenwich mean time). This shock was observed, so far as we know, at the places named in the subjoined list. Details concerning most of these observations are given in the paragraphs following the list. For the location of the places mentioned see Plate II (p. 14) or Plate XXXIII (in pocket).

Points of observation of the earthquake of September 3.

Place.	Location with respect to Yakutat Bay.	Observer.
Disenchantment Bay	In Yakutat Bay	J. Bullman, L. A. Cox, S. Cox, A. Flenner, J. P. Fults, jr., A. Johnson, T. Smith, D. Stevens.
Yakutat village	Mouth of Yakutat Bay	C. E. Hill, R. W. Beasley, Mrs. Esther Early, Albin Johnson, and others.
Dry Bay village	75 miles southeast	Dry Bay natives.
Yakataga	100 miles west	B. Durkee, S. E. Doverspike.
Katalla	170 miles west	C. W. Chamberlin.
Copper River delta	220 miles west	H. P. Ritter, E. B. Latham, and others.
Valdez	250 miles west-northwest	L. S. Camicia.
Latouche	295 miles west	E. F. Glenn.
Kenai Lake	380 miles west	W. E. Lennox.
Chugach Mountains	210 miles northwest	W. R. Abercrombie.
Do	240 miles northwest	W. C. Babcock.
Do	do	E. S. Larson.
Copper River	250 miles northwest	J. F. Rice.
Do	do	A. N. Powell.
Wrangell Mountains	170 miles northwest by north	Oscar Rohn.
Nutzotin Mountains	250 miles northwest	G. B. Rorer.
Tanana River	250 miles north-northwest	A. H. Brooks, W. J. Peters, and others.
Skagway	160 miles east-southeast	F. S. Williams and others.
Haines Mission	do	Prospectors.
Dyea	150 miles east-southeast	A. J. Walker, J. R. Beegle, and others.
Surprise Lake	240 miles east	John Bimms.
White Horse	170 miles northeast	G. S. Fleming.
Upper Yukon River	190 miles northeast	Northwest Mounted Police.
Homer	430 miles west	George Jammé.
Susitna River	390 miles west-northwest	F. R. Falconer.
Tyonek	410 miles west-northwest	Prospector.
Alaska Range	480 miles northwest	J. S. Herron.
Koyukuk River	670 miles northwest	F. C. Schrader, T. G. Gerdine, D. C. Witherspoon, and others.
Lower Yukon River	730 miles west-northwest	Rev. N. N. Amcan.

DETAILS OF OBSERVATIONS.

Disenchantment Bay.—This shock is described by J. P. Fults, jr.,[1] who was in Disenchantment Bay, as "slight and not enough to throw a man off his feet." It is rather disappointing that fuller and more specific information concerning the initial shocks on September 3, as felt in Disenchantment Bay, is not available. The prospectors barely mention these early disturbances, no doubt because the later ones, especially those of September 10, were so much more violent.

Yakutat.—At Yakutat, however, the intensity seems to have been greater; for there, it was said by C. E. Hill,[2] "the house began to rock and shake violently, * * * so violently that the door swung to and fro and finally shut with a crash. Dishes rattled, the table moved, and it seemed every minute as if we were going to be overturned.

"We all rushed out of doors to find the whole village gathered in the streets. Everybody was scared, and it was enough to frighten almost anyone, for looking toward the timber we could see the trees rocking back and forth, and the water crossing the reef in the bay was whipped into a mass of seething foam.

"The vibrations of the earth were from two to three seconds in length, coming from the northwest and running southeast, slow at first and then coming shorter and faster and irregular until they had lasted about five minutes. There were slight tremblings the rest of the day."

A native woman, now Mrs. Esther Early, of Juneau, but then a resident of Yakutat, says: "The first earthquake occurred one Sunday in September, 1899, about 2 o'clock in the afternoon, and lasted for about two minutes. At first it was a general shivering of the earth, but ended with a long jerk from west to east. Then we had no earthquake before the following Sunday at 8 or 9 a. m., which lasted for about three minutes and was more severe and stronger than the earthquake we had the previous Sunday. Then again in the afternoon at about 3 or 4 o'clock we had a still stronger earthquake than the first and second; the water in the bay began to run out toward the ocean heavily and went far below any low-water mark that I ever have seen, but after a short while returned in a strong current and made a big swell on the beach, and the houses in the Indian villages came pretty near being washed away as the water washed all around them.

"For about two weeks we then had earthquakes almost every day—first a small shock, then a stronger one, but none so heavy as the two we had on the second Sunday. In fact, for a whole year afterwards we frequently had small shocks now and then."

The hour of occurrence of this earthquake of September 3 as given by R. W. Beasley,[3] the storekeeper at Yakutat, who has kept a written record, was 3.30 p. m. "sun time," which corresponds with the actual time record better than any other time given by an observer in or near Yakutat Bay. The shock, Mr. Beasley says, lasted "long enough to enable me to run out of doors and to watch people falling on the beach, * * * and caused the trees and flagpoles

[1] Seattle Daily Times, Sept. 28, 1899.
[2] San Francisco Examiner, clipping dated Seattle, Sept. 21, 1899; date of publication not known; Seattle Post-Intelligencer, Sept. 23, 1899.
[3] Reply to earthquake circular, 1907.

to vibrate. Indeed I was afraid mine was going to break. It was impossible to stand up without holding on to something, and then some were on their knees before it was over. It made me dizzy and caused nausea which lasted three days, and it affected others the same way."

Rev. Albin Johnson [1] states that the women in the place were more affected by dizziness than the men.

Dry Bay.—The natives at the Dry Bay village, 75 miles east of Yakutat, at the mouth of Alsek River, state that the shock was so severe that men were unable to stand.

Yakataga.—At Cape Yakataga, 100 miles west of Yakutat, Capt. Ben Durkee,[2] commanding the schooner *Bellingham*, also experienced this earthquake. On September 3 he was on board the schooner a mile off the coast. The first shock, at 12 o'clock noon, was heavy and was followed by shocks every 10 to 15 minutes. The first shock continued probably two minutes; the others were shorter. The first shock was plainly felt on the boat, which vibrated and shook as if it were on a rock. Dust and smoke "from the breaking of the tops of the mountains" were plainly seen, beginning at Icy Bay, 40 miles to the east, and extending to Cape Suckling, 70 miles to the west, consuming from five to six minutes in running that distance. The tide set out from the shore at the rate of 3 or 4 miles an hour, and the schooner sailed out at the end of her anchor chain. The tide was slow about returning and reached about half the proper height, according to the tide tables. It returned quietly, the weather being perfectly calm. Before the quake everything was perfectly calm; there was no noise, the shock being first noticed by the trembling of the boat. During the quake there was a kind of a roar, as of a train of cars, but this was heard during the shock only. Capt. Durkee reached Kayak about 4 p. m. September 4 after a run in a heavy sea which taxed the schooner to the utmost.

S. E. Doverspike,[3] a prospector and miner who was ashore at Yakataga, writes that on September 3 at 2.30 a violent shock caused the tops of the trees to break and landslides to occur. Earth waves were distinctly felt. During the next six hours 48 distinct shocks occurred, followed by light shocks during the week and a heavy shock on September 10 about 5 o'clock. The duration of the shocks was not taken "on account of falling timber." There were no buildings to be damaged and no apparent crack openings. The tide was at half ebb and receded to low water in 20 minutes, not returning high for 36 hours. The ocean beach was raised 3 feet, as was noticed at the landing place on Yakataga beach, the tide not rising high enough to get over the reef. It was very hard to stand, but Mr. Doverspike was not dizzy, although some others were very dizzy. There were very heavy ground waves with a heaving motion similar to ocean waves. During the vibration there was a heavy rumbling sound.

Katalla.—At Katalla and Kayak Island, in Controller Bay, 170 miles west of Yakutat, Dr. C. W. Chamberlin[4] reports severe shocks on September 3, with great avalanches and dust clouds in the adjacent mountains.

Copper River delta.—At Cape Whitshed, near the mouth of Copper River, about 220 miles west-northwest from Yakutat, H. P. Ritter,[5] of the Coast Survey, from whose observations the times of origin of the shocks at Yakutat are determined, reports the heavy September 3 shock as beginning at 2.40 p. m. and lasting two minutes. He says it was a "violent earthquake, direction northeast and southwest. Two shocks close together. Bottles turned toward northeast. Water in shallow creek thrown out on bank." Eight or more after-shocks were also felt, two of them in the evening being severe.

Mr. Ritter's record of these shocks is given below.

Record of earthquake shocks September 3 to September 29, 1899.

[By Homer P. Ritter, assistant, Coast and Geodetic Survey. Survey of Prince William Sound and vicinity, Alaska. Camp Whitshed, Orca Inlet longitude, 145° 54′ 35″ west of Greenwich; latitude, 60° 27′ 34″ north.]

Date.	Beginning of shock.	End of shock.	Remarks.
	P. M.	P. M.	
	h. m. s.	h. m. s.	
Sunday, Sept. 3 [a]	2 40 00	2 42 00	Violent earthquake, direction northeast and southwest. Two shocks close together. Bottles turned over toward the northwest. Water in shallow creek thrown out on bank. Weather clear, pleasant, warm.
Do	3 22 30		Few seconds' duration.
Do			Two light shocks; time not noted.
Do	6 45 00		Shock lasting about 10 seconds.
Do	7 10 00	7 10 15	Two quite severe shocks.
Do	7 44 00	7 44 10	Two moderate shocks. Several light shocks followed before observers went to sleep.
Sept. 4-9			Series of easterly gales.
Sept. 8			Very high water at noon.
	A. M.	A. M.	
Sunday, Sept. 10 [b]	7 43 00		Weather calm and cloudy; occasional showers. Few seconds' duration; light but distinct.
Do	8 01 00		
Do	10 38 34		Distinct, continuous, vibrations lasting over 100 seconds.
Do	10 53 45	10 54 00	Camp flagstaff vibrating violently.
Do	10 59 55		Violent at beginning, tapering off toward end. Vibrations continuous for 180 seconds. Direction at right angles to shock of last Sunday.

[a] Corresponding to British Association record No. 333, at Shide, Isle of Wight.
[b] Probably corresponding to British Association record No. 337, Shide.

[1] Reply to earthquake circular, 1907.

[2] Reply to earthquake circular, 1908. This and some of the succeeding records supplied by local observers are given essentially in the words of the writers, though quotations are not full and exact unless inclosed in quotation marks.

[3] Reply to earthquake circular, 1908.

[4] Seattle Daily Times, Sept. 21, 1899; San Francisco Examiner, dispatch dated Juneau, Sept. 14.

[5] Unpublished manuscript furnished by United States Coast and Geodetic Survey. Reply to earthquake circular.

Record of earthquake shocks September 3 to September 29, 1899—Continued.

Date.	Beginning of shock.	End of shock.	Remarks.
	A. M.	A. M.	
	h. m. s.	*h. m. s.*	
Sunday, Sept. 10	11 05 05	11 05 35	
Do.[a]	11 58 33	12 01 33	Shaking violently all the time. Direction part of the time one way, then another. Top of 40-foot flagstaff vibrating from 1 to 4 feet. People in camp spread out their legs in standing.
	P. M.	P. M.	
Do.	12 07 08		Little.
Do.	5 36 08		Short.
Do.	5 44 02		Slight.
Do.	5 51 41		Little stronger. Earth practically vibrating all day.
Monday, Sept. 11			Weather windy. Think there were a few slight shocks.
Sept. 12 to 16			Storming all the time. A number of shocks, but hard and uncertain to determine time and duration on account of general uproar.
Sept. 20			Easterly gale, extreme high water to-day.
	A. M.	A. M.	
Saturday, Sept. 23	1 22 00	1 24 00	Short shock, followed after a few seconds by one of longer duration. Weather clear, windy. Direction, southeast and northwest; ½-second oscillations; woke up entire camp; lasted long enough to jump out of cot and light candle.
Do.	1 28 09	1 28 11	One short.
Do.	1 33 09	1 33 11	Do.
Do.	1 40 09	1 40 11	Two short.
Do.	1 41 51		Two ½-second shocks.
Tuesday, Sept. 26	2 49 00		Raining and storming. Shock woke most of camp.
	P. M.	P. M.	
Do.	12 05 38		½-minute duration.
Do.	2 46 00		Short. One shock during night, according to a number of men in camp.
Friday, Sept. 29			Earthquake during night.

[a] Corresponding to British Association record No. 338, Shide.

No shocks were felt after September 29 up to the time the party left for San Francisco on October 23, 1899.

Mr. Ritter is inclined to think that during the shocks of September 3 "all the apparent movements were lateral." He was in camp on a shingle beach just above high tide, and all around was marshy ground and mud flats, bare at low water.

E. B. Latham,[1] a member of the same Coast and Geodetic Survey party, supplies further data concerning the heavy shock at 2.40 on September 3, based on notes written at the time.

"At the time of the shock I was hunting, in company with one of the men, about 1½ miles from camp, in the hills. I was walking out on a peninsula approximately 20 by 100 meters that extended into a small fresh-water lake about 1 mile in length by one-fourth of a mile in width and about 400 feet above sea level.

"The vibration or trembling was not great and there seemed to be a shock. The first noted sensation was that of some impending danger and a feeling of passiveness to ascertain what the outcome was to be. The next sensation was to note the time of what I then knew to be an earthquake shock. The variation in the volume of sound due to the variation in the volume of water flowing over a slight fall in the outlet of the lake next attracted my attention. The first wave was approximately 20 seconds after the noted time of the shock. The maximum variation in height was about 10 inches, with a 5-second interval between the times of the waves (from maximum to maximum). The heights and times between waves decreased very slowly, being noted for 20 minutes, at which time they were almost imperceptible."

Valdez.—The same earthquake was recorded at Valdez by L. S. Camicia[2] as a strong shock at 2.33 p. m., during which it was impossible to stand on one's feet. The time is doubtless nearly accurate, as Mr. Camicia is a watch repairer and optician and should have had accurate timepieces in his shop. He states, however, that he was not using solar or local meridian time.

Latouche, Prince William Sound.—Just east of Kenai Peninsula, at Latouche Island, 295 miles west of Yakutat Bay, Lieut. E. F. Glenn, of the United States Army, felt the shocks of September 3. He states[3] that "on September 3, while superintending some work, I suddenly felt as though I were about to fall. I at first attributed this to my physical condition, but soon discovered that we were having an earthquake of no mean proportions."

Chugach Mountains.—Just west of Copper River, in the Chugach Mountains, on Tsina River, 210 miles northwest of Yakutat Bay, Capt. W. R. Abercrombie,[4] of the United States Army, felt this earthquake about 2 p. m. He says that it consisted of "a succession of shocks like the surf beating on the shore. It threw me down—that is, tripped me in walking. Groves of cottonwood trees waved to and fro like wheat. It caused heavy landslides, broke ice off glaciers, and stopped work on Valdez trail by the motion of the earth."

As observed in another portion of the Chugach Mountains, about 240 miles northwest from Yakutat Bay, the heavy shock of September 3 is described in Capt. Abercrombie's report,[5] from data by Lieut. Babcock, as follows: "It began

[1] Reply to earthquake circular, 1909.
[2] Reply to earthquake circular, 1908.
[3] Explorations in and about Cook Inlet, in Compilation of narratives of explorations in Alaska: S. Rept. 1023, 56th Cong., 1st sess., 1900, p. 713.
[4] Reply to earthquake circular, 1907.
[5] Copper River exploring expedition: S. Doc. 306, 56th Cong., 1st sess., 1900, pp. 73–74. Narrative of explorations in Alaska: S. Rept. 1023, 56th Cong., 1st sess., 1900, p. 776.

gently, gradually increasing in violence until it became impossible to stand erect, and then gradually decreased. The shock lasted 1 minute and 10 seconds. The vibrations were from north to south and were so violent that one could actually see the ground move. Cook pails resting on the ground were upset and tall spruce trees about us swayed dangerously. The sensation experienced was not so much that of fear as of utter helplessness, accompanied by a slight nausea resembling seasickness. After the shaking had subsided we heard eight muffled reports, sounding more like gunshots than any other sound, occurring at intervals of about 12 seconds."

The following are extracts from the diary of Capt. (then First Lieut.) Walter C. Babcock, Eighth United States Cavalry, written on the spot: "September 3, 1899: We arrived at the new camp, No. 15, at 2 p. m., and at once set to work to get dinner. Just as we were about to eat I felt an earthquake shock and asked Paulson to look at his watch at once. It was 2.28 p. m.[1] The shaking increased till it was impossible to stand erect. * * * After supper, at 7.30 p. m., there was another slight shock, lasting three seconds and preceded by one of the reports above noted. We are camped on a large flat, timbered with spruce, near the river, about 300 yards from the trail. The atmosphere has been very smoky all day."

Just west of Copper River, in the Tiekel Valley, Chugach Mountains, E. S. Larson[2] experienced a shock of unrecorded date, which caused the trees to wave and the ground to move, and awoke a man sleeping on the ground.

Upper Copper River.—Concerning the shock in the Copper River valley, about 250 miles northwest of Yakutat Bay, J. F. Rice[3] says: "At 2 p. m., September 3, while standing on a stump making observations, I was violently precipitated to the ground by a sudden seismical disturbance. The ground seemed to rock like the angry billows of the ocean. The trees swayed to and fro as if a hurricane was raging. In the midst of the convulsion of nature there were borne to our ears far-off sounds resembling the discharge of heavy artillery."

Another scout and guide for the Copper River military exploring expedition[4] reports: "I was at the junction of Klutina and Copper rivers, Alaska, on September 3, 1899, at which time, about 1 or 2 p. m., there was a violent earthquake shock. The earth seemed to give about three swings, but it was not a jar, and no noises were heard. The swinging was probably about five seconds, but no record was made of it at the time. I was told by prospectors that Tonsina Lake dashed its water as if it was water in a small vessel. There was black smoke issuing from the crater of Wrangell at the time, but nothing unusual was noticed from that, as it alternates in sending out steam and smoke."

A. N. Powell,[5] who was a short distance north of Mr. Rice, in the Copper River valley, reports that while the earthquake of September 3 was in progress Mount Wrangell was emitting heavier smoke than usual. This was also reported by Mr. Rice. Oscar Rohn[6] and Capt. Abercrombie[2] both refer to the slight apparent activity of Mount Wrangell at about this time, but this activity was doubtless only coincident with the earthquake and not an effect of it.

Wrangell Mountains.—On September 3 Oscar Rohn[7] was in the Wrangell Mountains, near the summit of the Nizina and Chisana (formerly Tanana) glaciers, and about 170 miles northwest by north from Yakutat. He says:

"Suddenly the surface of the glacier began swaying up and down in the most amazing manner * * * with a slow, undulating movement so violent and persistent as to cause a touch of nausea. I can not make even a rational guess as to the length of time the shocks lasted. It seemed as though we were bounced up and down 3 feet, although I suppose this is wholly impossible, and I should guess that the vibrations were not more frequent than two or three a minute. I had no way of knowing the direction of movement. My impression, however, was that the motion was in a direction approximately northeast and southwest." There were minor rapid shocks afterwards.

Mentasta Pass, Nutzotin Mountains.—On an unrecorded date in September, 1899, G. B. Rorer,[8] a prospector, now at Dry Creek, Alaska, felt the earthquake shocks near Mentasta, 250 miles northwest of Yakutat Bay.

Tanana River.—A. H. Brooks, W. J. Peters, and a United States Geological Survey party were north of Tanana River near latitude 63°, longitude 143°, about 250 miles north-northwest of Yakutat Bay, September 3, when the earthquake occurred. Brooks records it in his journal as follows:

"This afternoon at 3.30 we heard a series of loud, distant sounds resembling the sound of blasting or the discharge of heavy artillery. They were repeated at irregular intervals with varying intensity for 5 or 10 minutes. They seemed to gradually lose their intensity and die away. At about 8 p. m. we heard several similar sounds, but they were not continued more than a minute. The consensus of opinion was that they came from the direction of the upper valley of Tetlina River beyond the lakes. Ed. Brown heard similar sounds at about 8 p. m. August 27. Camp 55."[9]

Skagway.—At Skagway,[10] 160 miles east-southeast from Yakutat, the shock of September 3 "caused buildings, telephone poles, and the like to rock back and forth for 3¾ minutes. The quake was not a sudden jar, but a steady motion

[1] The 10 or 12 minute discrepancy in the time of this shock, as observed by Lieut. Babcock, was doubtless due to his not using local solar time. He says (reply to earthquake circular, 1907) that he used "an ordinary cheap silver watch, probably correct within a few minutes."

[2] Reply to earthquake circular, 1907.

[3] Copper River exploring expedition: S. Doc. 306, 56th Cong., 1st sess., 1900, p. 102. Narratives of explorations in Alaska: S. Rept. 1023, 56th Cong., 1st sess., 1900, p. 788.

[4] Reply to earthquake circular, Valdez, Sept. 22, 1908.

[5] Copper River exploring expedition: S. Doc. 306, 56th Cong., 1st sess., 1900, p. 132. Narratives of explorations in Alaska: S. Rept. 1023, 56th Cong., 1st sess., 1900, p. 804.

[6] Letter dated Feb. 16, 1907.

[7] Copper River exploring expedition: S. Doc. 306, 56th Cong., 1st sess., 1900, p. 123. Narrative of explorations in Alaska: S. Rept. 1023, 1900, p. 800; letter dated Feb. 16, 1907.

[8] Reply to earthquake circular, 1908.

[9] For location of camp 55 and position of party on September 3 (camps 60 and 61) see Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, Pl. XL.

[10] San Francisco Chronicle, Sept. 10, 1899. The time given (3.17 p. m.) is almost exactly what would be expected, with corrections for longitude, transmission, and failure to use mean local time.

of the earth from north to south. So perceptible was the shaking up that pools of water collected in the streets and sloshed about like water does in a bucket or basin when shaken violently." Barrels of beer were thrown out of the vats in the Skagway brewery.

F. S. Williams,[1] deputy collector of customs at Skagway, regards the first shock on Sunday afternoon, September 3, as the most violent, lasting "long enough to run from second floor to street, and then to wait in street for shocks to end. Not strong enough to knock a man down, but to make him stumble. It caused me to stumble while walking, but when I came to realize that it was an earthquake, I had no difficulty in standing. It caused telegraph poles to vibrate, two-story frame building (large) to sway back and forth with a terrifying quaking, and to crack the putty around the plate-glass windows (about 5 by 7 feet) in the same building—Klondike Trading Co.'s building at Skagway. Reported small tidal wave on Lynn Canal about 1 or 2 feet high."

Haines.—At Haines Mission,[2] near Skagway, the shocks were accompanied by the moving of furniture, swaying of trees, rolling of logs, difficulty in standing and in walking, etc. The ground is said to have cracked open in places. Needless to say, the natives were put in the utmost fear by these occurrences.

Dyea.—At Dyea, about 150 miles east of Yakutat Bay, A. J. Walker,[1] of the United States Customs Service, reports that a shock about 8 a. m. lasted long enough for him to "walk across a large room, open door, and observe large warehouse across the street sway back and forth. It caused water to slop out of vessels on stove, doors and windows to rattle, and piles of freight in the warehouse on the wharf to fall over. There was difficulty in walking and a slight dizzy sensation. There was a peculiar noise, like the approach of a heavy wind, which gradually grew louder and gradually died away."

J. R. Beegle,[1] a deputy collector of customs at Dyea, states:

"Beginning at 2 o'clock a. m., 13 distinct shocks were felt within 24 hours, some within a few minutes of each other and others at longer intervals. The longest shock probably lasted 30 seconds; very severe. Buildings were damaged, glaciers were shaken up; * * * it caused lamps to swing, doors to rattle, etc. * * * Dyea is on a large sand flat and it waved like the sea, the waves traveling from west to east. The shaking was sufficient to wake both myself and wife from a sound sleep."

Surprise Lake.—Near Surprise Lake, east of Atlin, in the Canadian Coast Range, 240 miles east of Yakutat, John Bimms[3] felt severe shocks on September 3. Dust from distant mountains suggested smoking volcanoes (or avalanches). There were occasional aftershocks up to September 7.

White Horse.—At White Horse, Yukon Territory, about 170 miles northeast of Yakutat Bay, the Government telegrapher, G. S. Fleming,[1] made notes at the time concerning the earthquake of September 3. He says that this shock, which came at 3 p. m., lasted 30 to 40 seconds, but was of slight intensity. He realized that it was an earthquake, but there was no unpleasant sensation or alarm. When the motion began, a dog on a small hill near the house crouched in terror, whined, and ran down the hill.

Upper Yukon River.—An extract from the diary kept at the headquarters of the Tantalus detachment of the Royal Northwest Mounted Police on Yukon River, about 190 miles northeast of Yakutat Bay, in about 62° 6′ north latitude and 136° 15′ west longitude (marked on some maps as Carmacks), says: "September 3, 1899: Slight shock of earthquake felt here during the afternoon."

Homer.—At Homer, Kachemak Bay, near the entrance to Cook Inlet, 430 miles west of Yakutat, the shock of September 3 was felt by George Jammé, a mining engineer, and was of sufficient intensity to throw him against a drawing board over which he was working.[4]

Head of Cook Inlet.—At Susitna station, about 20 miles above the head of Cook Inlet, fully 390 miles northwest by west from Yakutat Bay, the earthquake was experienced by Rev. F. R. Falconer, a Presbyterian missionary, who says that "the shock occurred about 2 o'clock in the afternoon the first Sunday in September, 1899. The shock seemed gentle, with a wavelike motion."

At Tyonek, on Cook Inlet, a prospector reported to A. H. Brooks a "severe shock" in September, 1899, but whether on the 3d or 10th was not recorded.

Northwest of Mount McKinley.—Lieut. J. S. Herron, of the United States Army, was in about 63° 30′ north latitude, 152° 30′ west longitude, near the Tatlathna branch of Kuskokwim River, on September 3, near the Indian village called Telida. This is about 50 miles northwest of Mounts McKinley and Foraker in the Alaska Range and more than 480 miles northwest of Yakutat Bay. Lieut. Herron states[5] that "a violent earthquake occurred at 2 p. m. on the 3d." Another was felt at 2.30 p. m. by chronometer set to Seattle time. Lieut. Herron's diary, written at the time, states that one shock was "very severe and seemed to be right under us and the creek, on which it made big waves and shook the ground under us."

The heavy shock lasted five seconds and Herron was compelled to hold to a tree to keep on his feet.[6] He was near the bank of a creek about 25 feet wide. He says:

"The shock caused waves on this small creek nearly 2 feet high, which splashed on the banks with considerable violence. It was difficult to stand up; impossible to walk. I experienced no nausea, but did experience either dizziness or surprise. Others in my party had same or similar sensations. I did not know it was an earthquake at first; was too surprised at the waves on the creek and my own staggerings to realize what had happened. After it was over I knew it was an earthquake. There was no appearance of waves in the ground as far as I could see. I was in dense underbrush at the time and engaged in chopping trail for my pack train, which was following. It was a severe and

[1] Reply to earthquake circular, 1907.
[2] San Francisco Chronicle, Sept. 22, 1899.
[3] Idem., Oct. 5, 1899.
[4] Personal communication in 1909, based on diary kept in 1899.
[5] Explorations in Alaska, 1899: War Dept., Adjt. General's Office, No. 31, 1901, p. 38.
[6] Reply to earthquake circular, 1909.

FOAM AND MARKS OF EARTHQUAKE WATER WAVE (X–X) ON BANK OF KOYUKUK RIVER 670 MILES FROM YAKUTAT.

Photographed September 3, 1899, at 2.22 p. m., by F. C. Schrader.

continued rocking or shaking of the earth and not a gradual movement. The earthquake seemed to be right under our feet; all the others agreed to this. I do not recall any noises. There might have been some, however. As stated above, I was busy trying to keep on my feet."

Koyukuk River.—On September 3, F. C. Schrader, of the United States Geological Survey, was coming down Koyukuk River, a northern tributary of the Yukon, and had reached a point on the north shore of Treat Island,[1] in about 156° 15′ west longitude and 66° north latitude, approximately 262 miles from the Yukon and 670 miles northwest of Yakutat. Here the Koyukuk meanders through an extensive lowland of lacustrine Pleistocene silts called the Koyukuk Flats.

At 2.22 on that afternoon, in a stretch of the river which was otherwise as calm as a millpond, pronounced waves were encountered, two of which were 1½ to 2 feet high in midstream and rose a foot or more above normal river level upon the banks, "where they left pools and patches of water, foam, froth, sticks, and vegetable rubbish as the water subsided."[2] These waves moved upstream, north-northwest, rather rapidly, and on very flat shores washed the débris back several hundred yards, the phenomena being noted for about half a mile along the river bank.

At the time Mr. Schrader associated the waves with an earthquake, but, being in a canoe, he was not certain whether the land was shaken. He landed at once and photographed the subsiding wave (Pl. XXV), recording it in the photographic laboratory of the United States Geological Survey on his return as "due to earthquake disturbance, September 3, 1899, at 2.22 p. m." The same phenomena were noticed independently by several other members of Mr. Schrader's party, including T. G. Gerdine and D. C. Witherspoon, the topographers, farther along the river, and by one man, H. B. Baker, on the shore.

The distances involved here and the topography and structure of the region suggest a comparison with the San Francisco earthquake. The Koyukuk Flats are between the Rocky Mountains of Alaska and the Alaskan equivalents of the Sierra Nevada. They are 120 miles farther from Yakutat Bay than Great Salt Lake (just west of the Rocky Mountains in the United States) is from San Francisco. The faulting which caused the San Francisco earthquake of 1906 did not propagate waves through the rocks and structures of the valley of California, the Sierra Nevada, and the Great Basin of sufficient strength to produce noticeable water waves in Great Salt Lake. The Yakutat earthquake of September 3 did produce water waves on the river in Koyukuk Flats. Corroborative evidence is found in an examination of the time of Schrader's observations. On correcting his time of observation (2.22) for longitude[3] and for transmission,[4] it comes within 19 minutes 20 seconds of the time of the Yakutat earthquakes. As Schrader states that he did not use accurate or local time, and as we may have used too fast a rate of transmission, the time seems close enough to warrant a correlation of the Koyukuk waves with the Yakutat earthquake. It should be noted that this plain of unconsolidated silts is just the sort of place that would be affected by even a weak earth tremor, shaking like a bowl of jelly and raising waves in the streams. In the Lisbon earthquake of 1755 the water of Loch Lomond, in Scotland, at a considerably greater distance, is reported to have been affected by the shocks at the proper time.[5] It is possible, however, that the disturbance on the Koyukuk may have been due to a nearer earthquake,[6] related to a release of strain in the earth's crust nearer to the Koyukuk region and set off by the Yakutat earthquake.

Lower bend of Yukon River.—At the Russian mission, Ikogmut, on Yukon River, Rev. N. N. Amcan, a Russian orthodox priest, observed what was perhaps this same earthquake,[7] although his description is in some respects less specific than the last one cited. The place of observation was near 62° north latitude and 160° 45′ west longitude, about 730 miles west-northwest of Yakutat Bay and over 315 miles from Schrader's place of observation.

Father Amcan states that "there was a very heavy shock at 2 o'clock in the afternoon." Unfortunately he has not kept a record of the exact date; but from the facts that he places it in the period between September 3 and September 29, 1899, and that it came at 2 p. m. (almost the same time as the shock of September 3 on the Koyukuk, and far too late in the afternoon for the shock of September 10), it is believed to have occurred on September 3. When corrected for longitude and transmission it coincides with the time of the September 3 shock at Yakutat within 18 minutes 17 seconds, an error easily accounted for by inaccuracy of the timepiece. Like the Koyukuk Flats, this place is located at the edge of a great plain of unconsolidated Pleistocene strata, in which earth waves might be generated, even at so great a distance. The shock lasted long enough for Mr. Amcan to "run out of the door." A severe shock was felt at this place in 1867, when it was reported by Messrs. Dall and Whymper, who felt it on the water, and by the priests at the mission.

SUMMARY OF OBSERVATIONS OF EARTHQUAKE OF SEPTEMBER 3.

This earthquake was felt at about 30 known localities, the most distant being 730 miles from Yakutat Bay. The phenomena recorded include uplift of the coast, trembling of the earth, water waves, avalanches, earth waves, difficulty in standing up and nausea on the part of human beings, fear incited in animals, and shaking of houses, but no appreciable damage to life or property.

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1 Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, Pl. LX.

2 Described in discussion at meeting of Geological Society of Washington, Apr. 25, 1906, and in letters Jan. 10, Mar. 22, and Apr. 3, 1907.

3 Disenchantment Bay, Yakutat, latitude 59° 59′ 20″ north, longitude 139° 33′ west; Treat Island, Koyukuk River, latitude 66° north, longitude 156° 15′ west.

4 Six hundred and seventy miles at 3 kilometers (1.86 miles) per second.

5 Lyell, Charles, Principles of geology, 10th ed., 1868, p. 149.

6 The existence of secondary earthquakes of this sort, called "sympathetic earthquakes" by Oldham (The great earthquake of 1897: Mem. Geol. Survey India, vol. 29, 1899, pp. xxv-xxvii), has never been positively established.

7 Reply to earthquake circular, 1908.

PLACE OF ORIGIN OF EARTHQUAKE OF SEPTEMBER 3.

The place of origin of this September shock is not definitely known and has hitherto been assumed to be Yakutat Bay, so our time records have been computed on that assumption. As there was uplift of the coast and probably faulting at Yakataga, 100 miles west of Yakutat, on September 3 and as no water waves are reported in Disenchantment Bay and Russell Fiord, where water waves accompanied the faulting of September 10, it might be safer to assume that the shock of September 3 originated nearer Yakataga. Moreover this first earthquake seems to have shown less intensity in Disenchantment Bay than at Yakutat village, and less there, in proportion to the distance from a possible center of disturbance in and near Disenchantment Bay, than near Yakataga or Copper River. An alternate hypothesis is that the unexpected distant intensity is only apparent; that is, that we are reading it into the accounts by the different observers. It would be perfectly possible, for example, that the observers in Disenchantment Bay described the first shock in the mild terms quoted, because the first shock seemed mild to them after the later, more violent earthquakes, especially those of September 10.

AFTERSHOCKS OF THE EARTHQUAKE OF SEPTEMBER 3.

Light shocks occurred between September 4 and 9, as recorded by Mr. Ritter at Cape Whitshed, near the mouth of Copper River (p. 71), and by a number of other observers near by. Mr. Hill speaks of "one or two slight tremors at Yakutat, but nothing of any consequence." Mr. Fults [1] speaks of "intermittent shocks" in Disenchantment Bay all the week following September 3, usually coming at the extremes of the tide—"two distinct shocks a day, one at high tide and one near low tide."

EARTHQUAKES OF SEPTEMBER 10, 1899.

NUMBER AND INTENSITY.

The seismic disturbances which had been felt ever since the initial earthquake of September 3 came to a climax on September 10. It is reported that at the camp of the prospectors in Disenchantment Bay over 50 shocks were felt during that day, of which two were severe. Two of the many shocks felt at Yakutat village that day are described as particularly severe. Ten or more shocks were strong enough to be felt in the Coast Survey camp near the Copper River delta, several of them being very violent. Six were felt in the Chugach Mountains near Prince William Sound. Five were felt 190 miles to the northeast, on Yukon River. A number are reported from other distant points, like Skagway and Juneau, to the southeast. Two shocks were of sufficient intensity to be recorded on seismographs throughout the world, and these records have been studied by Milne, Omori, Oldham, the Italian observers, and others.

THE EARLY SHOCK.

POINTS OF OBSERVATION.

Little could be learned concerning the first considerable shock on September 10, though there is no doubt that a shock of sufficient intensity to be recorded by seismographs throughout the world was severe enough near its place of origin to merit more detailed description, which it would doubtless have received but for the overshadowing violence of the later and heaviest shock on the same day. This early shock, which occurred either just before or just after 8 a. m.,[2] is said to have lasted a minute and a half. Observations of this shock were procured from the places named in the following list. This list is doubtless very incomplete, for though this shock seems to have been more severe at Yakutat than that of September 3, yet the list is much smaller. For the location of the places mentioned, see Plate II (p. 14) or Plate XXXIII (in pocket).

[1] Seattle Daily Times, Sept. 28, 1899.

[2] $8^h\ 6^m\ 28\frac{1}{3}^s$ local time at Yakutat if based on the first record at Camp Whitshed that day ($17^h\ 24^m\ 40\frac{1}{3}^s$ Greenwich meridian time); or 23 minutes 10 seconds earlier ($17^h\ 1^m\ 30^s$ Greenwich meridian time) if based on distant seismograph records.

Points of observation of the earlier shock of September 10.

Place.	Location with respect to Yakutat Bay.	Observer.
Disenchantment Bay	In Yakutat Bay	J. Bullman, L. A. Cox, S. Cox, A. Flenner, J. P. Fults, jr., A. Johnson, T. Smith, D. Stevens.
Yakutat village	Mouth of Yakutat Bay	C. E. Hill, R. W. Beasley, Albin Johnson, and others.
Copper River delta	220 miles west-northwest	H. P. Ritter, E. B. Latham, and others.
Chugach Mountains	240 miles northwest	W. C. Babcock.
Valdez	250 miles west-northwest	L. S. Camicia.
Upper Alsek River	90 miles east	A. E. Acland.
Upper Yukon River	190 miles northeast	Northwest Mounted Police.
Skagway	160 miles east-southeast	B. F. Shelton and others.
Juneau	220 miles southeast	H. H. Folsom and others.

DETAILS OF OBSERVATIONS.

Disenchantment Bay.—Mr. Fults [1] has recorded that in Disenchantment Bay the early shock September 10 was severe enough "to throw a man off his feet." In the adjacent camp, Dr. Cox [2] states there was movement of the ground and low shrubs shook and were bent as if in a strong wind. After this there were less severe shocks every few minutes all the forenoon, the total number reported to us by Mr. Flenner being 52.

Yakutat.—From Yakutat village C. E. Hill [3] reports:

"Sunday morning, September 10, at 8 o'clock, we were all asleep in the mission when an earthquake shock came that made the one of the week before pale into insignificance. It was shorter than the former one and from the same direction; only we noticed this difference by watching the swaying of the swinging lamp: The tremor would start almost due north and south and would work its way around until the lamp was swinging almost due west and east. We all piled out of the houses as soon as we could and witnessed the same swaying of the trees, but much more than before, until the houses creaked and groaned as if being shaken to pieces. None of us had stopped to dress before rushing out, so as soon as the shock was over we returned and got our clothing on.

The missionary, Mr. Johnson, did not intend to hold services that morning because the slight shakes kept coming every few minutes and he was afraid to gather a crowd in the building; but the Indians, all of whom had once more fled to the hills, begged him to have church, saying that Ankow—their name for God—was angry at the earth and was shaking it. To oblige them Mr. Johnson held church, and during the whole service there was not a single shake."

R. W. Beasley,[4] storekeeper at Yakutat, gives the time of the early shock as 7.40 a. m. This is probably very nearly correct, for the time which he gives for the heavy shock later in the day, recorded with the same timepiece, is almost absolutely correct. The duration of this early shock he gives as three seconds.

Copper River delta.—In the Coast Survey camp at Cape Whitshed, west of the Copper River delta, some 220 miles west of Yakutat Bay, the earliest shock recorded by Mr. Ritter was at 7.43 a. m., the disturbance being "light but distinct" and lasting a few seconds. This, as already stated, was one of the observations "taken with a good and well-rated chronometer, giving mean local time," so that the time may be regarded as almost absolutely correct. Mr. Latham had a "sensation of the earth trembling or vibrating," following more or less distinct shock. Other shocks during the forenoon, at the same place, came at $8^h 1^m$; at $10^h 38^m 34^s$, when Mr. Ritter says there were "distinct continuous vibrations lasting over 100 seconds;" at $10^h 53^m 45^s$, when the "camp flagstaff vibrated violently" for 15 seconds; at $10^h 59^m 55^s$, when the shock was "violent at beginning, tapering off toward end. Vibration continuous for 180 seconds. Direction at right angles to last Sunday;" and at $11^h 05^m 05^s$. when the shock lasted 30 seconds.

Mr. Latham made the following notes regarding these shocks. His times vary from Mr. Ritter's because he used his watch rather than the accurate chronometer. "September 10, 10.40 a. m. Distinct heavy shocks, wave motion rather than trembling. In the heavy shocks the vibrations per unit of time seemed to be of less number than during the lighter shocks. After this shock placed a plumb-line bob in tent and hung watch on pole so that it could be quickly read. Bob was of brass, 4 inches in length by 1 inch in greatest diameter, suspended by a silk fish line 2 meters in length.

"11.00 a. m. Strong shock, plumb bob moving through arc of 6 to 8 inches from southeast to northwest. Shocks very strong, slow, and distinct. Flag pole (8-inch spruce, 40 feet long) vibrating; estimated to move through arc of 2 to 8 feet by various members of party. Slight shocks practically continuous, in waves of varying intensity."

Chugach Mountains.—In the Chugach Mountains, 240 miles from Yakutat Bay, on September 10, 1899, Lieut. Babcock wrote in his diary as follows: "This morning at 7.08 o'clock there was a slight earthquake shock lasting eight or ten seconds. * * * During the morning there were six slight earthquake shocks, including the above mentioned."

Valdez.—L. S. Camicia [5] reports a light shock at Valdez at 7 a. m.

Upper Alsek River.—At Dalton House, Yukon Territory, 90 miles east of Yakutat, Sergt. A. E. Acland, of the Royal Northwest Mounted Police, observed the first shock on September 10 at 7 a. m.

More distant points.—The early shock of September 10 does not seem to have been of sufficient intensity to be recorded in many other places; at least, we have seen only a few records of observations. In the diary of the Tantalus

[1] Seattle Daily Times, Sept. 28, 1899.
[2] Sitka Alaskan, Oct. 14, 1899.
[3] San Francisco Examiner, dispatch dated Seattle, Sept. 21, 1899; date of clipping not known.
[4] Sitka Alaskan, Sept. 16, 1899; reply to earthquake circular, 1907; conversations with the authors.
[5] Reply to earthquake circular, 1908.

detachment of the Royal Northwest Mounted Police (Carmacks), which was on the upper Yukon, 190 miles northeast of Yakutat Bay, the first shock on this date is recorded as occurring at 8.15 a. m., two other earthquakes being recorded the same forenoon at 11.45 and 11.55. At Skagway, 160 miles east of Yakutat Bay, there were five or six shocks in the forenoon before the heavy shock. At Juneau, 220 miles southeast of Yakutat Bay, and at several other places, this early shock and those preceding the heaviest one, next to be described, were also felt. No doubt there were other instances of which we have no record.

THE HEAVIEST SHOCK.

POINTS OF OBSERVATION.

The heaviest shock of the day, and evidently the most violent in the whole series of earthquakes, occurred at 12.22 p. m.,[1] local solar time at Disenchantment Bay, or $21^h\ 40^m\ 13\frac{1}{3}^s$. Greenwich mean time. It was everywhere reported as the greatest disturbance of the series—in Disenchantment Bay, at Yakutat, near the Copper River delta, in the Chugach Mountains, at Valdez, near Skagway, at Juneau, etc.

This shock was observed, so far as is known, at the places named in the subjoined list. Details concerning most of these observations are given in the paragraphs following. For the location of the places mentioned see Plate II (p. 14) or Plate XXXIII (in pocket).

Points of observation of the heaviest shock of September 10.

Place.	Location with respect to Yakutat Bay.	Observer.
Disenchantment Bay	In Yakutat Bay	J. Bullman, L. A. Cox, S. Cox, A. Flenner, J. P. Fults, jr., A. Johnson, T. Smith, D. Stevens.
Yakutat village	Mouth of Yakutat Bay	C. E. Hill, R. W. Beasley, Mrs. Esther Early, Albin Johnson, and others.
Dry Bay	75 miles east	Charles Johnson.
Controller Bay	170 miles west	T. G. White.
Copper River delta	220 miles west-northwest	H. P. Ritter, E. B. Latham, and others.
Chugach Mountains	240 miles northwest	W. C. Babcock.
Do	250 miles northwest	J. D. Jefferson.
Valdez	250 miles west-northwest	L. S. Camicia, Philip Glesener, and others.
Upper Alsek River	90 miles east	A. E. Acland.
Do	115 miles east	Prospectors.
Glacier Bay	150 miles southeast	August Buschmann.
Dundas Bay	160 miles southeast	M. G. Munly.
Tagish	180 miles east	Telegraph operator.
White Horse	170 miles northeast	G. S. Fleming.
Hootalinqua	200 miles east	D. Hunt.
Nordenskiold River	180 miles northeast	J. J. McArthur.
Upper Yukon River	190 miles northeast	Northwest Mounted Police.
Five Fingers	200 miles northeast	Telegraph operator.
Stewart River	240 miles north	Lars Gunderson.
Fortymile district	290 miles north-northwest	F. Dennison.
Eagle	340 miles north-northwest	W. G. Myers.
Birch Creek district	430 miles northwest	J. E. Kinnaley.
Cook Inlet	410 miles west-northwest	E. F. Glenn.
Homer	430 miles west	George Jammé.
Skagway	160 miles east-southeast	C. L. Andrews, B. F. Shelton, and others.
Juneau	220 miles southeast	H. H. Folsom and others.
Berners Bay district	180 miles southeast	H. W. Mellen.
Atlin Lake	215 miles east	J. C. Gwillim.
Atlin district	230 miles east	J. H. Pottinger and others.
Surprise Lake	240 miles east	John Bimms.
Teslin Lake	275 miles east	George Boulter.
Sumdum	275 miles southeast	R. V. Rowe.
Sitka	260 miles southeast	P. T. Rowe, Andrew Malakoff, and others.
Klondike trail	Observations besides those listed were made at Pyramid Harbor, White Pass, Bennett, Caribou Crossing, White River, Fort Selkirk, and other places.	
Pacific Ocean	At numerous points west of Yakutat Bay storms are reported during these earthquakes, but there is no reason for correlating them with the earthquakes.	Five different vessels.
Lake Chelan, Wash	1,200 miles southeast of Yakutat Bay. Water waves perhaps due to this earthquake.	Residents of Chelan.

[1] People who live in places out of touch with the world and to whom there is little point in keeping precise time are very likely to pay scant attention to the accuracy of their timepieces and have few facilities for regulating them. The time of this shock has been variously stated. In our earlier papers (Bull. Geol. Soc. America, vol. 17, 1905, p. 31; Geog. Jour., July, 1906, p. 38) we have given the time as 3 p. m., based on a single statement by a local observer. It has also been stated by men on the ground as 12.15, 12.30, 1.20, 1.30, 1.50, 2 o'clock, etc., from timepieces varying in relation to solar time. The present figure is computed from the Coast Survey observations near the Copper River delta and the distant seismograph records, which agree within 43 seconds and may be accepted as correct.

DETAILS OF OBSERVATIONS.

Disenchantment Bay.—This major shock at noon September 10 is said to have been severe enough in Disenchantment Bay to throw a man violently across a tent, and the ground is said to have "swayed and undulated so that men could not stand." Unfortunately the men closest to the center of the shock were in such peril of their lives that they naturally noted little about the nature, duration, and severity of the shocks. The facts they have given us concern an unsteady earth, the formation of cracks in the ground, the water waves, the bursting of a glacial lake, the breaking of the ice front of Hubbard Glacier, the avalanches, and similar effects of the earthquakes. (See the story of the prospectors, pp. 15–17.)

Yakutat.—The heaviest shock as felt at the village of Yakutat, 30 miles from Disenchantment Bay, is described by C. E. Hill [1] as follows:

"September 10, at 12.30 p. m.—Shock was the most severe of the three.[2] * * * People trying to descend the outside stairs were unable to do so and were compelled to hold to the railing to keep from being thrown off. The schooner *Crystal*, which was lying on the mud, rocked from side to side.

"This was the shake that did all the damage. We were in our tent, and, to give you some idea of the violence of the quake, we could not get up and stand on our feet at first. The mission rocked until the church bell rang, and if anything was needed to complete the terror of the natives it was the ringing of the bell. Just as the earthquake ceased we saw a wonderful thing happen on the bay. From the ocean began rolling in great tidal waves. There were three of them following each other at intervals of about five minutes, and we stood and watched the bay rise 15 feet, from low tide to a foot above the highest tide point. The bay itself was full of whirlpools that were whirling trees, lumber, and driftwood around and around so fast that the eye could hardly follow them. They circled around like a flash while the water was churned into a mass of seething foam. The whirlpool caught the chute of a sawmill a short way below us and ripped it away in a twinkling.

"Just across from Yakutat in the bay is the island of Kanak [Khantaak]. On the shore of this island was situated an old Indian graveyard, up about 6 feet above the highest tide mark. It was out on a point and we suddenly noticed that the point, graveyard, and all had disappeared, sunk out of sight.[3] There was in the graveyard a very high pole with a cross on the top, and we soon discovered this way out from the water, some 4 or 5 feet of it sticking out of the water and still upright. [I would guess that 25 acres or more of the built-up sand on the inside of the point sunk to a depth of 20 feet or less.[4]] The next day we took a boat and rowed over to the island. Our boat was rowed right over the place where the graveyard had formerly been, and looking down into the water we could see the tops of [brush spruce] trees. In several places we made soundings and were unable to get bottom at all [with an oar].

"We then rowed down to the mouth of the harbor to a place called Ocean Cape. Here we found the shore plowed with great furrows about 4 feet apart. Originally they must have been 20 feet in depth [and 5 feet wide; not more than 10 acres affected], but the sandbanks had caved in on them and filled them up until they were only 4 or 5 feet deep when we saw them. A little farther along the shore we found the marks of a number of gigantic waterspouts [which left holes 4 or 5 feet deep]. They had bored great holes into the sand and had carried the sand and earth inland and scattered it 6 inches deep over acres of ground. From every indication the force of the waterspouts and waves must have been irresistible, and Yakutat must surely have been washed away had the tidal waves swept the bay at high instead of low tide.

"The earthquake was undoubtedly a magnificent sight, but hardly one a fellow would hunt up for the sake of looking at it. The Indians are frightened out of their wits and many of them have already left the place, 15 of them coming down with us to Juneau. Mr. Johnson, the missionary, wanted to come away on account of his wife, but the Indians begged him so hard to stay that he finally did so, but I do not think he will stay long."

Mr. Hill left Yakutat on the *Dora* on September 12, and he noted a great amount of drift timber and thick muddy water in the ocean between Yakutat Bay and Mount Fairweather.

R. W. Beasley [5] gives the time of the heavy shock on September 10 as 12.15 p. m. "sun time." This is more nearly correct than the hour given by Mr. Hill. The shock, he says, lasted about five seconds.

"From that time on it was shaking almost continuously until 11 p. m., when I fell asleep on my lounge. At 12.15 p. m. September 10 the shock was so severe that cracks were opened in the ground and craters were caused that threw out water and sand. The water in the bay was greatly agitated and from that time until dark it rose and fell 8 or 10 feet in 8 or 10 minutes. I had a tough wrestle with the scow to save her from being carried out of the lagoon. * * * At 12.15 p. m. some natives noticed a cloud of smoke to the northeast and we thought that an extinct volcano had broken out, but on subsequent investigation it proved to be a landslide up Roosevelt River. * * * After the shock at 12.15 p. m. the store looked as if a bull had been in it. The shelves were nearly clear of canned goods. Kettles, pails, and lanterns had been shaken off the nails overhead and were on the floor. * * * All the afternoon it appeared that there were waves in the ground. * * * I never heard any noise either before or after the shocks."

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1 Seattle Post-Intelligencer, Sept. 23, 1899; San Francisco Examiner, dispatch dated Seattle, Sept. 21, 1899; date of clipping not determined.

2 Mrs. Early's description (p. 70) agrees perfectly with this.

3 In 1905 part of the graveyard on Khantaak Island was still standing, so that it could not have completely disappeared, as Mr. Hill's description intimates. However, it is stated by many people at Yakutat, both natives and white residents, that a part of the graveyard was destroyed, and of this therefore there seems no doubt. In 1910 we found stumps of trees below high-tide level on the mud flat in front of the graveyard.

4 Phrases in brackets from Mr. Hill's reply to earthquake circular, 1907.

5 Sitka Alaskan, Sept. 16, 1899; reply to earthquake circular, 1907; and conversations with the writers.

Mr. Hill, Mr. Beasley, and Rev. Mr. Johnson all agree [1] that the shocks came from the east and moved westward.

Dry Bay.—At Dry Bay, the mouth of Alsek River, 75 miles southeast of Yakutat, the native village was severely shaken and some houses were damaged. Charles Johnson, who interviewed some of the Dry Bay natives for us and translated their statements, finds that the earthquake of Sunday, September 10, was much more severe than that of the preceding Sunday.

Controller Bay.—At Katalla, on Controller Bay, 170 miles west of Yakutat, T. G. White [2] reports, there were at least 75 shocks during the week from September 3 to 10. He says that on September 10 "the day was perfectly calm and the first thing I knew the trees began to wave. There was an oil spring which began to flow at First Creek close to the mouth of Katalla River. It continued to flow during the eight days of the shocks. You could not stand up, and there was a tidal wave went up Bering River 4 feet high. * * * Rock slides and the loudest noises followed the shock in about two minutes."

G. C. Martin[3] also states that "oil is reported to have been seen in large amount at the time of the earthquake, 1899, on the surface of the water of the small ponds and the creek at the south end of the town of Katalla."

Copper River delta.—At the Coast Survey camp, near the Copper River delta, 220 miles away, Mr. Ritter characterizes this heavy shock at noon ($11^h\ 58^m\ 33^s$ true local time) as "shaking violently all the time (three minutes). Direction part of the time one way, then in another. Top of 40-foot flagstaff vibrating from 1 to 4 feet. People in camp spread out their legs in standing." The other shocks later in the day were less severe, one coming at $12^h\ 7^m\ 8^s$, one at $5^h\ 36^m\ 8^s$, another at $5^h\ 44^m\ 2^s$, and the final one recorded at $5^h\ 51^m\ 41^s$, and a little stronger than the preceding ones. The earth is said to have been "practically vibrating all day."

Mr. Ritter notes that "the effect of the earthquakes on the topography in the immediate vicinity of camp was not very marked. Our work of sounding and running shore line during and after the disturbances gave me an opportunity to minutely examine the country for a radius of 10 to 15 miles from camp, and only here and there an overhanging tree or soft bank or a soft portion of an overhanging rocky bluff had tumbled down."

Mr. Latham's notes made at the time vary slightly as to the times of the shocks but furnish additional information concerning the phenomena of the earthquakes, as follows:

"September 10, 12 noon. Most violent shock noted. All hands outside tents. Impossible to stand with heels together; experimented by placing feet at various distances apart; found necessary to place heels 8 inches apart for stability. Shock peculiar in that displacement seemed rotary or in different directions. Plumb swinging in various directions. Noted time $12^h\ 01^m\ 30^s$ as shocks being very strong. Noted time of duration of heavy shock as three minutes. Slight shocks, with plumb slightly swinging all day."

Chugach Mountains.—In the Chugach Mountains, about 240 miles from Yakutat, the army officers who were building the military trail also experienced this heavy earthquake. Lieut. Babcock, who was still in the range east of Valdez, recorded in his diary on September 10 that the last shock "occurred at 10.45 a. m. and lasted one minute and three seconds and was the most severe. Shortly after the last we heard the peculiar reports mentioned after last Sunday's shock."

J. D. Jeffersón,[2] now assistant postmaster at Valdez, was in camp on Fall Creek, about 55 miles east of Valdez. He says: "Suddenly the tent began to pull and strain at the ropes, very much inflated like a balloon. * * * The trees and mountains both seemed swaying. An immense slide came down the mountain side. The creek seemed to stop running. A sickening feeling came over me."

Valdez.—During the heaviest shock L. S. Camicia,[4] at Valdez, was so dizzy he could not stand. The disturbance came at 1 p. m. There was no cracking of the ground, but chairs swayed and creaked, trees were rocked to and fro, and waves rolled as high as 7 feet on the shore.[5] Philip Glesener, a quartermaster sergeant of the United States Army, reports[4] that the shock lasted long enough for him to run outdoors, that trees and a flagpole waved violently, a large office safe moved, and people had difficulty in walking. A shock at 2 a.m. the next day awoke him from sleep.

Glacier Bay.—During the shocks August Buschmann [2] was in Glacier Bay, about 12 miles from Muir Glacier and 150 miles southeast of Yakutat, at the Bartlett Bay salting station, of which he was superintendent. He states that he felt two shocks, whose exact time he did not note. "The first shock lasted about 10 seconds and the second about 5 seconds. * * * These shocks were strong enough to cause a trunk standing on the floor, on small casters, to move several inches. They also caused a few empty barrels to fall from beams overhead in fish house. Muir Glacier was shaken up considerably and the flow of drift ice from that time on was increased manyfold, as it made navigation with our small steamers quite difficult at times. An old employee almost fell, walking up the beach. * * * My employees and myself were of the opinion that the shock came from the westward."

Dundas Bay.—At the Dundas Bay cannery, at the western entrance of Glacier Bay, 160 miles southeast of Yakutat, the superintendent, Judge M. G. Munly, reports [6] very severe shocks, which overturned apparatus in the salmon cannery. He corroborates the evidence of Mr. Buschmann as to the sudden increase in icebergs. There were relatively few icebergs up to the time of the earthquake of September 10, but immediately afterwards the adjacent waters became clogged with floating ice, making it impossible for the cannery boats, which bring in the salmon from adjacent streams,

[1] Replies to earthquake circulars, 1907.
[2] Reply to earthquake circular, 1907.
[3] Geology and mineral resources of the Controller Bay region, Alaska: Bull. U. S. Geol. Survey No. 335, 1908, p. 117.
[4] Reply to earthquake circular, 1908.
[5] Seattle Daily Times, Sept. 21 and 29, reprinted in Weekly Times, Sept. 27 and Oct. 4, 1899. Also a San Francisco paper, exact date of clipping unknown.
[6] Personal interview with the authors in August, 1911.

to make their regular trips. These reliable observations regarding icebergs show that the great retreat of Muir Glacier was initiated by the earthquake shocks, whether the subsequent continuation of retreat was a climatological coincidence or not.

Upper Alsek River.—From Dalton House, Yukon Territory, east of Alsek River (60° 6½′ north latitude, 137° 4′ west longitude), about 90 miles somewhat north of east of Yakutat Bay, Sergt. A. E. Acland,[1] of the Royal Northwest Mounted Police, reports:

"On Sunday, September 10, 1899, shocks occurred all day, about 15 or 20, the first at about 7 a. m.; then at intervals till night. The majority of the shocks lasted 5 to 40 seconds, one shock at noon lasting fully a minute. A log cabin was so shaken as to be unsafe. The vibration could be distinctly seen in the trees and flagpole, as when a whipstock is shaken. Waves appeared to run up trees from the ground, three or four bends being seen in a tree at the same time. Water spilled from wash dishes and pails. Kitchen utensils were started swinging on their nails. Plates and cups were shaken off shelves. Horses grazing 2 miles away came home at a gallop, frightened and snorting.

"I had to brace my knees in standing up and expected to see the ground crack. The motion in all the shocks was a gentle shaking at first, growing gradually more severe and then dying away. It appeared to come from west to east, judging by the way the water spilled out of the wash dish. It spilled out on the east and west sides. Another man there at the time was of the same opinion. There were heavy noises from the southwest, resembling far-away explosions, or rumbling of thunder, but these did not appear to be directly connected with shocks." (These noises may have been caused by avalanches.)

At Glacier camp, on the Dalton trail, about 40 miles south of Dalton House (and therefore only 115 miles east of Yakutat Bay), where two men were building a cabin, one of them was shaken off the log he was adjusting on the wall.

White Horse.—At White Horse, Yukon Territory (60° 45′ north latitude, 135° west longitude), about 170 miles northeast of Yakutat Bay, G. S. Fleming,[1] the Government telegrapher, reports the severe September 10 earthquake came at 1.30 p. m. and lasted from 45 to 60 seconds. There was but one building (log) in 1899 at White Horse, which was then in the wilderness, and this building was not damaged, nor was there visible change in the earth's surface. Several waves were noticed crossing Yukon River. Windows and dishes rattled. A 3-gallon pail of water setting on the floor of the log building had 2 to 3 quarts splashed out by undulating motion. He ran out of the house, alarmed. Much dust rose from cut banks along the river. The wave motion was gradual and there was no difficulty in walking.

A few minutes after the shock was felt at White Horse, the telegrapher at Five Fingers (62° 15′ north latitude, 136° 20′ west longitude), wired that the shock was felt there. It was also felt at Tagish, 50 miles southeast of White Horse.

Mr. Fleming also noticed slight movements of the earth on two other occasions later in September, several days apart, one about 8 a. m., the other about 9 p. m., but unfortunately the exact dates were not noted.

Hootalinqua River.—Sixty miles above the mouth of the Hootalinqua or Teslin River, one of the headwaters of the Yukon, and 200 miles northeast of Yakutat Bay, D. Hunt[2] heard distinct rumblings coming from the west. This was on a Sunday (date not recorded).

Nordenskiold River.—On the Yukon near the mouth of Nordenskiold River, J. J. McArthur, who was in charge of the telegraph line then under construction, noted these earthquakes early in September, 1899. From the time of day of the observations (about noon) and from other observations near by, it is evident that the heavy shock of September 10 was the one felt. Mr. McArthur says:

"I was engaged opening a winter mail route along the Yukon River, in the neighborhood of the mouth of the Nordenskiold River. I was traveling horseback and did not notice anything unusual at the time, but heard an irregular succession of loud detonations like the booming of cannon, which I assumed were caused by prospectors blasting in the hills far to the southwest.

"When coming over this trail a few days previous, several windfalls obstructed the way, and when starting a pack train out on this particular morning, I sent a couple of axmen along with instructions to cut them out. Following them up later in the day, I was surprised to find several large trees still across the trail. On overtaking the packers at night I took the axmen to task for not having carried out my orders. They insisted that they had done so, and were corroborated by the packers. I was greatly puzzled, as there had been no wind during the day.

"A couple of days later I visited another of our parties working in the neighborhood of the Five Fingers rapids. The first remark of the foreman was: 'Where were you during the earthquake?' He related that they were having lunch along the new telegraph line and were attracted by the violent swaying of the wire and the heaving of the trees. Several of the men were seized with vertigo and the distant booming noise caused great consternation among them.

"I later made an examination of the trees that had fallen across the trail. The soil is not more than 7 inches deep and rests on a thick stratum of volcanic ash, into which the roots do not penetrate. The trees were of good size, up to 12 inches diameter, and the swaying motion had broken the soil around the extremities of the roots, and the upturned section exposed the volcanic ash underneath."

Upper Yukon River.—The diary kept at the headquarters of the Tantalus detachment of the Royal Northwest Mounted Police (Carmacks) (62° 6′ north latitude, 136° 15′ west longitude), on the Yukon, 190 miles northeast of Yakutat Bay, says: "September 10, 1899, five distinct shocks of earthquake, one rather severe, at 8.15, 11.45 11.55 a. m., and 12.30 and 12.45 p. m."

[1] Reply to earthquake circular, 1907.

[2] Reported through Prof. W. H. Hobbs, 1909.

At the confluence of Yukon and Stewart rivers, south of Dawson and about 240 miles north of Yakutat Bay, according to Judge Lars Gunderson,[1] a United States commissioner, very light shocks were felt during the first ten days in September, 1899. Persons in the houses noticed clothes swinging gently from lines inside. There was a slight sensation of dizziness so that people thought themselves sick.

Fortymile district.—F. Dennison[2] reports that on an unrecorded date in September, 1899 (presumably September 10, because of the time of day), at "about noon, sun time," there was "a shaking of the ground," felt by a number of prospectors in and near Wade Creek. This is approximately 290 miles north northwest from Yakutat Bay.

Eagle.—At Eagle, about 340 miles north-northwest of Yakutat, Judge W. G. Myers,[1] United States Weather Bureau observer and United States commissioner, felt the September 10 shock at 12.15 p. m.: "One hundred and forty-first meridian time. Time believed to be accurate, being observations of sun every few days. The shock lasted three or four seconds, jarred suspended mercurial barometers against rings at bottom, caused poles to vibrate and lamps to swing, rattling tin plates on shelves."

Birch Creek district.—In the Birch Creek gold district, south of Fort Yukon, about 430 miles northwest of Yakutat Bay, J. E. Kinnaley[1] felt an earthquake September 11 (probably September 10), which lasted long enough for one to run about 20 feet. It caused a landslide on Birch Creek at Pitkas Bar. On Independence Creek, about 20 miles distant, the water was thrown out of a sluice box. During the shock, which all the persons observing it agreed came from the southeast, "it felt as if the cabin was moving and sinking at the same time."

Cook Inlet.—About 5 miles north of Tyonek, at Ladds station, on the west side of Cook Inlet, about 410 miles a little north of west from Yakutat Bay, Lieut. E. F. Glenn,[3] of the United States Army, felt this earthquake about noon. He states that he noticed it while eating. "It lasted long enough to walk outside of a frame building, and perceptibly thereafter, and was very severe. I do not know how to measure this. * * * The frame building in which I was dining rocked back and forth perceptibly, even after we had staggered or reeled outside. Everything and every person or animal staggered or reeled."

Homer.—At Homer, on the end of a long sand spit in Kachemak Bay at the south entrance to Cook Inlet, 430 miles west of Yakutat, the great earthquake of September 10 was observed by George Jammé.[4] He was doing drafting work in his office and after the shocks of the preceding Sunday he arranged his surveyor's plumb bob so it would swing freely. At noon on September 10 the plumb bob swung in an ellipse with axes 9 and 17 inches long, the longer one extending northwest-southeast. This gives some suggestion of the magnitude of the earth waves at this point and shows clearly the direction in which they moved.

Skagway.—At Skagway, 160 miles east-southeast of Yakutat, B. F. Shelton[1] noted six or seven shocks between 4 a. m. and 3 p. m. on September 10, that at 11.40 alarming the people in church, "the vibrations increasing until everyone felt the motions distinctly in their seats." At 12.40 shocks became so violent that Mr. Shelton "clung to the side of a bunk for support." There were "literal earth waves, both motion and feeling being exactly as if on board a vessel." He became "as sick as a dog through the unnatural sensation. The women and children suffered most, having a strange, pallid, and half-frightened look. The term 'earthquake face' was given to those possessing it."

Severe shocks were noted during the whole forenoon, resulting in many cracked chimneys and gaping walls. Only two buildings are said to have escaped injury. Electric lights were set swinging almost to the ceiling, clocks were stopped, and crockery was knocked from the shelves.

C. L. Andrews,[2] deputy collector of customs at Skagway in 1899, who later visited Muir Glacier and described the changes in that glacier from 1899 to 1903, states that the shock lasted "long enough for me to take my two children by the hand, run out of office, down hall 25 feet, downstairs one story, and out into street." He states that it was "so hard it threw me against doorway as I went out, and against wall of stairway, making glass in windows vibrate till it looked as if it would break. Lamps swung violently; pictures against wall rebounded. Many persons were nauseated."

Juneau.—Three hard shocks were felt at Juneau, 220 miles southeast of Yakutat, on September 10, shaking buildings severely but doing no serious damage. Judge H. H. Folsom,[1] United States commissioner at Juneau, says: "One shock occurred at or about 12.55 p. m. and one at about 4 o'clock same day. Was in barber's chair, had time to get to the sidewalk—20 feet—and watch electric-light poles sway. This was at 1 p. m. and was very severe. Taku Inlet, Stephens Passage, and Gastineau Channel were filled with icebergs for some time after the shock. Ice came from Taku Glacier."

During this shock at Juneau the hotels, hospital, churches, and all dwellings were severely shaken, but no serious damage was done. People hastened into the streets and miners in the Treadwell gold mine at Douglas, across the fiord from Juneau, hurried from the underground workings when they felt the tremors.

Berners Bay district.—In the Berners Bay district, on Lynn Canal, 45 miles north of Juneau and about 180 miles southeast of Yakutat Bay, H. W. Mellen,[2] a mining engineer, observed the earthquake at the Jualin mine. He reports that there were two shocks 15 minutes apart, about half past 12.

"At first shock I was at office door just leaving dinner table. I went in office, cared for lamps, and out along walk 50 feet. At second shock I ran in tunnel to shaft, about 75 feet, called to miners, and came out before end. It was strong enough to make one walk crooked.

"The first shock was a little more severe than the second, but not much. There was no damage to buildings. Books such as a ledger 24 inches square slid off solid table. Raincoat hanging on wall swung about a foot. Nearly

[1] Reply to earthquake circular, 1907.
[2] Reply to earthquake circular, 1908.
[3] Reply to earthquake circular, 1909.
[4] Personal communication, 1909, based on diary kept in 1899.

all dishes were broken. We heard many bowlders rolling down mountains. It was impossible to walk except as upon ship's deck when vessel is in swell. Large man was slid off chair. Distinct feeling of waves in ground, hard shaking at first, and then undulations and rumbling noise like distant thunder during latter part of shocks, and others of bowlders rolling in the gulches.

"It seemed to come from the northwest. If walking northwest one staggered forward and if walking northeast one staggered sidewise. All books and dishes slid off to the southeast."

Atlin.—At Atlin and Discovery City, British Columbia, about 215 miles east of Yakutat Bay, severe earthquakes were felt on September 10[1] At Atlin J. H. Pottinger[2] felt two distinct shocks, one in the afternoon and one in the evening. The former was distinct and displaced implements from the shelves in a hardware store. Fifteen miles farther east, in the Atlin mining district, the shocks were felt by prospectors.

The hardest shock of September 10 was also clearly felt by Prof. J. C. Gwillim, of the school of mining at Kingston, Ontario, who was at that time a geologist of the Geological Survey of Canada. He says:[3].

"An earthquake movement was felt at 12.45 sun time on Atlin Lake on September 10. This was an undulating motion lasting about 30 seconds. It was felt as far north as White Horse, and probably farther, and was most severe on the coast, where it shook up the glaciers, causing much ice to appear along the steamboat route."

In a letter dated September 25, 1907, Prof. Gwillim adds:

"This observation was made at a point 12 miles south-southeast of Atlin town, on the eastern shore of Atlin Lake. A heavy wind from the east was bringing surf upon this shore line, hence the conditions were not good for a quick apprehension of the phenomenon. Besides, we were in the vicinity of some hot springs which, at first, I thought might have something to do with the movement.

"We were on ground made from the deposit of these springs. The shock was sufficient to spill water out of the little kettles we used for our lunch at that point. * * * The time taken was accurate, but I suspect seismic shocks require still greater accuracy in the matter of time. I had taken a latitude observation on the sun at noon of that day.

"I have no other information more accurate or more startling or remarkable than this record of my own. Many people hardly knew whether it was an earthquake or not."

Prof. Gwillim also quotes N. E. Porter, a prospector, who told him of the trees swaying over his head on a perfectly still noon.

All in all, despite Prof. Gwillim's modest disclaimer, this is one of the best records that we have procured. It was made in a remote place, near the farthest known limit of the sensible shock in this direction, and the writer tells modestly and accurately just what he saw or felt and nothing more. Next to the Ritter records at the Coast and Geodetic Survey's Cape Whitshed camp, near the Copper River delta, this is doubtless our most accurate time record, for Prof. Gwillim had determined the noon and set his watch to correct solar time only 45 minutes before he recorded the earthquake shock.

Surprise Lake.—At Surprise Lake, east of Atlin, B. C., and 240 miles east of Yakutat, John Bimms[4] observed that the shock of September 10 was the heaviest which he observed in this series. Certain glaciers near by are said to have been broken at this time and he saw what he interpreted as smoke from a volcano, but what seems more likely to the authors to have been dust from avalanches.

Teslin Lake.—At the Hudson Bay post near Teslin Lake, east of Atlin and 275 miles east of Yakutat, the earthquake was felt by George Boulter[5] and two other men and was so severe that they rushed out of doors, expecting the building to fall.

Sumdum.—At Sumdum, south of Juneau and 275 miles southeast of Yakutat, R. V. Rowe,[6] on an unrecorded date in September, 1899, was "helping to build a hotel * * * and was fitting the window frame in the gable when the shock came." He "had to catch hold of the studding to keep from being thrown out." The house rocked east and west for about 10 seconds. On examining the building immediately afterwards it was found to have settled back exactly plumb.

Sitka and more distant points.—The shocks were very slight at Sitka, 260 miles southeast of Yakutat Bay, and over 100 miles farther from the center of disturbance than Skagway. Bishop P. T. Rowe,[6] of Sitka, says: "One very slight shock felt at Sitka, only by one or two persons, about 2.30 p. m. Was lying down and so felt it. Those going about did not notice it."

Andrew Malakoff,[6] now a school-teacher at Ellamar, says: "We were sitting in school at the time. All at once the teacher opened his eyes and asked us if we felt the earthquake. Several boys said they did, but I had not felt a thing."

C. C. Georgeson,[6] in charge of the Alaska agricultural experiment stations, says: "I was here in Sitka at the time, but was out of doors and did not feel the earthquake. It was felt slightly here, however, as I remember people spoke of it at the time."

The heavy earthquake of September 10 was also distinctly felt at a number of small places on the seacoast near Sitka, Juneau, and Skagway, and inland from Skagway along the Yukon trail to the Klondike.

[1] Victoria Semi-Weekly Colonist, Oct. 2, 1899.
[2] Reported through Prof. W. H. Hobbs, 1909.
[3] Twelfth Ann. Rept. Geol. Survey Canada, Summary Rept. for 1899, p. 62A.
[4] San Francisco Chronicle, Oct. 5, 1899.
[5] Reported to the authors by Archibald Ainslie, 1910.
[6] Reply to earthquake circular, 1907.

Lake Chelan, Washington.—It is stated in a dispatch[1] dated September 14, that on the previous Sunday (Sept. 10) waves suddenly rose upon the glassy surface of Lake Chelan, on the east side of the Cascade Mountains, in the State of Washington (about 120° west longitude, 47° 50′ north latitude). There was no wind. The waves were observed on at least four different parts of the coast, rising to 15 or 20 feet, driving a small boat on shore, and lasting nearly two hours. The first waves came "at about 2 o'clock" in the afternoon. The most severe earthquake on this date in Yakutat Bay came at 12.22 p. m. Allowing for the difference of time with longitude this would be about 1.40 on Lake Chelan. The time of transmission for this distance should be 10 to 20 minutes. This would make the time on Lake Chelan between 1.50 and 2 o'clock. At Victoria, B. C., the nearest seismograph station, this earthquake is said to have occurred at 1.45 p. m., also lasting nearly two hours.[2] As 1.45 at Victoria equals 1.59 at Chelan, it seems possible that the tremor was felt on the lake at almost exactly 2 o'clock.

The coincidences of date and hour suggest that these abnormal water waves were caused either by the tremors from this Yakutat Bay earthquake, in some way naturally amplified in the mountain structures of the Cascades, or by a secondary earthquake set off here. The distance is great—nearly 1,200 miles (see fig. 4)—though not so great as in the case of the water waves on Loch Lomond, in Scotland, and lakes and ponds in England that were disturbed during the Lisbon earthquake of 1755.

SUMMARY OF EARTHQUAKES OF SEPTEMBER 10.

There were two great earthquakes on September 10, 1899, and of these two the early shock was inferior to the great earthquake at noon, which was felt at more than 40 localities at distances ranging from 75 miles to 430 miles from their place of origin in Yakutat Bay. Water waves were probably caused at a distance of 1,200 miles. The phenomena observed include earth movement, faulting, water waves, floods, avalanches, fissures, spouting from sand craterlets, slight damage to buildings and to a cemetery, terror on the part of animals as well as human beings, difficulty in standing and in walking, and nausea. Because of the absence of water waves during the previous shock we assume that the observed faulting in Yakutat Bay took place during the great earthquake of September 10. Therefore, uplift of shore lines from 5 to 47⅓ feet, depression from a foot to 7 feet, and the uplift of new reefs and islets were among the physical accompaniments of this shock. Glaciers were broken, among them Muir Glacier, the shattering of which directly or indirectly started the rapid discharge of icebergs and the subsequent great retreat of this and other ice tongues in Glacier Bay. The avalanching during this group of seismic disturbances, and especially the great earthquake of September 10, resulted in the later advance of at least nine glaciers in Yakutat Bay (p. 57) and perhaps many others in more remote regions (p. 60), a phenomenon probably to continue after the publication of this report. There was wholesale destruction of plant and animal life, especially in the sea, but no loss of human life.

Light shocks occurred at Yakutat all through the night of September 10, and others followed until the end of the month.

AFTERSHOCKS OF EARTHQUAKES OF SEPTEMBER 10.

In Disenchantment Bay and at Yakutat many light aftershocks followed the great one at noon, continuing into the night. Four considerable aftershocks are reported at the Coast Survey camp on Copper River delta. There were several shocks in the upper Alsek Valley, at least one at Juneau, and doubtless many unrecorded shocks in other parts of Alaska.

EARTHQUAKES OF SEPTEMBER 11 TO SEPTEMBER 29.

On September 11 shocks were felt in the Coast Survey camp near the Copper River delta; and from the 12th to the 16th severe earthquakes were noticed there during heavy storms; but the times were not recorded because of the general uproar of weather and sea at the time.

R. W. Beasley[3] states that severe shocks were felt at Yakutat village on September 15 at 7.15 and 7.30 p. m., each lasting as long as it takes to run out doors, causing "lamps to swing and kettles to beat against each other."

[1] San Francisco Chronicle, Sept. 15, 1899. Salt Lake Semi-Weekly Tribune, Sept. 19, 1899. Partly verified through information obtained from C. E. Rusk, of Chelan, in 1909.

[2] Victoria Semi-Weekly Colonist, Sept. 21, 1899; interview with the Government observer, Napier Denison. Unfortunately this valuable seismogram was subsequently lost in the mails.

[3] Reply to earthquake circular, 1907.

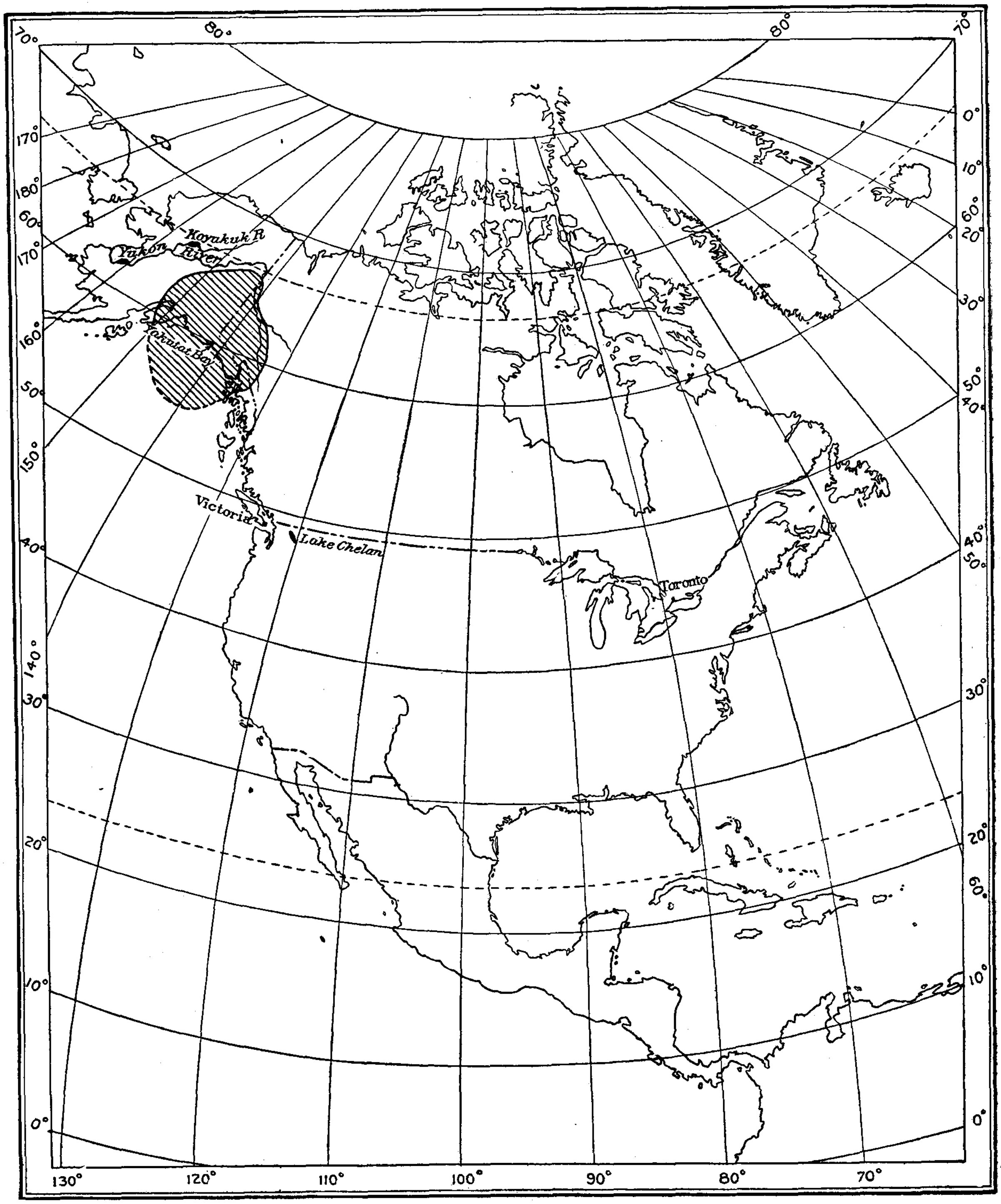

FIGURE 4.—Map showing relation of known area of sensible shocks, Sept. 3 and 10, 1899, to the isolated areas of water waves, etc., thus far known. Areas northwest of Yakutat Bay, on Koyukuk and Yukon rivers (Sept. 3), are 670 and 730 miles respectively from the point of origin. Lake Chelan, in Washington (Sept. 10), is nearly 1,200 miles from the point of origin.

At Skagway a shock was felt with considerable intensity on September 15 at about 8 p. m., causing electric lights to swing back and forth 18 inches. This shock is said to have been even more pronounced than those of September 3 and 10.[1] Rev. B. F. Shelton,[2] an Alaskan missionary, has written a vivid though reasonable account of this shock at Skagway.

On Friday night (Sept. 15), at 8.30 or 8.40 p. m., Mr. Shelton was, he says—

with many others in the Panice mission room holding services, when the rocking motion commenced violently again lasting, it seemed, for a great length of time. The old lamp over the platform in the center swung exactly as if on board a vessel. * * * The streets seemed deserted, the dens most empty, and a look of woe hung over the town. The report had got abroad that the Salvation Army and Panice mission were praying the Lord to "Shake up old Skag." * * * One of the long piers at Skagway sank into the water for a portion farthest out, but no very severe damage was done. * * * There is no doubt, however, that if Skagway had been a town of brick and stone buildings very much damage would have been done and possibly lives lost.

Several buildings in Skagway are said[3] to have been moved a foot or two on their foundations, and two small ones toppled over. Men walking had a sensation suggesting intoxication.

On September 17 there is said to have been a shock at Skagway, but it was not felt at Yakutat, Juneau, or the Coast Survey camp near the delta of Copper River. On that date, however, seismographs in many parts of the world recorded an earthquake and from the record in England John Milne[4] computed that it originated in Alaska.

In the Coast Survey camp eight shocks were noted on September 23 and four on September 26, one of each date being sufficiently strong to wake all those in the camp in the middle of the night. Mr. Latham records that on September 23, at 1.22 a. m., a plumb bob vibrated through 10 inches from northwest to southeast, the vibrations or waves being distinct and slow.

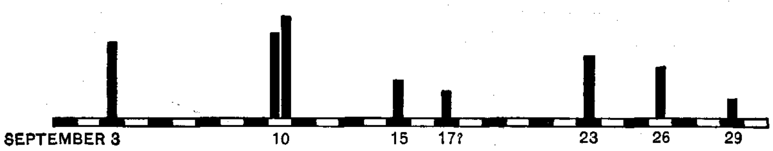

FIGURE 5.—Diagram showing the relative time intervals and the approximate relative intensities at Yakutat Bay of the earthquakes of September, 1899.

J. F. Williams[2] states that during one of these nights at Cordova, north of the Copper River delta, several men sleeping in a log cabin were awakened by the violence of the shock. Two of the shocks were felt at Valdez[5] on September 23, one at 7 a. m. and one at 10 a. m. The shock of September 26 is said to have been felt in Eagle,[2] 340 miles north-northwest of Yakutat, though not directly observed by the Weather Bureau man there. That of September 23 was possibly felt also at Sitka.

During the night of September 29 the last earthquake of the series was felt by the Coast Survey party, none others being recorded up to October 23, when the party left the Copper River delta.

From the seismograph records (see p. 122) it seems likely that the shocks of September 23 and 26 were world-shaking earthquakes, though probably not of the magnitude of the second shock of September 10.

SUMMARY OF EARTHQUAKES OF 1899.

During a period of 27 days, September 3 to 29, 1899, inclusive (fig. 5), the Yakutat Bay region was shaken by a series of earthquakes, the most violent of which were felt at all settlements within a radius of 250 miles, and at known scattered localities as much as 480 miles distant. (See Pl. XXXIII, in pocket.) At two points 670 and 730 miles distant earthquakes were recorded which may be correlated with those of the Yakutat Bay region, and water waves observed at a locality over 1,200 miles away (fig. 4) were perhaps due to the same cause.

[1] Victoria Semi-Weekly Colonist, Sept. 25, 1899. Seattle Weekly Times, Oct. 4, 1899.
[2] Reply to earthquake circular, 1907.
[3] Victoria Semi-Weekly Colonist, Sept. 25, 1899. Seattle Weekly Times, Oct. 4, 1899. Clipping dated Vancouver, Sept. 22, 1899.
[4] Nature, vol. 60, 1899, p. 545.
[5] Camicia, L. S., reply to earthquake circular, 1907.

The earthquakes were most severe on two dates, September 3 and 10, especially on the 10th, when there were more than 50 small shocks and 2 violent ones, the second of which was most severe of all and probably caused the greater part of the changes observed in and around Yakutat Bay. The shocks of September 15, perhaps of September 17, 23, 26, and 29, were also severe.

The greatest disturbance took place September 10, not September 12, as inferred by Dr. G. K. Gilbert[1] from an erroneous newspaper clipping, nor September 15, as stated by Comte F. de Montessus de Ballore.[2]

The writers have seen no description of a region being shaken longer, more vigorously, or more continuously, even in Italy, Japan, or Formosa, since the beginning of the seismographic recording of earthquakes. For four weeks the earthquakes were to be counted by the hundreds and on four or five days world-shaking disturbances took place.

The authors feel certain that the great earthquake at noon on September 10 was central in Yakutat Bay and think it fairly probable that the shock of September 3 may have originated 100 miles farther west, near Yakataga. The other shocks may or may not have been caused by earth movements in Yakutat Bay. The intensity at various places of observation suggests a complex of origins, the shock of September 17, for example, possibly being due to faulting nearer Skagway. Some of the minor shocks were probably purely local. A local shock close to Skagway might be very severe there, but might not be felt at a very great distance. The early shock on September 10, though locally sharp and of world-shaking caliber, seems to have been more restricted and was observed at fewer localities in Alaska than the great earthquake at noon on the same day. The volume affected by the earth movement must be great in order to shake a wide area, and on the morning of September 10 there was no great physical disturbance, in Yakutat Bay at least, while at noon a great areal extent of mountains was actually hoisted, the mountain west of Disenchantment Bay increasing in height nearly 50 feet.

During all these seismic disturbances there was no recorded loss of life and little damage to property—not because of the inefficiency of the earthquakes, but because of the sparseness of the population in the shaken area and the fact that the few buildings there were lightly and strongly built and were mainly at a distance from the center of greatest disturbance. Most of these buildings were low, one-story cabins built loosely of heavy logs or boards, difficult to tear apart.

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[1] Harriman Alaska Expedition, vol. 3, 1904, p. 23.

[2] La science séismologique, Paris, 1907, pp. 31 and 415.

CHAPTER VI.

EARTHQUAKES BEFORE AND SINCE SEPTEMBER, 1899

MISCELLANEOUS EARTHQUAKE OBSERVATIONS.

OLDER RECORDS.

The first tectonic earthquake in Alaska whose record we have seen is that stated by Grewingk[1] to have occurred in the Sannak and Shumagin islands, south of the Alaska Peninsula (see Pls. II, p. 14; XXXIII, in pocket), in 1788, when "there were no volcanic phenomena reported, but on the 27th of July a flood submerged the islands of Saunakh and Ounga and a portion of the peninsula (evidently a tidal wave owing to earthquake)." Dall[2] states that during this inundation many natives lost their lives and that hogs on Sannak Island were drowned.

Grewingk,[3] Perrey,[4] and Dall[5] have listed the earthquakes occurring in connection with volcanic eruptions in 1790, 1792, 1796, 1802, 1812, 1817, 1818, 1820, and 1826. In 1827 there was an earthquake on Copper Island in June, but it is not stated whether in association with a volcanic eruption or not. On April 2, 1836, and in August of the same year earthquakes, during which it was impossible to stand erect, were felt on the islands of St. Paul and St. George, in the Pribilof group.

Davidson[6] notes earthquakes recorded at Unalaska by Weniaminof as follows: Seven in 1825, five in 1826, two in 1830, four in 1831, seven in 1832, four in 1833, three in 1829 and 1834. These were doubtless all volcanic shocks.

In 1843 there were three earthquakes at Sitka. The first occurred on December 15 and is described by Perrey, from whose account the following is translated:

> On the 15th of December, at 1.20 a. m., there were two light shocks on Sitka Island, during which the unifilar and bifilar magnetometers oscillated in a vertical plane.
>
> There was a second shock 25 minutes later. The position of the vertical-force needle changed 55 parts during the first two shocks.

This is the first precise scientific observation of a tectonic earthquake in Alaska, instrumentally recorded, that has come to the attention of the authors.[7] Perrey states that on the following day, December 16, at 1.30 p. m., there was a feeble earthquake at New Archangel (Sitka). At 4 p. m. the same day there was a stronger shock, lasting three seconds. The houses were rent, and workmen saw trees apparently move back and forth during a calm. At the warm springs 28 versts from the town Baron Osten-Sacken observed these shocks but 35 minutes earlier.

In 1847 a general earthquake was felt on the Alaskan coast, being very severe at Sitka.[8] This is doubtless the shock referred to by the newspapers of 1899, which allude to the Yakutat Bay earthquakes as "the most severe since the time of the Russians."

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1 Grewingk, C., Treatise on the volcanic character of certain regions of the Russian possessions: Proc. Min. Soc. St. Petersburg, 1850; translated by Ivan Petrof in Report on seal and salmon fisheries and general resources of Alaska: S. Doc. 59, 45th Cong., 1st sess., p. 313; H. Doc. 92, 55th Cong. 1st sess., pt. 4, p. 313; Tenth Census, 1880, vol. 8, pp. 95–96.

2 Dall, W. H., Alaska and its resources, Boston, 1870, pp. 310, 467.

3 Op. cit., pp. 311–315.

4 Perrey, Alexis, Documents sur les tremblements de terre et les phénomènes volcaniques des îles Aleutiennes, de la péninsule d'Aljaska, et de la côte nord-ouest d'Amérique: Mém. Acad. Imp. de Dijon, deuxième serie, tome 13, 1865, pp. 158, 216–237.

5 Op. cit., pp. 466–470.

6 Davidson, George, Earthquakes at Unalaska: Bull. Seismol. Soc. America, vol. 1, 1911, p. 131.

7 Doubtless there are others. Perrey quotes this from Annuaire magnétique et météorologique du corps des ingénieurs des mines de Russie, année 1843, p. 553.

8 Dall, W. H., op. cit., p. 342.

On October 22, 1849, a severe earthquake, reported by Perrey,[1] occurred in the Commander Islands, lasting all night. Perrey also described the shocks (noted below) of 1853, 1857, 1859, 1861, and 1866.

On November 13, 1853, about 138 miles east of Ikogmut, on the lower Yukon, there was a shock at the village of Paimüt, moving from south to north. Earthquakes there are infrequent, the last having been felt 60 years before. The above note is from a meteorological register kept at Ikogmut by P. Netzvetor and quoted by M. Vesselofski, permanent secretary of the Academy of Sciences, St. Petersburg.

On September 8, 1857, at 11 a. m., two earthquakes, several seconds apart, were felt at St. Paul (now called Kodiak), on Kodiak Island. The second shock was rather severe though it did no damage.

On August 8, 1859, there was a light shock, lasting several seconds, on Bering Island.

Sitka was again shaken by an earthquake[2] on April 21, 1861, at 9.36 a. m.

On May 3, 1861, there was a light shock on St. George, Pribilof Islands, with a subterranean noise, observed by Baron Osten-Sacken.[3]

At some date shortly before October 22, 1866, there was an earthquake near Kodiak.

In 1867 an earthquake was felt at the Russian mission (Ikogmut) on the lower Yukon, where the shock of September 3, 1899, was also felt. W. H. Dall[4] was on the river at about 11 p. m. July 19, when it occurred, and reports that it felt as if the boat had struck a snag. This has also been reported by Frederick Whymper.[5] The shock was severe enough at the mission to throw books and other articles from the shelves.

Becker[6] states that in 1868 "during a slight earthquake the elevation is said to have amounted locally at Unga to over 20 feet."

Petrof[7] states that a violent earthquake was felt at Sitka in the autumn of 1880.

Earth tremors and a 30-foot water wave in Cook Inlet are said to have occurred on October 6, 1883, in connection with an eruption of the St. Augustine volcano there.[8]

Earthquakes of the local volcanic type have also accompanied the frequent eruptions of Bogoslof, just north of the Aleutian Islands, and of Mount Wrangell, in the Copper River valley.

Deckert[9] shows many of the earthquakes referred to above on his map of earthquakes in North America, and in addition lists three earthquakes in the Aleutian Islands in 1877, 1878, and 1879, all presumably volcanic shocks. A fourth was felt at Kodiak in 1889.

F. G. Plummer's list of earthquakes on the Pacific coast,[10] as reprinted by E. S. Holden,[11] contains nearly all the earthquakes thus far cited and a few others, most of them in connection with volcanic outbursts, as during the eruption of Pavlof in 1786, at Kaviak in 1854, at Black Peak, near Chignik, on August 28, 1892, at Unalaska September 23, 1892, and at St. Augustine in the summer of 1893.

Several of the Alaskan shocks referred to above are also recorded in the yearly lists of Pacific coast earthquakes from 1888 to 1898 by E. S. Holden,[12] T. F. Keeler,[13] and C. D. Perrine.[14]

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[1] Perrey, Alexis, op. cit., pp. 239, 243, 244, 246, 247, 251.
[2] Ann. météor. et magn. de Russie, 1861, p. 455.
[3] Compte-rendu de la Compagnie russe-américaine, 1861.
[4] Alaska and its resources, Boston, 1870, pp. 118, 470. The Yukon Territory, London, 1898, 118.
[5] Jour. Royal Geog. Soc., vol. 38, 1868, p. 234; Travel and adventure in the Territory of Alaska, New York, 1869, p. 266.
[6] Becker, G. F., Reconnaissance of the gold fields of southern Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 19.
[7] Petrof, Ivan, Alaska, its population, industries, and resources: Tenth Census, 1880, vol. 8, p. 91.
[8] Davidson, George, Science, vol. 3, 1884, pp. 186–189.
[9] Deckert, E., Zeitschr. Gesell. Erdkunde Berlin, 1902, Pl. 5, pp. 367–389.
[10] Reported earthquakes on the Pacific coast: Publ. Astron. Soc. Pacific, No. 8, 1896, p. 78.
[11] Catalogue of earthquakes on the Pacific coast, 1769 to 1897: Smithsonian Misc. Coll. No. 1087, vol. 37, 1898, pp. 1–253.
[12] Am. Jour. Sci., 3d ser., vol. 37, 1889, pp. 392–402; Bull. U. S. Geol. Survey No. 95, 1892.
[13] Bull. U. S. Geol. Survey No. 68, 1890.
[14] Bull. U. S. Geol. Survey Nos. 112, 114, 129, 147, 155, 161, 1893 to 1899.

F. de Montessus de Ballore,[1] out of 131,292 earthquakes and 10,499 epicenters catalogued down to the year 1897, assigns 86 earthquakes to 15 epicenters, or localities so considered, in the Aleutian Islands and 12 earthquakes to 7 epicenters in Alaska.

There have doubtless been many other earthquakes in Alaska, but no list or description of them is available. The Russian records of various sorts are a great unused storehouse of information of this kind. The records of the voluntary Weather Bureau observers of the United States Department of Agriculture doubtless also contain much information concerning other earthquake shocks in Alaska at various places and dates between the time of the American purchase of Alaska and the end of the century.

RECENT DATA.

In connection with the gathering of information concerning the seismic disturbances of 1899 at Yakutat, which are the subject of this report, a considerable amount of unpublished information has come into our hands concerning other earthquakes in Alaska. We have thought it best to briefly summarize this material, both because it enables us to place the Yakutat Bay shocks in their proper setting as a series of especially severe tectonic disturbances in an earthquake-shaken region, where there are both tectonic and volcanic earthquakes, and because we feel that this information, fragmentary and incomplete as it is, should be placed on record for the use of those interested in seismology. In 1901 a magnetograph and on April 29, 1904, a Bosch-Omori seismograph were installed by the United States Coast and Geodetic Survey at Sitka, so that future earthquake records from Alaska will be fairly complete.

EARTHQUAKE OF 1896.

A severe earthquake in the St. Elias and Prince William Sound region, late May, 1896, is reported by John Shepard, of Orca.[2] It was felt by him about 8 miles north of Orca, or approximately 215 miles west of Yakutat Bay. Mr. Shepard characterizes it as "the most severe I ever felt in Alaska. It caused trees to vibrate and bend almost to the breaking point, distinct waves in the ground, and water in the creek to swash from one bank to the other, lasting about 25 seconds. I had to catch hold of a stump to keep on my feet." All the men unloading a ship at Orca ran in terror from the hold. Earthquakes are felt at Orca nearly every year, most of them light.

FREQUENCY OF EARTHQUAKES AT VALDEZ.

L. S. Camicia,[3] an optician and watch repairer at Valdez, has kept a list of earthquakes felt by him at Valdez since 1899, as follows:

July 30, 1900, 1 p. m., one shock.
October, 1900, 3 a. m., two shocks.
September, 1901, 2.50, one shock.
June 2, 1903, 3.45, one strong shock, direction northeast to southwest.
July 13, 1903, 11.40 a. m., one shock.
February 6, 1905, 7.20 a. m., one shock.
November 22, 1905, midnight, one shock.
May 25, 1906, 5 a. m., one shock.
October 25, 1906, 2.10 a. m., one shock.
February 14, 1908, 1.30 a. m., one strong shock; 1.35 a. m., one light shock.
May 4, 1908, 7 a. m., one shock.
May 14, 1908, 11 p. m., one shock.

[1] Introduction à un essai de description sismique du globe et mesure de la sismicité: Beitr. Geophysik, vol. 4, 1900, p. 363.
[2] Reply to earthquake circular, 1907.
[3] Reply to earthquake circular, 1908.

FREQUENCY OF EARTHQUAKES AT KODIAK.

L. L. Bowers, deputy United States marshal at Kodiak, has kept a complete list of the earthquakes felt at Kodiak in the fall of 1900 and the first half of 1901. His list is as follows:

October 11, 1900, west wind, clear.
October 12, light quake, 5.15 a. m.
October 14, light quake, 2.30 and 5.15 a. m.
October 15, light quake, 8 and 8.15 a. m.
October 22, quake during the evening; no time.
October 23, quake, 3 a. m.
October 24, slight shocks during the day.
October 26, slight during the day and night.
December 27, short heavy quake, 12.05 a. m.
January 17, 1901, two quakes, 8.30 a. m.
April 4, light quake, 6.30 a. m.
May 30, two light quakes, 7.15 p. m.
July 23, light quake, 4.25 p. m.

FREQUENCY OF EARTHQUAKES AT UNGA.

The following is a list of earthquakes felt in 1899 at Coal Harbor, Unga, Shumagin Islands, Alaska, latitude 55° 24′ 2″, longitude 160° 49′ 24″, as recorded by H. S. Tibbey, voluntary Weather Bureau observer:

March 18, lasting four seconds; motion west-east.
April 1, 4.45 p. m.; felt at Coal Harbor, Unga, and Sand Point; west-east; threw light articles off shelves.
June 8, 10 a. m.; north-south; light.
July 14, 2.55 a. m.; two shocks; north-south; six seconds; rumbling noise preceding.
September 22, 9.30 p. m.; severe; north-south; felt at Unga and Sand Point.

It may be noted that none of the severe Yakutat Bay shocks of 1899 were felt here.

FREQUENCY OF EARTHQUAKES AT YAKUTAT.

Seismic disturbances have been felt in the coast region of Alaska since 1899. Rev. Albin Johnson[1] has reported "smaller shocks now and then during the whole winter" following the earthquakes of September, 1899, and Mrs. Early[2] records that for a whole year there were small shocks now and then.

R. W. Beasley[3] lists these shocks as follows:

December 14, 1899, 12 m., short but hard shake.
December 20, 1 a. m., long shake that made us get out of bed.
December 20, 6 a. m., short shake that made us get out of bed.
December 20, 7.45 p. m., heavy shake.
December 28, 11 p. m., light shake.
January 12, 1900, 7.45 a. m., light shake.
January 27, 6.45 p. m., light shake.
February 16, 12.40 p. m., heavy shake.
August 7, 4.15 p. m., light shake.
August 8, 5.25 p. m., light shake.
August 9, 7.40 p. m., light shake.
August 9, 11 p. m., light shake.
October 9, 3 a. m., two shakes.
December 17, 5 a. m., shake.
December 31, 1.40 a. m., shake.
January 19, 1901, 7 a. m., shake.
January 24, 5 a. m., shake.
September 28, 12.30 p. m., shake.
March 10, 1903, 6 a. m., shake.
September 10, 5 a. m., shake.

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[1] Rept. Comm. Education for 1898-99, vol. 2, 1900, p. 1402.
[2] Reply to earthquake circular, 1909.
[3] Reply to earthquake circular, 1907.

Mr. Beasley states that "most of these shakes were severe enough to make a person get out of bed, if during the night. We often have a shake during the winter, but I got so used to them that I stopped taking account of them."

While we did not ourselves observe any earthquakes in the Yakutat Bay region in 1905, Mr. Flenner told us at Yakutat on August 31 of that year that there had been several slight shocks during the summer, and one even the day before. One or two slight tremors were felt by the senior author in the summer of 1906 near the shores of the bay, and one was felt by both of us in Russell Fiord on July 16, 1909.

MISCELLANEOUS EARTHQUAKES.

Many earthquakes of varying intensity before and since 1899 have been reported as follows from various parts of Alaska. For the location of the places mentioned, see Plates II (p. 14) and XXXIII (in pocket):

Miscellaneous earthquakes in Alaska.

Date.	Place.	Observer.	Remarks.
1893.			
March	Yakutat	T. G. White	
1894.			
Nov. 3	do	R. W. Beasley	3 light shocks.
1896.			
May	Orca	John Shepard	Very severe; earthwaves.
1897.			
Jan. 11	Yakutat	R. W. Beasley	Severe, shaking the house.
Winter	Wood Island	C. P. Coe	7 p. m.
May 6	Selkirk	H. H. Pitts	Buildings vibrated and gravel slid in river banks.
1898.			
About Aug. 1	Tyonek	Prospector	Slight.
August	Susitna Station	F. R. Falconer	Trees swayed violently on calm, windless day.
Aug. 24	Valdez	Charles Brown	Heavy earthquake at 10 p. m.
Oct. 15	Katmai	J. E. Spurr	Near hot springs.
October	do	Oscar Rohn	
October or November	Skagway	F. E. Fuller	7.30 a. m., slight.
	Juneau	S. S. Sharick	Northeast, 15 seconds; 15 minutes later, 8 to 10 seconds.
1899.			
Mar. 18	Unga	H. S. Tibbey	4 seconds, motion west to east.
Apr. 1	do	do	4.45 p. m., east to west; threw light articles off shelves.
June 8	do	do	10 a. m., north to south, light.
July 14	do	do	2.55 a. m., 2 shocks, north to south, 6 seconds, rumbling noise preceding.
July 11	Tyonek	Prospector	Severe.
July 14	Unalaska	W. A. Sawtelle	2.15 a. m.
Sept. 22	Unga	H. S. Tibbey	9.30 p. m., severe, north to south.
Oct. 21–22	Alaska Range	J. S. Herron	Shocks, with low, rumbling noises.
	Tanana	C. K. Corbusier	Bottles rattled on shelf; same at Fort Gibbon.
Nov. 1	Fort Gibbon	R. McCoy	11.05 p. m.
1900.			
July 30	Valdez	L. S. Camicia	1 p. m.
Aug. 7	Yakutat	R. W. Beasley	4.15 p. m., light.
Aug. 8	do	do	5.25 p. m., light.
Aug. 9	do	do	7.40 p. m., light.
Do	do	do	11 p. m., light.
August	Cross Sound, 80 miles west of Juneau	August Groot	Light shocks.
Oct. 7	Tyonek	Prospector	Severe shock.
October	Katalla	T. G. White	
Oct. 11	Kodiak	L. L. Bowers	
Oct. 12	do	do	5.15 a. m.
Oct. 13–14	do	H. P. Cope	
Oct. 14	Wood Island	C. P. Coe	
Do	Kodiak	L. L. Bowers	2.30 and 5.15 a. m.
Oct. 15	do	do	8 and 8.15 a. m.
Oct. 22	do	do	During evening.
Oct. 23	do	do	3 a. m.
Oct. 24	do	do	Slight shocks during day.
Oct. 26	do	do	Slight during day and night.
Dec. 17	Yakutat	R. W. Beasley	5 a. m.
Dec. 27	Kodiak	L. L. Bowers	12.05 a. m., short and heavy.
Dec. 31	Yakutat	R. W. Beasley	1.40 a. m.
Fall, 1900, or spring, 1901.	Prince of Wales Island	H. W. Mellen	Frequent rumbling noises and light tremblings.

Miscellaneous earthquakes in Alaska—Continued.

Date.	Place.	Observer.	Remarks.
1901.			
Jan. 1	Kodiak	L. L. Bowers	8.30 a. m.
Jan. 19	Yakutat	R. W. Beasley	7 a. m.
Jan. 24	do	do	5 a. m.
March	Fort Gibbon	R. McCoy	Hard earthquake.
Apr. 4	Kodiak	L. L. Bowers	6.30 a. m.
May 30	do	do	7.15 p. m., light.
July 12	Fairbanks	G. F. Baker	8.30 a. m.
July 23	Kodiak	L. L. Bowers	4.25 p. m.
September	Valdez	Simeon Post	
Do	do	L. S. Camicia	2.50 p. m.
Sept. 28	Yakutat	R. W. Beasley	12.30 p. m.
1902.			
February	Bethel	Adolph Stecker	
Apr. 18 or 19	Tyonek	Prospector	Slight.
Dec. 6	Koserefsky	Brother Constantine	Thought building would be crushed.
Winter 1902–3	Tanana	A. R. Hoare	
1903.			
Mar. 10	Yakutat	R. W. Beasley	6 a. m.
Spring	Eagle	J. H. Robinson	
March	Valdez	Charles Simonstad	Drove people into streets.
May	Landlock	W. A. Dickey	
June 2	Valdez	L. S. Camicia	3.45 p. m., strong shock; direction, northeast to southwest.
July 13	do	do	11.40 a. m.
July	Dry Bay	G. C. Martin	Cliffs fell.
August	Enochkin Bay	do	Waves on still water of bay.
1903	Seward	L. N. Gordon	Very severe.
Sept. 10	Yakutat	R. W. Beasley	5 a. m.
1904.			
Dec. 8	Koserefsky	Brother Constantine	Violent shaking of log church.
1901–1905	Nushagak	J. H. Romig	
1905.			
Feb. 6	Valdez	L. S. Camicia	7.20 a. m.
August	Seward	E. E. Ritchee	20 to 30 seconds.
Nov. 22	Valdez	L. S. Camicia	At midnight.
Dec. 8	Onhagmute	N. N. Amcan	
Dec. 9	Bethel	Adolph Stecker	
Dec. 8	Ogavik, Kuskokwim	John Hinz	House rocked; also felt 80 miles away, at Bethel.
1906.			
May 25	Valdez	L. S. Camicia	5 a. m.
Aug. 6–7	Loring	Mrs. J. R. Heckman	10 p. m. and 3 a. m.
Summer	Yakutat Bay	R. S. Tarr	Slight tremors.
Sept. 19	Fairmont Island	J. R. Hayden	2 p. m.
Oct. 25	Valdez	L. S. Camicia	2.10 a. m.
Nov. 28	Dutch Harbor	J. J. Tolbert	Slight, 12.30 a. m.
Dec. 20	do	do	Slight, during day.
Dec. 25	Cold Bay	C. L. Boudry	7 a. m.
Dec. 22	Dutch Harbor	J. J. Tolbert	7 a. m. and 7.55 p. m.
Dec. 28	Cold Bay	C. L. Boudry	
1906–7	Nushagak	J. H. Romig	
1907.			
March	Marys Igloo, Hot Springs, and Shelton.	Lars Gunderson	
Aug. 22	Dutch Harbor	J. J. Tolbert	11.25 a. m.
Sept. 6	Nushagak	J. H. Romig	
Oct. 5	Killisnoo	S. Kilborn	Light shocks.
Fall	Prince William Sound	J. R. Hayden	
Dec. 10	Valdez	J. D. Jefferson	
1908.			
May 3	Fort Liscum	L. H. Hansen	7 p. m., 10 seconds.
May 4	do	do	7.35 a. m., 15 seconds; slight shock, with rumbling sounds.
Do	Valdez	L. S. Camicia	7 a. m.
June 8	Kuskokwim River	N. N. Amcan	
Mar. 15	Dutch Harbor	J. J. Tolbert	3 shocks, 1 at 3 o'clock and 2 about 7.
Dec. 20	Hot Springs	B. F. Baker	6 a. m., sharp shock
1909.			
Feb. 16	Yakutat	E. A. Rasmussen	Stopped clocks.
May 6	do	do	Spilled water out of reservoir on stove and from barrels outdoors.
July 16	Russell Fiord, Yakutat Bay	Tarr and Martin	Slight, with booming noise, as of avalanche.

VOLCANIC AND TECTONIC SHOCKS.

One might naturally expect earthquake shocks in a region adjacent to active volcanoes like Mount Wrangell and those of the Alaska Peninsula and Aleutian Islands. Many of the shocks felt at Unga and at Dutch Harbor (Unalaska), and perhaps most of those at Kodiak, are related to the active Aleutian Island and Alaska Peninsula craters and are doubtless chiefly volcanic. Most of those reported from points near the Chugach, St. Elias, and Coast ranges are regarded by the writers as tectonic, though some of those from parts of this region, such as the Copper River valley and Prince William Sound, might be volcanic shocks, due to eruptions of Mount Wrangell and adjacent volcanoes, or subterranean movements of lava without effusion. Nevertheless (*a*) in the absence of substantiated correlation of any eruption of a volcano in the Wrangell Mountains with a known earthquake, (*b*) with our knowledge that volcanic shocks are generally weak while many of the shocks from this region are world shaking, and (*c*) with the substantiated proof that in the Chugach, St. Elias, and Coast ranges of Alaska the mountain-forming movements are still in progress in association with known earthquakes, we feel no hesitancy in stating our belief that most of the shocks in the Prince William Sound, Mount St. Elias, and Lynn Canal regions and some of those in the interior of Alaska are tectonic. The statement that there was a severe eruption of Mount Wrangell during the Yakutat earthquakes of 1899 does not seem to be well founded. Of the shocks reported by Grewingk, Perrey, Dall Petrof, and Becker, those of 1788, 1843, 1847, 1853, 1861, 1866, 1867, 1868, and 1880 were probably tectonic and some of them may have been world shaking; the remainder were doubtlesss largely volcanic and merely local in their effects.

PERSPECTIVE OF YAKUTAT BAY EARTHQUAKES.

IMPORTANCE OF ALASKA SHOCKS.

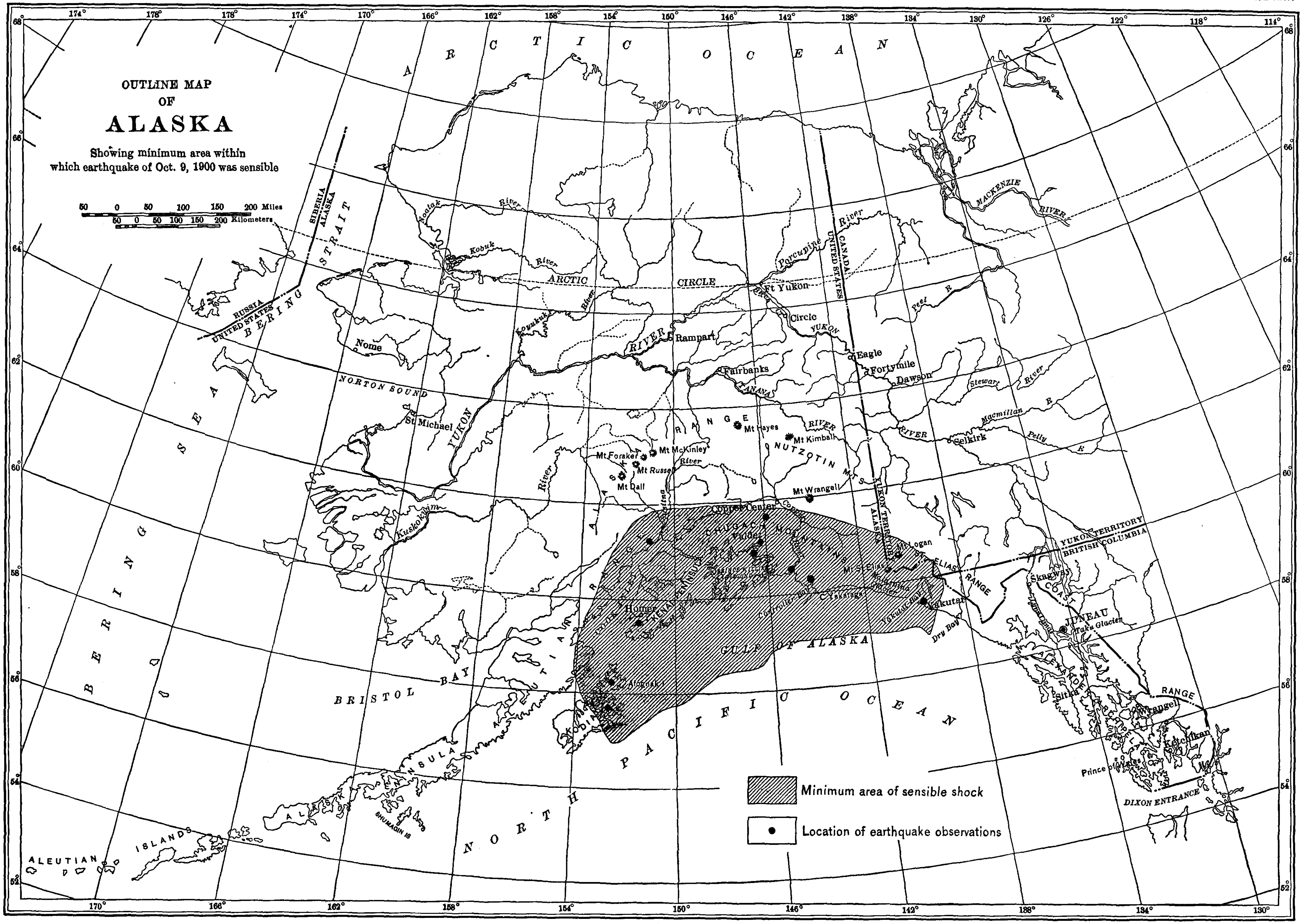
F. de Montessus de Ballore,[1] after cataloguing over 170,000 earthquakes throughout the world, reaches the conclusion that "Alaska is only peneseismic. The only important earthquake known is that of September, 1899, at Yakutat Bay." G. K. Gilbert,[2] however, credits Alaska with nine shocks of destructive rank, stating that the list probably omits more than it includes. To demonstrate that other world-shaking tectonic earthquakes like these in Yakutat Bay have occurred in this region, a wilderness from which few reports reach seismologists, and are still occurring at other times and elsewhere than at Yakutat, we will describe briefly four other earthquakes, one in 1900 and a group of three in 1907–8. Similar shocks both before and since 1899 are listed in the catalogue of Alaskan earthquakes on pages 92–93. That of 1896 at Orca (p. 90), west of the Yakutat Bay region, is a good illustration. We have evidence that the coastal ranges in this part of Alaska were growing before 1899 (1896 earthquake, etc.) and have continued to grow since (1900 and 1907–8 earthquakes); and that the faulting and earthquakes which accompany this growth are not limited to the Yakutat Bay region but are found both to the southeast (Lynn Canal earthquake) and to the west and northwest (Prince William Sound and Controller Bay earthquakes), as is shown on the following pages.

EARTHQUAKE OF OCTOBER 9, 1900.

On October 9, 1900, a severe earthquake, the exact origin of which is not definitely known though suspected to be in the St. Elias Range or Chugach Mountains, was felt over at least 120,000 square miles—about the Gulf of Alaska from Yakutat Bay to Kodiak Island (Pl. XXVI). This earthquake is described as follows, from points 480 miles apart and at intervening stations:

[1] Les tremblements de terre, Paris, 1906, p. 414.

[2] Earthquake forecasts, Science, new ser., vol. 29, 1909, pp. 125–126.


OUTLINE MAP
OF
ALASKA
Showing minimum area within which earthquake of Oct. 9, 1900 was sensible
50 0 50 100 150 200 Miles
50 0 50 100 150 200 Kilometers
Minimum area of sensible shock
Location of earthquake observations
ARCTIC OCEAN
BERING SEA
BERING STRAIT
NORTON SOUND
BRISTOL BAY
GULF OF ALASKA
NORTH PACIFIC OCEAN
ALEUTIAN ISLANDS
ALASKA PENINSULA
SHUMAGIN IS
DIXON ENTRANCE
ARCTIC CIRCLE
RUSSIA
UNITED STATES
SIBERIA
ALASKA
UNITED STATES
CANADA
YUKON TERRITORY
BRITISH COLUMBIA
Nome
St Michael
Ft Yukon
Circle
Rampart
Eagle
Fortymile
Dawson
Fairbanks
Selkirk
Copper Center
Valdez
Homer
Yakutat
Skagway
JUNEAU
Sitka
Wrangell
Ketchikan
Mt McKinley
Mt Foraker
Mt Russell
Mt Dall
Mt Hayes
Mt Kimball
Mt Wrangell
Mt Logan
Mt St Elias
NUTZOTIN MTS
ALASKA RANGE
CHUGACH MOUNTAINS
ST ELIAS RANGE
COAST RANGE
KENAI PENINSULA
Yukon River
Kuskokwim
Porcupine River
Tanana River
Peel R
Stewart River
Macmillan R
Pelly R
Mackenzie River
Kobuk River
Noatak River
Koyukuk River
Afognak I
Kodiak I
Yakutat Bay
Dry Bay
Taku Glacier
Prince of Wales

Yakutat, Controller Bay, and Copper River delta.—R. W. Beasley[1] has reported two shocks at Yakutat at 3 a. m. October 9. The same shocks were felt at Controller Bay by S. E. Doverspike,[1] and near the Copper River delta by Messrs. Schrader, Spencer, Gerdine, and Witherspoon, of the United States Geological Survey. Concerning this earthquake Mr. Schrader[2] writes: "The shock of this disturbance, Mr. Gerdine, who is a keen observer, reports was much more violent than the Charleston earthquake, which he himself experienced at his home in Atlanta, Ga., about 300 miles from Charleston."

Chugach Mountains, Valdez, and Seldovia.—Capt. W. C. Babcock,[1] of the United States Army, reports concerning what is evidently this same shock, that during the middle of October or early November (record of date not at hand) he felt a severe shock about 20 miles northeast of Valdez, sufficient to wake him from a sound sleep. He learned afterwards that the same shock tipped over a lighted lamp in his quarters at Fort Liscum, 4 miles from Valdez. Maj. Abercrombie also felt the earthquake of October 9 in another part of the Chugach Range. L. S. Camicia[1] felt this shock at Valdez, giving the time as 3 a. m. Adam Block,[3] postmaster at Seldovia, on Kenai Peninsula, felt the same shocks on October 9, between 3 and 4 a. m. There were two shocks, the first of which woke Mr. Block and lasted while he "got out of bed and went outside." A "severe shock" which a prospector at Tyonek, farther up Cook Inlet, reported to A. H. Brooks as occurring on October 7, 1900, may have been this shock of October 9.

Kodiak and Wood Island.—W. H. Osgood,[1] biologist in charge of Alaskan work for the United States Department of Agriculture, who was at Kodiak, 320 miles southwest of the mouth of Copper River and 480 miles southwest of Yakutat, states that he—

felt severe shocks at Kodiak October 9, 1900. Time noted was 2.15 a. m. First shock began with slight tremors, accompanied by loud rumblings, and ended with three sharp distinct movements which seemed fairly to lift us from the ground where we were lying. The wharf at Wood Island was partly destroyed, and windows, chimneys, and crockery in Kodiak were destroyed. Many secondary slight shocks, to the number of 50 or more, continued during next day.

C. P. Coe,[1] a missionary at Wood Island, near Kodiak, writes: "October 9, 1900, 2 a. m. Three shocks, severe. Merchandise in store tumbled to floor, crack in earth. Wharf pulled apart for 1 foot. Shocks continued through the day and the next day, slight."

A. C. Goss,[1] the Alaska Commercial Co.'s agent at Kodiak, has also described the disturbances in 1900 and 1901, beginning October 9; and L. L. Bowers,[1] deputy United States marshal at Kodiak, describes a shock on October 10 (probably October 9), 1900, as follows:

Heavy earthquake 2.17 a. m., lasting 45 seconds; small ones almost continually until 5 a. m. sun time; vibration causing some damage to the wharf at Wood Island, near by this place; knocked down chimneys and destroyed a quantity of drugs for the Alaska Commercial Co. The vibration was so strong it broke loose from the walls of the office a case of drawers and threw them across the room; a man sleeping in the next room to me was thrown from bed. I would have suffered likewise had I not caught myself. The cattle got scared and ran and bellowed; the dogs howled; the natives got scared and left their homes, believing the world was at an end, and ran to the church. The priest had some difficulty in pacifying them. Wind west, clear.

Seismographic record.—The earthquake of October 9, 1900, is recorded by seismographs throughout the world. A seismogram of this earthquake from an instrument at Laibach, Austria, is reproduced in Gerland's Beiträge zur Geophysik, Ergänzungsband I, 1902, as Plate V, figure 13, and one from an instrument at Tokyo, Japan, in Publications of the Earthquake Investigation Committee in Foreign Languages, No. 21, 1905, as Plate XXXVI, figure 51; the latter contains also, on pages 49–50, a detailed description of the Japanese record. The record in the Isle of Wight is also referred to by John Milne.[4]

[1] Reply to earthquake circular, 1907.
[2] Letter dated April 3, 1907.
[3] Reply to earthquake circular, 1908.
[4] Nature, vol. 65, 1902, p 203.

EARTHQUAKE IN LYNN CANAL REGION SEPTEMBER 24, 1907.

The first of the three recent tectonic shocks felt 150 miles or more southeast of Yakutat Bay came on September 24, 1907,[1] and was reported chiefly from the Lynn Canal region, notably at Skagway, at about 4 a. m. According to Philip Abraham,[2] the shock "lasted three to four seconds at 4.02 a. m. It moved clocks from position and stopped many." This time is correct within two minutes. The shock recorded by the seismograph at Sitka between 12^h 58.9^m and 13^h 04.3^m (Greenwich mean time) on September 24, 1907, is probably this Lynn Canal earthquake. It therefore occurred at Skagway, which is in the same longitude as Sitka, at 3^h 59^m 25^s solar time. It was reported [3] that "dishes rattled on shelves and chandeliers swayed. Many persons were awakened by the tremble." Sensational and altogether erroneous reports of a half-mile advance of Davidson Glacier were also quoted. At Klukwan, near Haines, H. E. Olson[2] reports that the shock of September 24 woke him at 4 a. m. and "was accompanied by a slight rumbling sound." Andrew Jackson,[2] keeper of the Point Sherman light station at Comet, Lynn Canal, reports an earthquake on September 19 (24?), 1907, at 3.40 a. m., which was also noted by Capt. Nyland, of the *Petrel*, who was 4 miles north of Haines and who observed a slight temporary change of water level.

It was commonly reported that this earthquake of September 24 was caused by a volcanic eruption somewhere near Lynn Canal. Several persons claim to have seen the smoke coming from the volcano. As no volcano is known to exist in this locality, it is believed by the writers that this was a normal tectonic shock similar in most respects to that at Yakutat Bay in 1899, the place of origin being as yet unknown. It is a well-known fact that dust from earthquake avalanches often gives from a distance the appearance of a steaming volcano.

The records of the United States Coast and Geodetic Survey seismograph at Sitka, about 170 miles south of Skagway, show the following data, the hours being given in Greenwich mean time, counting from midnight to midnight:

Seismograph record at Sitka, Sept. 24, 1907.

[Supplied by Supt. O. H. Tittmann, of the United States Coast and Geodetic Survey.]

Component.	First preliminary tremors.	Second preliminary tremors.	Large waves.	Maximum.	End.	Maximum amplitude (millimeters).
North	12^h 58.9^m	12^h 59.4^m	12^h 59.6^m	12^h 59.7^m	13^h 04.3^m	0.4
East	12 58.9	12 59.4	12 59.6	12 59.7	13 04.2	1.1

EARTHQUAKE IN PRINCE WILLIAM SOUND FEBRUARY 14, 1908.

The second shock of this recent group occurred in Prince William Sound (see Pl. XXXIII, in pocket), 250 miles west of Yakutat Bay, on February 14, 1908,[4] and is of especial interest because it broke two submarine cables in several places.

E. B. Spiers,[5] deputy collector of customs at Valdez, known to the writers as a reliable observer, refers to it as probably the most severe earthquake in the history of the town.[6] It came at 1.25 a. m.[7] (Valdez standard time) and is estimated to have lasted 45 to 60 seconds.

It caused tidal waves large enough to make steamer *Northwestern* rock very perceptibly, upset bottles and vases on shelves, and threw down cans of fruit, provisions, lard, etc., from

[1] Dawson Daily News, Oct. 18, 1907. Nome Nugget, Jan. 17, 1908.
[2] Reply to earthquake circular, 1907.
[3] Seattle Post-Intelligencer, cable dispatch dated Skagway, Sept. 24, 1907.
[4] Valdez Daily Prospector, Feb. 14 and 20, 1908. Juneau Record, Mar. 2, 1908.
[5] Reply to earthquake circular, Feb. 15, 1908.
[6] Mr. Spiers was not there during the shocks of 1899 and 1900.
[7] Recorded by the seismograph at Sitka from 11^h 26^m 24^s to 11^h 37^m Greenwich mean time. When this is converted to true meridian time at Valdez it is evident that this earthquake began at 1.41 a. m.

the shelves in all the stores in the town. People who were in the San Francisco earthquake[1] said this seemed as violent as any of the shocks felt there April 18, 1906.

I sat up in bed, did not get up until after it was all over. No nausea or dizziness. Very violent, somewhat irregular shaking. First waves appeared to come from south or southwest, then, as it subsided, seemed to come from east or southeast, practically at right angles to first waves. It waked up everyone as far as I know. There was a second small shock 10 or 15 minutes later, and it was preceded by a very distinct rumbling five or ten seconds before.

Lieut. L. H. Hansen,[2] of the United States Army, assistant surgeon at Fort Liscum, says the shock occurred at 1.27 a. m. (Valdez time), lasting about three seconds. "Buildings swayed, lamps swayed considerably, clock in hospital stopped running, rumbling noise during shock."

G. M. Esterly,[2] a mining engineer, who was on the steamer *Northwestern*, which was approaching the dock at Valdez at the time of the shock, says it "felt as though the ship struck on bottom."

U. S. Grant, of the United States Geological Survey, procured the following additional information at Valdez during the summer of 1908:

William Glendenning, of Valdez, stated that a light shock came about 15 minutes before the main shock, and there was a light shock about 30 minutes after the main shock. The main shock lasted about two minutes, having a motion from south to north. He was awake, but in bed, at the time of the first shock, and had just got up at the time of the second shock. In his room some toilet bottles were shaken to the floor. No windows were broken and there was no marked earthquake wave in the sea. At the main shock many people rushed to the street. A roaring, coming from south to north, preceded the main shock by about 30 seconds.

Capt. H. B. Black, in charge of the cable and telegraph at Valdez, stated to Dr. Grant on July 11, 1908, that a fire in the cable office a few days before had destroyed the records of the breaks in the cable there during the earthquake of February 14, 1908; but that the Sitka cable had been broken in several places within 2½ to 4 miles of Valdez and the Seward cable twice in the same distance. He added that he himself was not present during the earthquake, but that his wife was, and that she was also at Benicia, Cal., 30 miles from San Francisco, during the San Francisco earthquake, and that she said that the earthquake at Valdez was about as violent as the San Francisco quake was at Benicia.

John H. Bruck, master signal electrician, was at Valdez during the earthquake. He states that he was awakened by the earthquake, which lasted one to two minutes, and another shock came 15 minutes or more after the main shock. People on a steamer that was coming to the landing at this time felt the shock. People on the wharf also felt the earthquake. No damage was done and there was no marked sea wave.

This earthquake was also felt practically everywhere in Prince William Sound, "shaking bottles off shelves, shaking store windows, and causing a door to fly open" at Ellamar;[3] causing house to sway, waking everyone, and shaking a candlestick loose from wall," in a mine where the night shift was working at Landlock,[4] "rocking a building and waking everyone by three shocks" at Latouche,[5] 100 miles southwest of Valdez; making a house and bed vibrate rapidly and waking people at Cordova,[6] 50 miles southeast of Valdez, and just west of the Copper River delta; and shaking a bed and waking people at Katalla,[7] 80 miles southeast of Valdez and just east of the Copper River delta.

It is thought certain that this series of shocks in and about Prince William Sound were associated with mountain-building forces in the St. Elias or Chugach Range similar to those operative during the 1899 earthquakes at Yakutat. In support of this theory the breaking of the cables during the shock of February 14, 1908, is of especial interest because so suggestive of submarine faulting. Gen. Allen,[8] Chief Signal Officer of the United States Army, states that

[1] Including Mr. Spiers himself.
[2] Reply to earthquake circular, 1908.
[3] Short, H. H., reply to earthquake circular, 1908.
[4] Dickey, W. A., reply to earthquake circular, 1908.
[5] Hayden, J. R., reply to earthquake circular, 1908.
[6] Hazelet, G. C., reply to earthquake circular, 1908.
[7] Thompson, A. C., reply to earthquake circular, 1908.
[8] Letter dated Apr. 1, 1908.

"both the Valdez-Sitka and Valdez-Seward cables were interrupted close to the city of Valdez, and well inside Valdez Narrows. * * * A short length of the cable was covered by the upheaval of the sea bottom, so that it had to be abandoned."

A map by Lieut. Paul Hurst, of the United States cableship *Burnside* (Pl. XXVII), shows the places where the cables were broken. The Valdez-Seward cable was broken in four places three-eighths to 1⅛ miles apart, while the Valdez-Sitka cable was broken in seven places five-eighths to seven-eighths mile apart. This later report shows that the cables were buried not in one place but in three, the outermost being 1½ to 3 miles from shore in 700 feet of water.

The United States Geological Survey party, under the direction of U. S. Grant, which worked in the region in 1908, did not discover actual faults running ashore nor changes of level of the land; one stretch of coast, however, along Valdez Inlet near the cable breaks, was not examined by them. Prof. Grant[1] says:

While at Valdez I went out to the Valdez Glacier and also walked westward from the town for about a mile and a half. On both of these trips I had in mind the possibility of earthquake cracks but saw no evidence of such. I think that cracks of any size made in February ought still to be visible the following summer. I also examined the south shore of Valdez Inlet from Fort Liscum westward to Entrance Island. This examination was done from a small gasoline launch which was practically everywhere within a few rods of the shore. When farther away I used a field glass. I saw no evidence of earthquake cracks along the shore, and I think that any displacements of a foot or so could easily be recognized. Neither did I see any evidence of elevated or depressed shore lines, although of course the shore was not examined in great detail.

There was a fire in the cable office at Valdez on the night of my arrival there and the maps and records of the earthquake of February, 1908, were destroyed. I did not get map showing the breaks in the cable until almost time to start home and so had no opportunity to study carefully the shore opposite the breaks.

The hypothesis that the pairs of breaks in parallel cables three-eighths to three-fourths of a mile apart are caused by faulting is of decided interest. The Coast Survey chart shows that this cable lies in soft mud under 280 to 800 feet of water where the breaks occurred. At these depths the alternate hypothesis of breaking of the cables by masses of silt sliding down the steep submerged delta front near Valdez does not seem plausible, for the soundings show no slopes down which the mud could slide to cause several of the breaks. Nor does a hypothesis of breaks a mile or more apart caused by jelly-like shaking of the fiord-bottom deposits during the earthquakes seem applicable. It is far more likely that the cables were broken at the points shown (Pl. XXVII) by actual fault movements during the earthquakes.

Some seismograph records of the earthquake of February 14, 1908, kindly supplied by Dr. H. F. Reid, of Johns Hopkins University, follow:

Seismograph records of earthquake of February 14, 1908.

Place.	Component.	Preliminary tremors commenced.	Large waves commenced.	Maximum.	End.	Maximum amplitude (millimeters).
Sitka, Alaska	North[a]	11h 26m 24s		11h 29m 35s	11h 34m	0.3
	East[a]	11 26 30	11h 28m 25s	11 29 30	11 37	.8
Victoria, B. C.	East[b]	11 28.6			11 43.6	.15
Toronto, Canada	do.[b]	11 51.1			11 53.1	.15
Baltimore, Md.	Northwest[b]		11 53.0	11 54.0	12 0	.5
Cheltenham, Md.	North[a]	11 49 22		11 53 22	11 57	.1
	East[a]	11 49 20		11 53 12	12 01	.1

[a] Bosch-Omori instrument [b] Milne instrument.

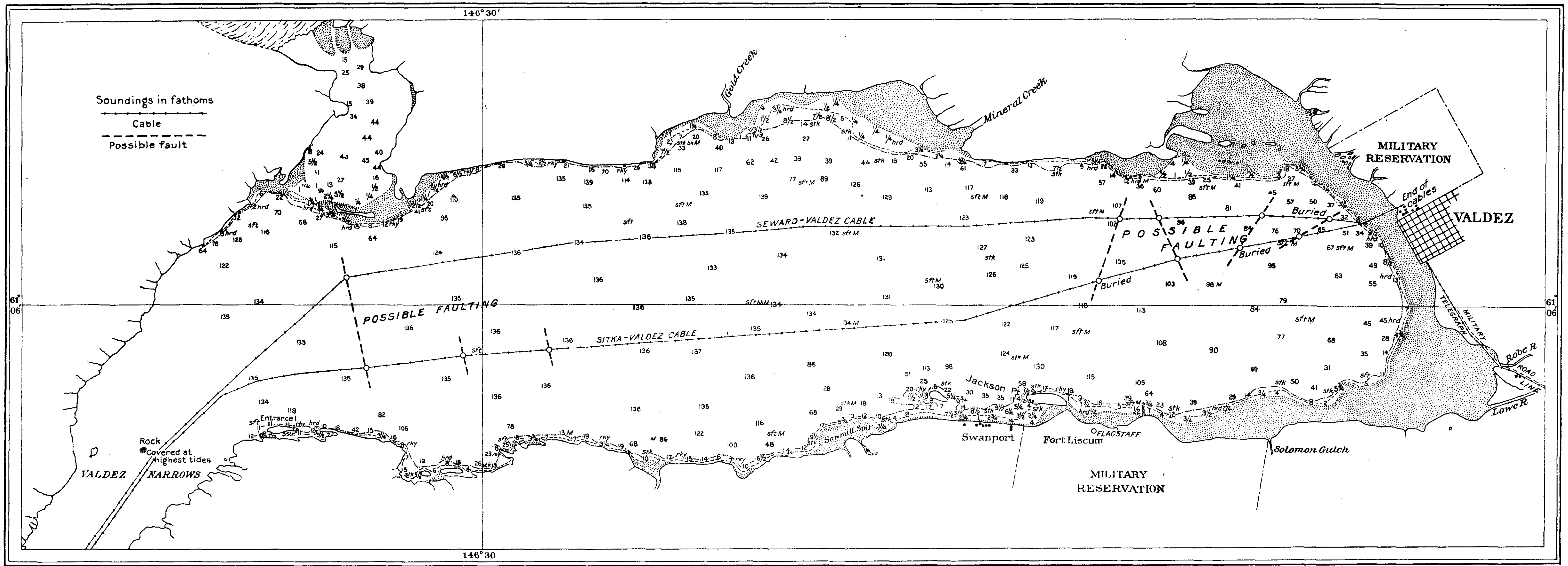
EARTHQUAKE IN CONTROLLER BAY REGION MAY 14, 1908.

The last of this group of three recent earthquakes took place May 14, 1908, and was probably the most severe of the three. It was felt slightly at Sitka and Juneau and generally at Valdez and Seward, as well as at intervening points. (See Pls. II, p. 14; XXXIII, in pocket.) It is reported from Katalla,[2] on Controller Bay, as follows:

Two earthquake shocks, occurring in quick succession at 11.07 o'clock Thursday night, set every building in town rocking, moved furniture about rooms, knocked dishes from shelves, and caused many of the people in town, many of whom had retired, to take to the streets.

[1] Letter dated Nov. 6, 1908.

[2] Katalla Herald, May 16, 1908.



Compiled from U. S. Coast and Geodetic Survey chart 8221 and a map by Lieutenant Paul Hurst of the U. S. cable ship "Burnside"

Scale $\frac{1}{62500}$

1 0 1 2 Miles

ECKERT LITHO. CO. WASH., D.C.

MAP OF PORT VALDEZ, PRINCE WILLIAM SOUND, ALASKA

Showing breaks in cables by faulting, February 14, 1908

According to the statements of a number of people, the shocks, of which there were two in almost instantaneous succession, lasted from 10 to 17 seconds. No damage was done. The shocks were accompanied by a vibratory motion pretty nearly north and south. In the Herald office the machinery and fixtures swayed perceptibly, while the building rocked as if it had been struck by a cyclone.

G. M. Weigel, the baker, says that he thought someone was trying to turn his building over, and Col. Barrett says that the ceiling in the room where he sat reading in his home was cracked.

A report was current yesterday that the English Co.'s oil well at the head of Katalla Slough was spouting oil and gas, but the report lacks verification.

Thursday evening, immediately after the shocks, many people thought that a tidal wave might follow, and they rushed to the water front, but no commotion disturbed the placid surface of the bay.

On the following morning, May 15, the United States Weather Bureau issued the following bulletin with regard to the earthquake:

WASHINGTON, D. C., *10 a. m. May 15, 1908.*

The seismographs of the Weather Bureau recorded an earthquake of considerable intensity during the early morning of May 15, beginning at 3.39.52 a. m. 75th meridian time.[1]

The strong motion set in at 3 o'clock and 55 minutes and continued for about 10 minutes. The duration of the whole earthquake was about 1 hour.

The duration of the first preliminary tremors, which were very sharply defined, amounted to 6 minutes and 40 seconds. This would place the origin of the earthquake at approximately a distance of 3,200 miles from Washington. Portions of Central America or the Pacific Ocean west of Central America fall within this distance, and possibly this might be the location of the disturbance, but no definite statement to this effect could be made.

MOORE, *Chief.*

Some of the seismograph records of this earthquake, from instruments in America, which have come into our hands through the courtesy of Prof. H. F. Reid, of Baltimore; Mr. R. F. Stupart, director of the meteorological service of Canada; Supt. O. H. Tittmann, of the United States Coast and Geodetic Survey; and Prof. C. F. Marvin, of the United States Weather Bureau, are as follows. Greenwich mean time is used.

Seismograph records of earthquake of May 14, 1908 (May 15, Greenwich mean time).

Place.	Component.	First preliminary tremors.	Second preliminary tremors.	Large waves.	Maximum.	End.	Maximum amplitude (millimeters).
Sitka, Alaska	North.[a]	8^h 32.7^m	....	8^h 32.9^m	8^h 36^m	9^h 56^m	68.0
	East.[a]	8 32.6	....	8 32.8	8 35	....	71.0
Victoria, B. C.	do.[a]	8 35.3	....	8 40.3	8 42.8	10 38.3	8.0
Toronto, Canada	do.[a]	8 46.1	....	8 53.3	8 54.2	9 42.1	5.7
Baltimore, Md.	Northwest[b]	8 39.9	....	8 55.2	8 55.7	9 06	3.5
Do.	do.[a]	8 42.5	8^h 47.0^m	8 55.7	8 56.3	10 30	4.0
Cheltenham, Md.	North [a]	8 39.8	8 46.6	8 54.4	8 55.7	10 32	6.7
Do.	East.[b]	8 39.8	....	8 54.8	8 55.7	9 35	9.7
Washington, D. C.		8 39.8	....	8 55.0	....	....	....
Porto Rico	North	8 51.8	....	9 04.0	9 14.6	10 36	.4
Do.	East	8 51.6	....	9 02.0	9 06.2	10 44	.2
Honolulu, Hawaii	do	....	....	8 45.3	8 50.2	....	1.8

[a] Milne instrument. [b] Bosch-Omori instrument.

EARTHQUAKE OF SEPTEMBER 21, 1911.

A fourth recent severe earthquake occurred September 21, 1911, in the vicinity of Prince William Sound and the Kenai Peninsula. It is described here because it is related to earth movements in the region disturbed by the earthquake of February 14, 1908, and because it seems to verify the hypothesis of faulting in Port Valdez (p. 98), discussed in connection with the breaking of cables during that shock. The list of places of observation is doubtless incomplete.

Valdez and vicinity.—This seismic disturbance was strongly felt at Valdez, where it broke a submarine cable. The direction of vibrations was northwest-southeast and their duration is said to have been 52 seconds.

[1] 8^h 39^m 52^s, May 15, Greenwich mean time, or 11^h 01^m 52^s p. m. May 14, Katalla time.

A. H. Brooks, geologist in charge of the division of Alaskan mineral resources of the United States Geological Survey, has given one of the best accounts of this earthquake, as follows:

The record in my notebook shows that on September 21 I noted four earthquakes between 7 and 8.38 p. m. I was at that time at the camp of the Ibex Mining Co., on the west side of Valdez Glacier, about 8 miles from the town of Valdez. I corrected my time observations in accordance with the clock at the Signal Corps station at Valdez upon my return. The correction shows the shocks to have been as follows:

The first one was at 7.01 p. m. This lasted 20 seconds by my observation. As, however, I was sitting across the tent from the candle and as I did not recognize it as an earthquake at once, I think it safe to add 5 or 6 seconds to this observation.

The second shock came at 7.13 and lasted between 5 and 10 seconds. The third shock came at 7.28 and lasted 3 to 5 seconds. The fourth shock came at 8.38 and lasted about 2 seconds. The earth movement seemed to be from west to east. I had no means of measuring the intensity of the shock, but it did not seem to have been sufficient to upset anything on the shelves where I was. I was told that at Valdez some articles were thrown from shelves and that a heavy glass bowl was moved, so that it was in danger of falling from a sideboard. The clock at the Signal Corps station at Valdez stopped at two minutes past 7.

So far as I know, there was no perceptible earthquake wave at Valdez, but of this I have no definite information. It would seem that there should have been a wave there when the cable was broken. Curiously enough, the operator at Valdez told me that the cable was not broken immediately, but that communication was kept up with Sitka some seconds after the earthquake shock. He was telegraphing to Sitka at the time of the shock. The shock at Valdez was sufficient to frighten the people very badly. Nearly everyone rushed out on the street. I did not learn, though, that it had done any damage whatsoever.

As I had never before felt an earthquake shock I had no basis for comparison. The tent in which I was sitting was located on a little spur jutting out from a steep slope about 1,000 feet above the Valdez Glacier, and the rumbling of the earthquake was confused with heavy falls of bowlders down the talus slopes. The talus slopes on both sides showed considerable movement after the earthquake shocks.

During this earthquake the submarine cable from Valdez to Sitka was broken just north of Fort Liscum, at a point $3\frac{3}{16}$ miles west of the dock at Valdez, near latitude 61° 06′ 08″ N., and longitude 146° 19′ 23″ W.,[1] and was buried for 1,650 feet. This is almost exactly at one of the points (Pl. XXVII) where the cable was broken during the earthquake of February 14, 1908, when twice as great a length of cable was buried near this break. The water here is 700 to 750 feet deep and the slope of the fiord bottom is less than 50 feet to the mile. The break at this same point in 1911 seems to verify our suggestion made in 1908 (p. 98), that a fault exists there. Mr. Brooks's statement that cable communication was not interrupted until several seconds after the shock may tend to show that there was slight flowage of fiord-bottom mud along a fault scarp, resulting in the burial of a great length of cable. We do not think that the earthquake shaking alone, without actual displacement by faulting, could have caused sufficient flowage on the flat fiord bottom to break the cable.

Northern Prince William Sound.—The effect of this earthquake at Golden, on the shores of Wells Bay in northern Prince William Sound, 45 miles west of Valdez, has been described as follows:

The tops of the mountains, which form a picturesque background for the new city, began to tremble, and these palpitations were followed by tremendous land and rock slides, which completely buried the gulch over which the trail extends. The residents of Golden acted as a unit in making for the boats pulled upon the beach, and practically all of them spent the night on the waters of Wells Bay. One tremendous slide, which carried with it a portion of a small glacier, passed within a few hundred feet of the town. That the floor of the ocean was violently disturbed was shown by the fact that the sea was covered with countless dead fish, which undoubtedly had been killed by the concussion. Thousands of red snapper, salmon, trout, halibut, and other kinds of fish were killed. When the fear of further earth oscillations had subsided the miners gathered hundreds of barrels of these fish and salted them down for the coming winter.

Kenai Peninsula.—In the mountains of Kenai Peninsula, which border the western shore of Prince William Sound, the earthquakes of September 21 were felt as heavy shocks all along the line of the Alaska Northern Railway between Seward and Kern Creek, 171 miles to the north, at points 110 to 125 miles southwest of Valdez.

G. C. Martin, of the United States Geological Survey, who was on the line of the Alaska Northern Railway north of Kenai Lake, observed four shocks on September 21, and also noted

[1] Information from map furnished by Capt. B. O. Lenoir, of the U. S. Signal Corps, Nov. 8, 1911.

a preliminary earthquake on September 10 at Seward, at 3.40 p. m. He states that on September 21 the trees waved when there was no wind, that he found it possible to stand only by bracing himself with the feet far apart, and that during and after the shock he heard rocks sliding down the talus slopes of the mountains. The first shock, which was heavy, ended at 7.07 p. m.; the second shock was lighter and ended at 7.19½ p. m.; the third and lightest disturbance ended at 7.35 p. m. There was a fourth shock (heavy) during the night. These times were noted with a watch which had been set at the United States cable office at Seward on September 10, but which was not compared with standard time afterward. There was an aftershock on September 22 at 9.42 p. m., the clock being perhaps 5 minutes fast or slow.

J. L. McPherson, a mining engineer, who was on Kenai River 4 miles below Kenai Lake and 140 miles southwest of Valdez, also felt the earthquake of September 21. His observation verifies that of A. H. Brooks at Valdez concerning the long duration of the shocks. He writes:

> The duration, as near as I could estimate it, was 25 seconds, and the wave motion was east-west. As soon as I realized that it was an earthquake I pulled out my watch and got on my feet to get the motion. As near as I remember now I allowed 5 seconds for lost time from the commencement of the quake until I commenced to observe the time.

ALASKA A SEISMIC REGION.

The strong recent shocks, together with the large number of earthquakes of which we have been able at this late date to obtain record (pp. 92–93) convince us that the coast region around the head of the Gulf of Alaska, as well as the Alaskan Peninsula and Aleutian Islands, is to be reckoned as one of the great seismic regions of the world. The shocks are both frequent and widely scattered, while at short intervals they are of great strength. Only because of lack of records of earthquakes in this region is there warrant for classing it as peneseismic.

The list below shows some additional earthquakes in Alaska since 1909.

List of earthquakes in Alaska from February 16, 1909, to January 31, 1912.

Date.	Time.	Intensity.[a]	Remarks.
1909.			
Feb. 16	7.50[b]	VI-VII.	Slightly at Sitka, Valdez, Juneau; stronger at Yakutat and Skagway. Registered on seismographs at Toronto, Sitka, and Victoria.
June 19	Noon		Slight shock at Dutch Harbor.
July 11	2.02.18[c]	III.	Distinctly felt in Sitka.
Sept. 9?			Aleutian Islands. Sufficiently strong to upset Aleutian dinners and disarrange the furniture in some houses.
Sept. 19	10 a. m	VI.	Seward. Duration 5 seconds.
Oct. 26	4.56.03[c]	V.	Recorded at Sitka and felt at Juneau (IV) and Skagway. Direction west-east, duration 1 second.
1910.			
Mar. 14	5.09 a. m.[b]	V.	Felt at Skagway. Duration 1 second, direction east-west. A second very light shock about an hour later.
June 24			Unimak Pass, at sea, lat. 54° 20′ N., long. 165° 20′ W.
July 6	7.40 p. m	V (?)	Origin near Skagway. Duration 28 seconds (?).
Aug. 5		Strong.	Yakutat. Shook up buildings along shore of the bay and rattled dishes and windows but did no noticeable damage. Shock felt on board steamer Bertha, which was in port at the time.
Sept. 1		Strong.	Dutch Harbor. Two violent shocks at the time of the appearance of a new island in the Bogoslof group, 50 miles to the northwest. Volcanic shocks.
September.			Volcanic shocks in connection with grand eruptions of Mount Shishaldin, in Alaska Peninsula. Earthquakes said to have accompanied eruptions earlier in the summer, and changes in coast line rumored.
Nov. 20	11.32 p. m	V.	Two shocks, of 5 seconds each, felt at Nome.
1911.			
Jan. 7	4–4.30 a. m	V-VI.	Felt at Fairbanks. Duration 6 to 8 seconds.
Early in September.		Severe.	Felt at Yakutat.
Sept. 21	7.01 p. m.[d]	IX-X.	Severe in vicinity of Prince William Sound and Kenai Peninsula (see p. 99).
1912.			
Jan. 31	11.12 a. m.[e]		Felt throughout Prince William Sound and in the Copper and Tanana valleys. Duration at Valdez, 20 seconds; at Fairbanks, 6 seconds. Registered on seismographs at St. Louis, Mo., Cambridge, Mass., and elsewhere.

[a] Intensity expressed in Rossi-Forel scale.
[b] 135th meridian time.
[c] Greenwich mean time.
[d] Valdez time.
[e] Cordova time.

CHAPTER VII.

INSTRUMENTAL RECORDS OF THE EARTHQUAKE.

SEISMOGRAPH RECORDS.

As has already been stated (p. 69), the shock of the greater Yakutat Bay earthquakes of September, 1899, was recorded by seismographs throughout the world, from that at Victoria, British Columbia (Pl. XXVIII), the nearest, to that at Cape Town, South Africa, the most remote (Pl. XXX, *A*, *B*.).

STUDY BY FOREIGN SEISMOLOGISTS.

It is worthy of notice that experienced authorities on earthquakes, like the English seismologists John Milne and R. D. Oldham; the Japanese Omori; the Italians Cancani, Agamennone, Grablovitz, Riccò, Bastogi, Oddone, Stiattesi; Lagrange in Belgium; Schwab in Austria; Verbeek in Java; and doubtless others, had been interested in these Yakutat earthquakes and had studied them from the seismograph records before the authors visited Yakutat Bay. Without knowledge of the important changes wrought by these earthquakes, or of the times of origin of the shocks, and with no knowledge of the place of occurrence except the information contained in one incomplete newspaper notice, several of them [1] worked out from the seismograms the time when and the place where these world-shaking earthquakes occurred, as well as many facts concerning the speed of transmission of shocks, etc.

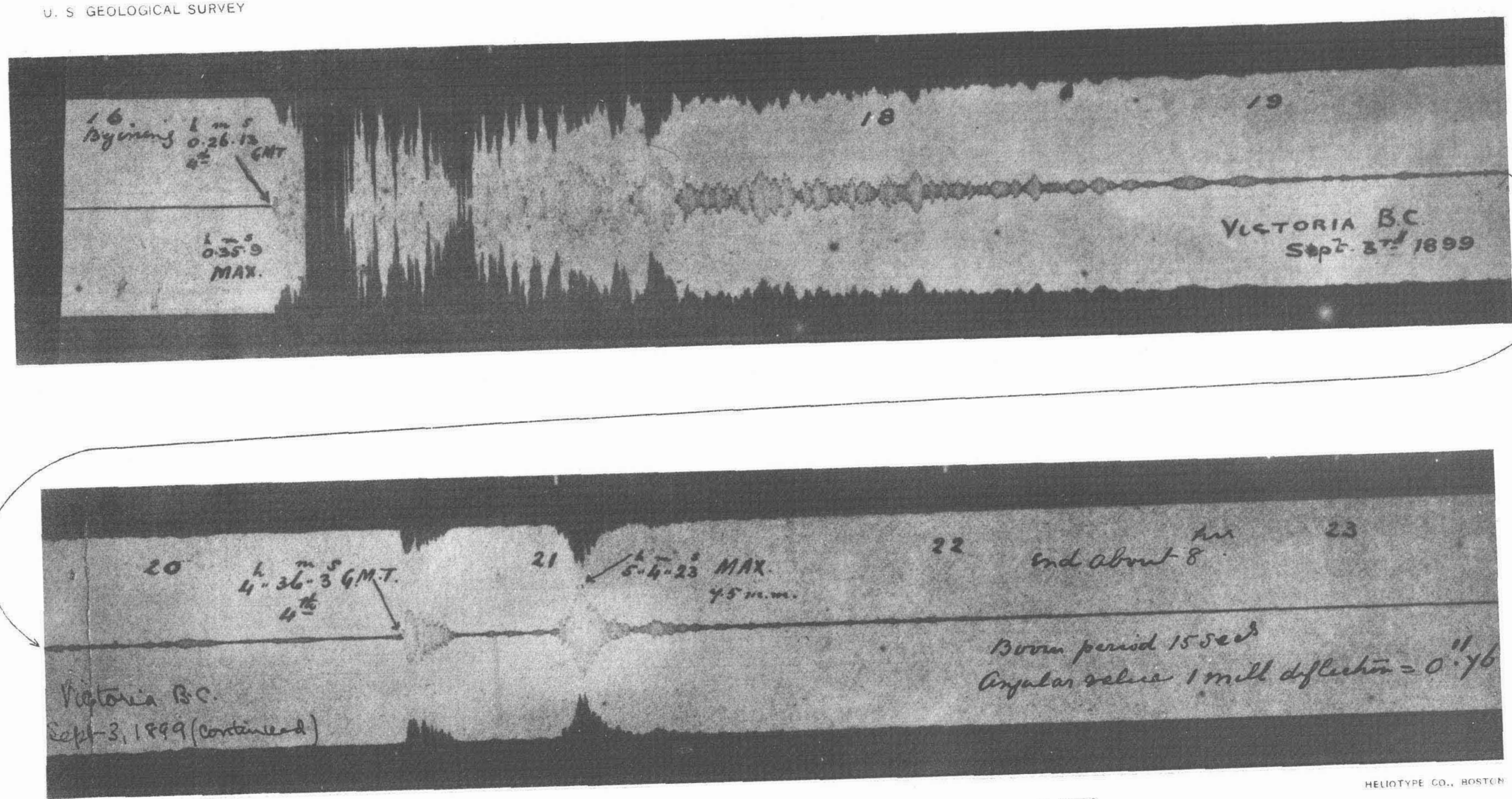
The records of these Alaskan earthquakes of 1899, from various observatories in Italy, have been compiled and published by Cancani.[2] His paper includes a detailed description of the earthquake of September 3, as recorded by instruments at Rocca di Papa (Rome), Casamicciola (Naples), Catania, Quarto Castello (Florence), Pavia, Turin, etc., as well as similar descriptions of the first shock of the earthquake of September 10, as recorded at Rome, Rocca di Papa, Casamicciola, Catania, Quarto Castello, Pavia, etc.; the second shock of September 10, as recorded at Rome, Rocca di Papa, Casamicciola, Portici, Catania, Siena, Quarto Castello, Pavia, Turin, etc.; and also of the shocks of September 23 and 26 at these and other observatories.

These earthquakes were also recorded by instruments in other parts of the world, including seismographs in eastern and western Canada, Mexico, Argentina, England, the Isle of Wight, Belgium, France, Spain, Germany, Austria-Hungary, Russia, India, Japan, Java, Mauritius, South Africa, and doubtless in other places from which the writers have seen no data. We have found no seismograph which was in operation in 1899 in any part of the world which did not record these earthquakes. However, the number of large earthquake-recording instruments in operation in 1899 was much smaller than at present.

PUBLICATION OF SEISMOGRAMS OF THESE EARTHQUAKES.

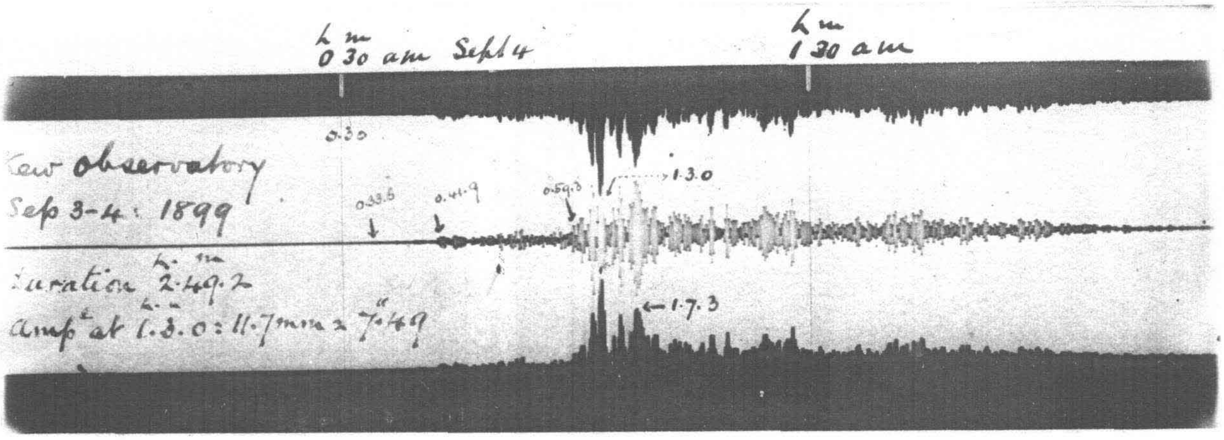
Certain of the distant seismograms of the Yakutat Bay earthquakes are so good that 23 of them were reproduced in the report of the seismological committee of the British Association for the Advancement of Science for 1900; [3] notably those of the earthquake of September 3 from the stations at Bombay, Cape of Good Hope, Mauritius, Kew, Shide, San Fernando, Toronto,

[1] Milne, J., Rept. British Assoc. Adv. Sci., 1900, pp. 64–108, passim, Pls. II and III; 1902, pp. 62, 64.
Omori, F., Publ. Earthquake Investigation Committee in Foreign Languages, No. 5, Tokyo, 1901, pp. 21–63, passim; No. 6, 1901, pp. 47–52, passim; No. 13, 1903, pp. 87–123, passim; No. 21, 1905, pp. 45–89, passim.
Oldham, R. D., Quart. Jour. Geol. Soc., vol. 62, Aug., 1906, pp. 465–473 (referring specifically to the Yakutat earthquakes on pp. 459, 461, 471).
[2] Notizie sui terremoti osservati in Italia durante l'anno 1899: Boll. Soc. sismol. ital., vol. 6, 1900–1901, appendice, pp. 178–190, 194–198, 199–208, 223–229, 231–234.
[3] Fifth Rept. Comm. Seismol. Invest., British Assoc. Adv. Sci., 1900, pp. 95–97, 100.

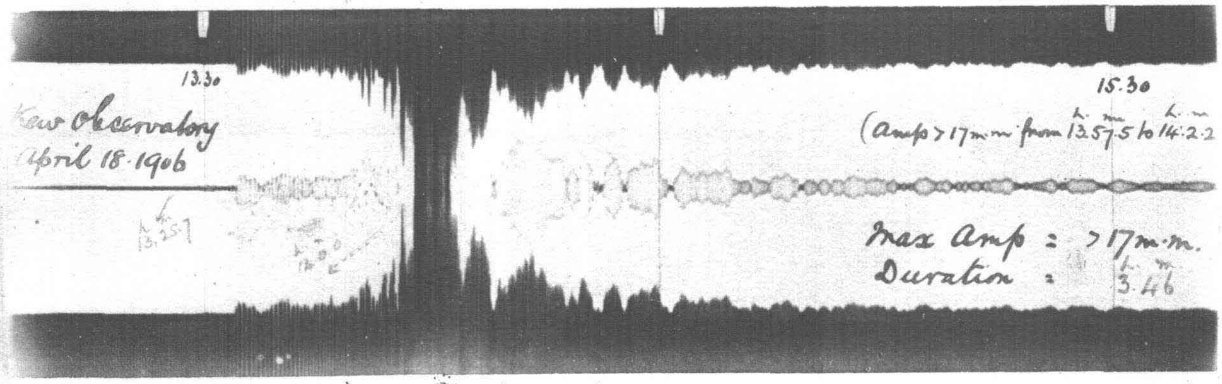


HELIOTYPE CO., BOSTON

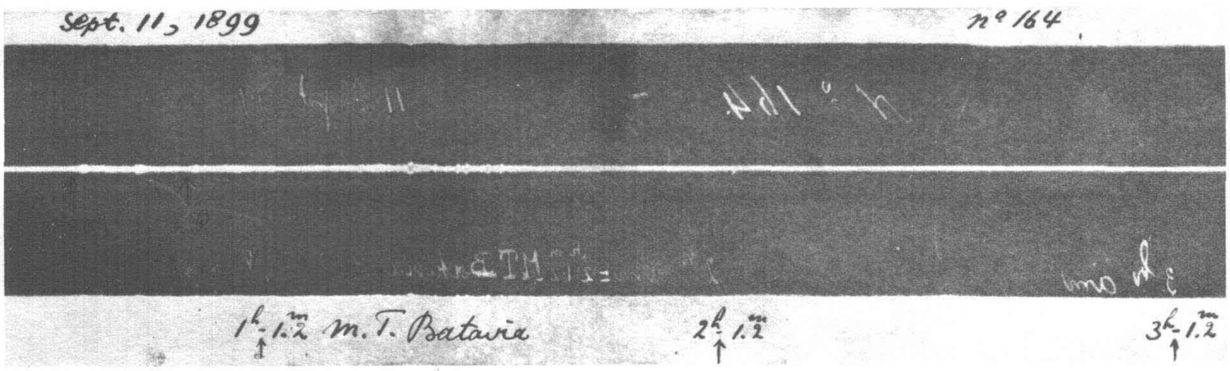
SEISMOGRAM OF YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 3, 1899
FROM INSTRUMENT IN BRITISH COLUMBIA



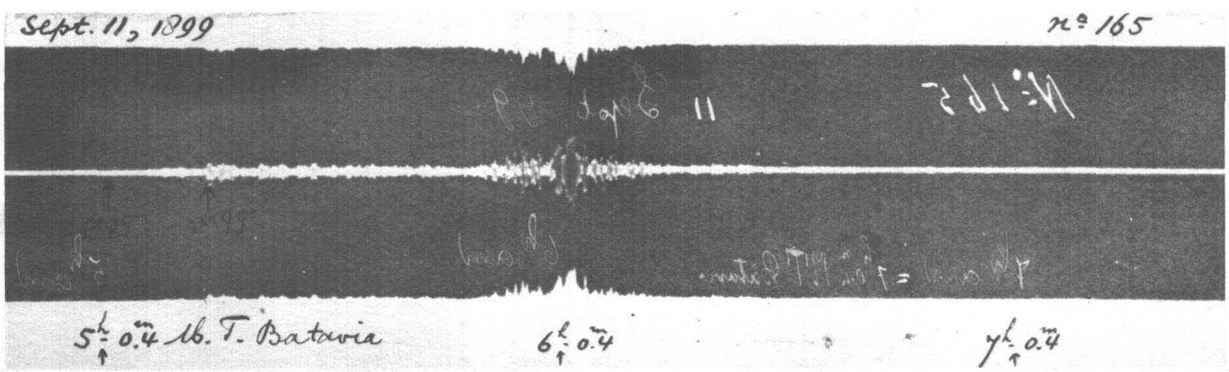
A



B



C



D

HELIOTYPE CO., BOSTON.

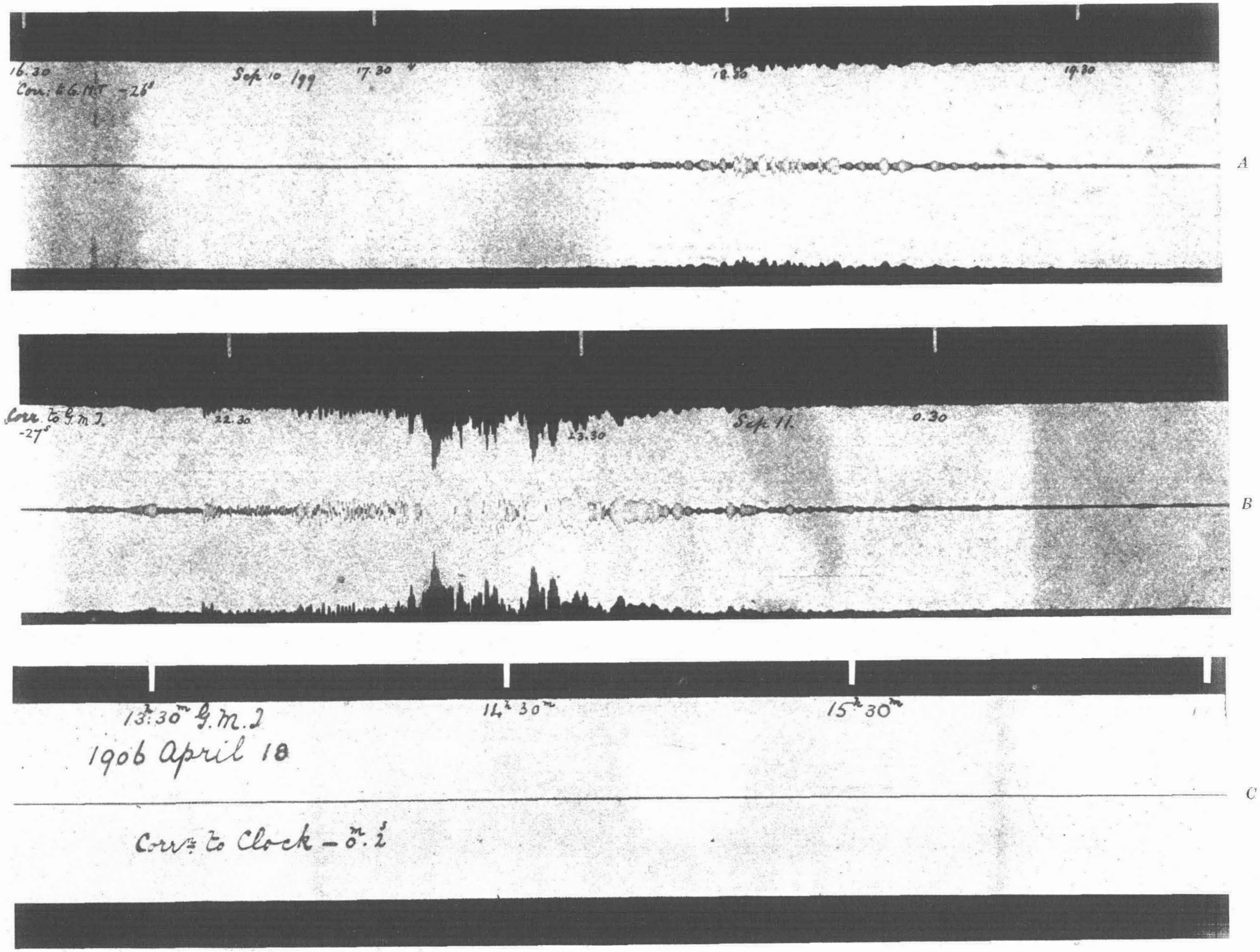
SEISMOGRAMS OF EARTHQUAKES, 1899 AND 1906

A YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 3, 1899, FROM INSTRUMENT AT KEW, ENGLAND

B CALIFORNIA EARTHQUAKE OF APRIL 18, 1906, FROM INSTRUMENT AT KEW, ENGLAND

C FIRST YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 10, 1899, FROM INSTRUMENT AT BATAVIA, JAVA

D HEAVIEST YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 10, 1899, FROM INSTRUMENT AT BATAVIA, JAVA



HELIOTYPE CO., BOSTON

SEISMOGRAMS OF EARTHQUAKES, 1899 AND 1906

A FIRST YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 10, 1899, FROM INSTRUMENT AT CAPE TOWN, SOUTH AFRICA

B HEAVIEST YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 10, 1899, FROM INSTRUMENT AT CAPE TOWN, SOUTH AFRICA

C CALIFORNIA EARTHQUAKE OF APRIL 18, 1906, FROM INSTRUMENT AT CAPE TOWN, SOUTH AFRICA

Tokyo, and Victoria; those of the early shock of September 10 from the stations at Bombay, Batavia, Cape of Good Hope, Kew, San Fernando, and Toronto; and those of the last and heaviest earthquake on September 10 from instruments at Batavia, City of Mexico, Bombay, Mauritius, Kew, San Fernando, Toronto, and Cape of Good Hope.

Seismograms written by instruments at the observatories of Hongo and Hitotsubashi, Tokyo, Japan, have been reproduced [1] and show the autographs of the earthquakes of September 3 and 10 in Alaska as recorded in Japan.

The seismographic records of the same earthquakes, as written by instruments in Canada, were published by R. F. Stupart.[2] The seismograms reproduced are the Victoria record of the shock of September 3, and the Toronto records of the shocks of September 3 and 10.

The seismogram of the shock of September 3, as recorded at Uccle, Belgium, has also been reproduced.[3]

The seismogram of the disturbance of September 10 at Batavia, Java, is reproduced by Dr. J. P. van der Stok [4] in an article in which he compares the records of the Ceram earthquake of September 29, 1899, and the Alaska earthquake of September 10, 1899, as recorded at Strasburg, Germany, and at Batavia.

In the present report we reproduce seismograms written on September 3 and 10, 1899, by instruments at Victoria, British Columbia (Pl. XXVIII); Tokyo, Japan (Pl. XXXI); Kew, England (Pl. XXIX, *A*); Catania, Italy (Pl. XXXII, *A*); Batavia, Java (Pl. XXIX, *C*, *D*); and Cape Town, South Africa (Pl. XXX, *A*, *B*). For purposes of comparison, seismograms made at Kew, England (Pl. XXIX, *B*); Catania, Italy (Pl. XXXII, *B*); and Cape Town, South Africa (Pl. XXX, *C*), by the same instruments under essentially similar conditions during the earthquake of April 18, 1906, at San Francisco, Cal., are also reproduced. The comparison of the Kew record of the earthquake of September 3 in Alaska with the Kew record of the California earthquake shows that the latter was the stronger shock, the distances and paths being essentially equal and similar. The Catania and Cape of Good Hope records of the earthquake of September 10, 1899, in Alaska and the California earthquake of 1906 show the Alaskan earthquake to have been far more severe, as both the duration and the amplitude indicate (Pls. XXX, XXXII). The Tokyo records reproduced (Pl. XXXI) show both the shock of September 3 and that of September 10.

The Victoria, Kew, Batavia, and Cape Town records were made by light pendula of the Milne type, with slow-moving photographic registration; the Tokyo and Catania records were made by heavily weighted horizontal pendula with mechanical registration. The Italian instrument (Pl. XXXII) showed the motion in two planes at right angles.

LOCATION OF ORIGIN IN ALASKA FROM SEISMOGRAMS.

The location in Alaska of the origin of these earthquakes seems to have been first made by the veteran seismologist, John Milne,[5] on September 27, 1899, as a result of the study of seismographic records of three of them, which he refers to as "unusually large seismograms." Later [6] Milne more specifically located the origin of the Alaskan shocks of September 3 and 10 in the Pacific Ocean west of Alaska, near 150° west longitude and 50° north latitude. This location is of interest, especially as he notes on the map that "the Alaskan origin for earthquakes Nos. 333, 337, and 338 might possibly be moved 10° to the east." Probably this correction was made in view of a newspaper account of the Yakutat earthquakes printed in the London Times or one printed in the Toronto World and quoted in the report of the seismological committee for 1900. This correction would have made the location nearly right for longitude. Considering that the location of earthquake origins by computation was only in its infancy in 1900, this location only 10° too far west and 10° too far south is remarkable.

[1] Publ. Earthquake Investigation Committee in Foreign Languages, No. 5, 1901, Pls. VII, VIII; No. 21, 1905, Pl. XXXVI.
[2] Proc. and Trans. Royal Soc. Canada, 2d ser., vol. 9, 1903, sec. 3, plate opp. p. 71.
[3] Bull. Soc. belge d'astronomie, 5e année, No. 2, 1901, Pl. XII.
[4] Two earthquakes registered in Europe and at Batavia: Proc. Sec. Sci., Koninkl. Akad. Wetenschappen Amsterdam, vol. 2, 1900, plate opp. p. 246.
[5] Note dated Shide, Isle of Wight, Sept. 27, 1899, in Nature, Oct. 5, 1899, vol. 60, p. 545.
[6] Fifth report of the committee on seismological investigations: Rept. British Assoc. Adv. Sci., 1900, Pl. III, opp. p. 77.

With practice and refinement of method much closer location subsequently became possible. In a paper published in 1906 R. D. Oldham,[1] from computations based on the seismograph records, makes these shocks originate in about 59° 5′ north latitude, 140° 0′ west longitude, which is within less than a degree of the correct latitude and longitude.

Dr. F. Omori[2] gives the origin of these shocks as "about latitude 60° north and longitude 140° west," but it is not evident whether he computed this location from the seismograph records or inferred it from the newspaper report seen by him. He refers to it also as near Cape St. Elias, which would be less than 170 miles too far northwest.

Our own field study in 1905 would lead us to place the origin (assuming that there was a single point of origin and that it was near the fault line associated with the 47⅓-foot uplift, the greatest observed change of level of the land) at about 59° 58′ 20″ north latitude, 139° 33′ 0″ west longitude. This is certainly correct for the earthquake at noon on September 10.

TOPOGRAPHIC CHANGES FORETOLD BY MILNE.

In the seventh report of the committee on seismological investigations[3] the relation of these earthquakes to possible topographic changes is suggested by John Milne in the following paragraphs, which our subsequent field observations have abundantly confirmed. The subject was also discussed by Milne before the Royal Geographical Society.[4]

That there is a relationship between the distribution of the origins of large earthquakes and the pronounced irregularities on the surface of the earth will be seen from the following notes:

A. Alaskan region (number of earthquakes, 25).[5] The average depth of the water in this bight is about 2,000 fathoms, but in its northern part depths of 2,200 fathoms have been found within 60 miles of the shore. On this shore Mount St. Elias rises to a height of 18,000 feet. An average slope from the land to the sea on a north-south line can be found which exceeds 100 feet per mile. This is over a distance of 180 miles.

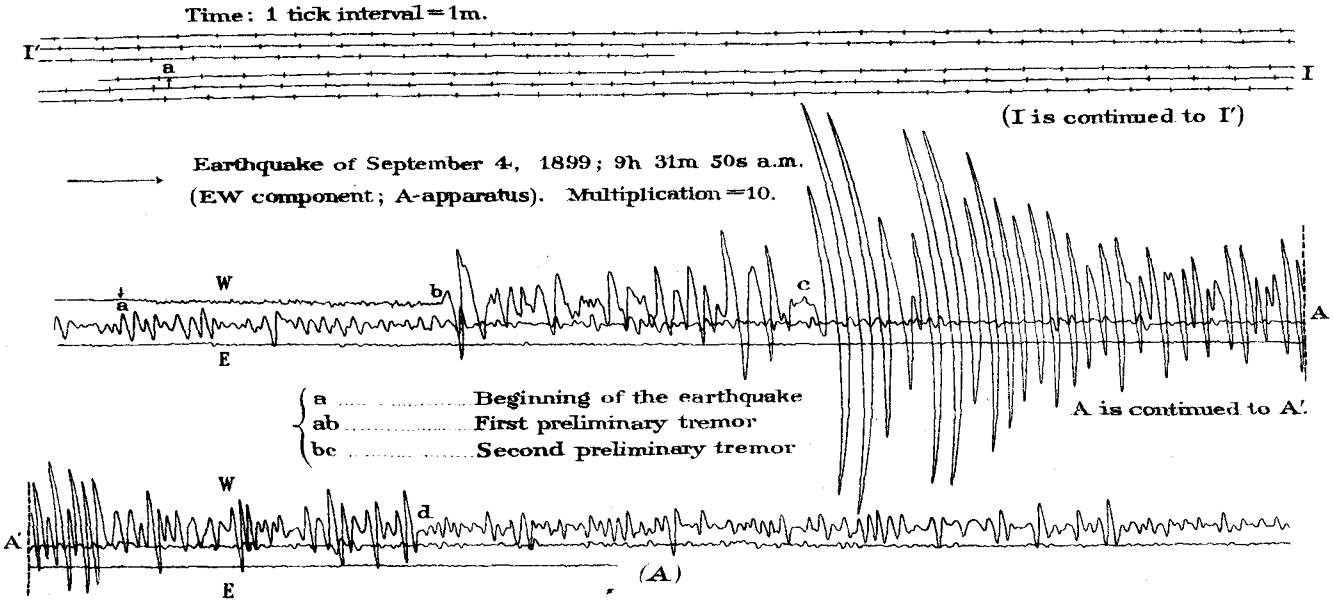
On the face of this and neighboring slopes during the last three years, it is probable that molar displacements of great magnitude have taken place. On September 10, 1899, in the island of Kanak [Khantaak], opposite Yakuta [Yakutat], a graveyard sank so that on the next day a boat was able to row over the place where it had been, and the tops of the submerged trees could be seen. Many of the earthquakes from this region have yielded large seismograms at the Cape of Good Hope, which is antipodean to Alaska. We have here a region partly belonging to the Aleutian Ridge, off the southern shores of which within 80 miles of land depths of 4,000 fathoms have been noted, where orogenic processes are now marked, the extent of which will probably be gaged by future soundings.

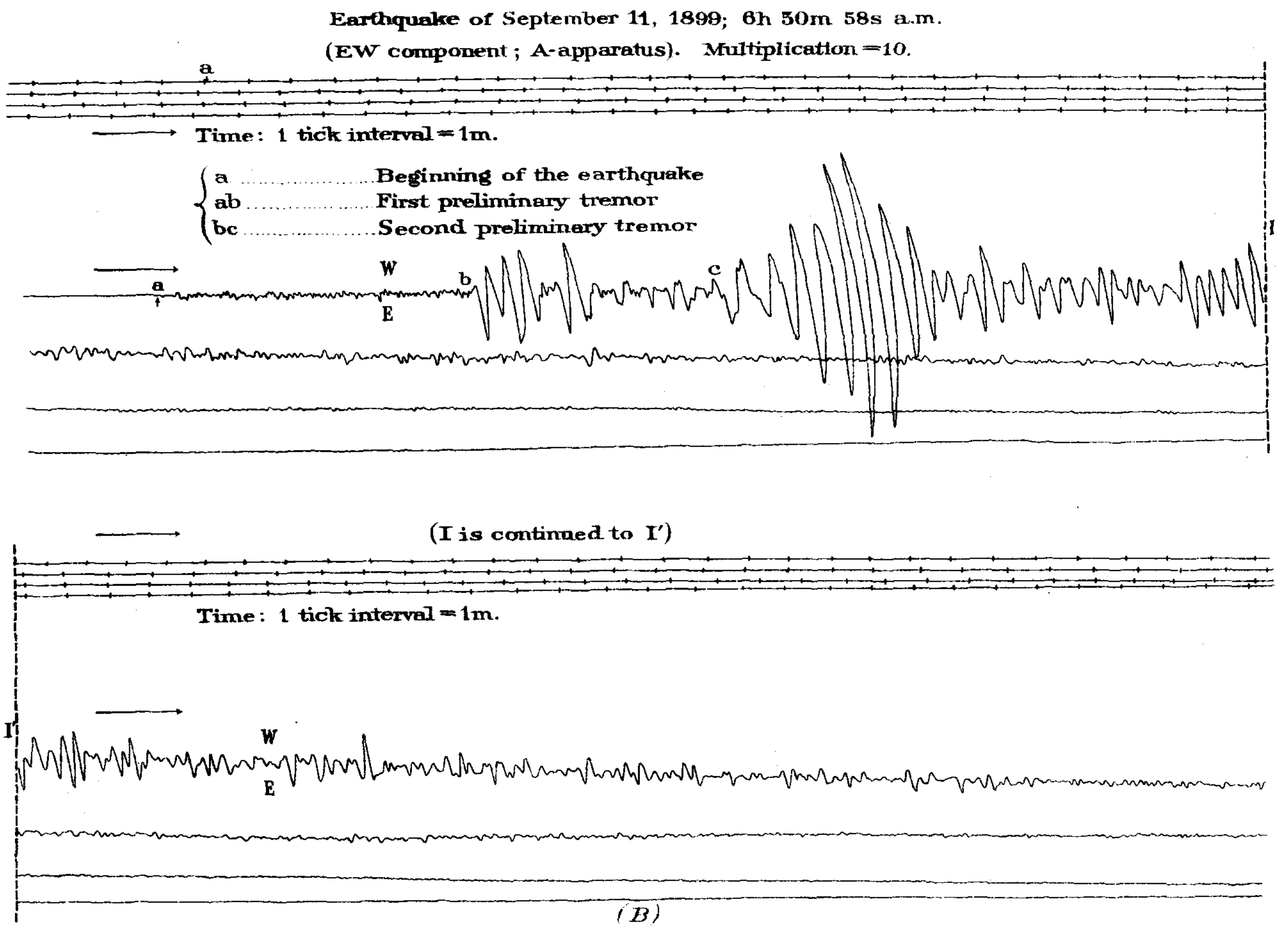
COMPUTATIONS FROM JAPANESE SEISMOGRAMS BY OMORI.

F. Omori makes use of the records of the Alaskan earthquakes, among other great shocks, to compute certain data. (See Pl. XXXI.) One such computation[6] brings him to the conclusion that the slow earthquake undulations are horizontal movements, not tiltings of the ground. Another[7] shows the relationship between the duration of the first preliminary tremors and the distance of the earthquake origin. One such series of computations by Omori, based on a duration at Tokyo of 7 minutes and 39 seconds for the first preliminary tremors of the shocks of September 3 and 10, checks with the actual distance to the origin in Alaska within less than 250 miles. A further consideration[8] of the same general problem, based, however, on the duration at Tokyo of the total preliminary tremor (September 3 shock, $14^{m} 23^{s}$; September 10 shock, $14^{m} 31^{s}$), comes even closer to the actual distance, being within about 150 and 200 miles, respectively, for the origins of these two shocks.

Still other computations[9] deal with the maximum ranges (double amplitudes) in the successive stages of motion of such distant earthquakes as these; with the periods of vibration in the different portions of the earthquakes; with the duration of their successive states of

[1] Constitution of the interior of the earth: Quart. Jour. Geol. Soc., vol. 62, 1906, p. 459.
[2] Publ. Earthquake Investigation Committee in Foreign Languages, No. 5, 1901, p. 62.
[3] Rept. British Assoc. Adv. Sci., 1902, p. 62.
[4] World-shaking earthquakes: Nature, vol. 67, 1902-3, p. 69.
[5] 1899-1902.
[6] Publ. Earthquake Investigation Committee in Foreign Languages, No. 5, Tokyo, 1901, pp. 47-51, 62.
[7] Idem, pp. 61-65.
[8] Idem, No. 13, 1903, pp. 86-88.
[9] Idem, No. 13, 1903, pp. 112, 114, 117, 121-123.





(A) SEISMOGRAM OF YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 3, 1899, FROM INSTRUMENT AT TOKYO, JAPAN.
(B) SEISMOGRAM OF YAKUTAT BAY EARTHQUAKE OF SEPTEMBER 10, 1899, FROM INSTRUMENT AT TOKYO, JAPAN.

motion, and with the average period and transit velocity of the earthquake waves which travel all the way around the earth. In the computation last mentioned Omori found that the vibrations set in motion in Alaska by the earthquake of September 10, took 2 hours 8 minutes and 47 seconds for the long journey around the world through the outer crust of the earth eastward from Yakutat Bay through the antipode of Alaska (W_2 waves) to Tokyo. They therefore had a velocity of 3.6 kilometers a second, or more than 8,000 miles an hour. Further computations[1] deal with the direction of motion, duration, period, and amplitude of motion, etc.

COMMENTS ON SEISMOGRAMS.

The seismograph records of the Yakutat earthquakes have been described and analyzed by several seismologists. Two rather complete descriptions from distant observations are here quoted. They deal with the seismograms of the earthquake of September 3 and the two shocks of September 10 as recorded at Tokyo, Japan, and at Catania, Italy, and indicate some of the differences in the record of the tremors set in motion at Yakutat Bay after they had traveled approximately 6,100 kilometers southwestward beneath the Pacific to Japan and after they had traveled half as far again eastward beneath the continent of North America and the Atlantic Ocean, or pursued the appropriate great circle routes around the earth or through its interior. The corresponding seismograms are reproduced in Plates XXXI and XXXII.

RECORDS FROM JAPAN.[2]

Earthquake No. 193.—September 4, 1899, 9^h 31^m 50^s a. m.[3] (east-west component). Total duration, three hours.

The first preliminary tremor, whose duration was 7^m 36^s, consisted of vibrations of an average period of 7.9^s (maximum double amplitude, 0.25 millimeters), superposed with still smaller ones of an average period of 18^s. The commencement was small and gradual but distinct, the amplitude remaining on the whole constant.

The second preliminary tremor lasted for 6^m 47^s and began with a motion of 0.46 millimeter toward the west, followed by a well-pronounced undulation, whose period was 34^s and which consisted of the two displacements, first, 2.5 millimeters toward the east; second, 4.1 millimeters toward the west. For the next 6^m 12^s the amplitude did not much vary and was slightly smaller than that of the above introductory wave, the average period being 25.2^s. After these took place two conspicuous undulations of an average period of 34.5^s, the first of which had the maximum double amplitude of 5.6 millimeters. There were also traces of slow undulations with an average period of 1^m 6^s. It is to be remarked that the second preliminary tremor was in this case not at all a small, insignificant tremor, but consisted of large well-defined waves.

The principal portion lasted for 22^m and began with seven large undulations, which together occupied 3^m 48^s, and had an average period of 32.6^s; the second having the (absolute) maximum double amplitude of 15.2 millimeters. These vibrations, which were apparently produced by the composition of the proper oscillations of the pendulum with the earthquake motion, were arranged as follows:

First motion: 5.5 millimeters toward the west; second motion, 11.3 millimeters toward the east; then followed the maximum motion above noted; the next vibration was a little smaller; the two next ones were small; then followed the second maximum double amplitude of 13.8 millimeters. After these the motion became quicker, the average period during the next 4^m 42^s being 23.5^s. For the next 4^m 51^s the motion consisted of well-defined vibrations, whose maximum double amplitude was 4.8 millimeters and whose average period 16.2^s. During the remaining part the average period was 14.9^s.

The end portion. For the first 26^m the motion was more or less large, the average period of the principal vibrations being 16.2^s. There were also traces of slower undulations of an average period of 51^s and of others of an average period of 24^s. During the next 12^m 30^s the principal waves had an average period of 20.8^s, superposed with smaller vibrations. From about 1^h 45^m after the commencement of the earthquake the motion consisted essentially of regular waves, whose average period deduced from three successive groups of 50 vibrations, was 10.4^s, 10.9^s, and 10.3^s; general means, 10.5^s.

Earthquake No. 196.—September 11,[4] 1899, 3^h 14^m 16^s a. m. (east-west component). Total duration, about three hours.

The first preliminary tremors lasted for 7^m 38^s and consisted of small vibrations of an average period of 6.8^s. The second preliminary tremors lasted for 6^m 53^s. The principal portion: The maximum double amplitude was 2.6 millimeters, and the average period was 32^s. The end portion: The average period measured at about 1^h after the commencement of the earthquake, was 10.4^s.

[1] Omori, F., Publ. Earthquake Investigation Committee in Foreign Languages, No. 21, 1905, pp. 60, 71, 76, 77, 79, 80, 85, 88, 89.

[2] Idem, No. 6, Tokyo, 1901, 48-51. Describes records from Hongo (Tokyo) observatory; a similar description based on records from the Hitotsubashi (Tokyo) observatory is found in Publ., etc., No. 13, 1903, pp. 96-99; No. 21, 1905, pp. 46-49.

[3] The time is given in the first normal Japan time, namely, that of longitude 135° E.

[4] September 10. Difference of time with difference in longitude.

Earthquake No. 197.—September 11, 1899, 6^h 50^m 58^s a. m. (east-west component). Total duration, four hours. This was a very large earthquake and, like the two preceding ones, originated off the southwestern coast of Alasca [Alaska]. It appears that, at the origin, shocks happened almost continuously after earthquake No. 196, the diagram showing more or less distinct traces of motion throughout the time interval between the latter and this earthquake.

The first preliminary tremors, whose duration was 7^m 43^s, consisted of small vibrations of an average period of 4.3^s superposed on larger ones of an average period of 9.3^s.

The second preliminary tremors, whose duration was 6^m 30^s, began with a well-defined displacement of 2 millimeters toward the east, followed by 14 large undulations with an average period of 27^s.

The principal portion, whose duration was about 15^m, began with four very slow undulations with an average period of 41^s. Then followed five large proper oscillations of the pendulum, their maximum double amplitude being 10.5 millimeters. The average period, measured at about 23^m from the commencement of the earthquake, was 24^s.

The end portion: The average period, measured at respectively 1^h, 2^h, and 3^h after the commencement of the earthquake, was as follows: 9.9^s (deduced from 57 vibrations); 9.8^s (deduced from 100 vibrations); 9.7^s (deduced from 60 vibrations); general mean, 9.8^s.

It will be observed that in the three foregoing earthquakes, Nos. 193, 196, and 197, the first preliminary tremors lasted for an almost exactly identical interval of time. This shows that these earthquakes originated very nearly at an equal distance from Tokyo. Assuming the position of their centers to be near the Cape St. Elias, the spherical distance between it and Tokyo would be about 6,100 kilometers.

RECORDS FROM CATANIA, ITALY.

THE YAKUTAT BAY EARTHQUAKES.[1]

September 4, 1899.—Large seismometrograph. From 1^h 34^m 42^s to 4^h 39^m 19^s [2] on the northwest-southeast component, and from 1^h 35^m 7^s to 2^h 47^m 51^s on the northeast-southwest component, seismic registration due to earth disturbance of very distant origin.

On the northwest-southeast component there is a preliminary phase from 1^h 34^m 42^s to 1^h 44^m 59^s, consisting of small undulations, the largest of which reaches about 1.5 millimeters, having a simple oscillatory period varying between 1^s and 3^s. Immediately after 1^h 44^m 59^s the movement increases a little in intensity and leaves on the paper zone undulations of an almost uniform amplitude of 1.5 millimeters and of irregular form, with a simple oscillatory period of 6^s for the greater part of them and of 5^s (per pendulum) for others; these undulations last until 1^h 58^m 2^s; after that hour the movement again increases in strength and there are undulations of an amplitude of 2 to 2.5 millimeters, with an oscillation period indeterminable on account of their irregularity.

A little before 2^h 9^m 28^s there are some undulations of a period of 12^s at 2^h 9^m 28^s; the maximum phase of the movement begins and lasts until almost 2^h 39^m 4^s. In this phase there is an absolute maximum at 2^h 13^m 23^s, represented by an undulation of an amplitude of 8 millimeters; after which the movement declines gradually and toward the end of the phase the amplitude is reduced to about 0.5 millimeter. From 2^h 39^m 4^s on, there come quite regular undulations with an amplitude of a little less than 2 millimeters and with a simple oscillatory period of 9^s, some of them having 7.5^s. These undulations last until almost 3^h 28^m 1^s; from the later hour up to 3^h 47^m 37^s there are not even vague traces of undulations similar to the preceding.

From 3^h 47^m 37^s to 4^h 0^m 28^s they reappear, and show quite plainly after 4^h 2^m 58^s; and in the period of time up to 4^h 29^m 31^s there is an amplitude of motion of about 1 millimeter and a simple oscillatory period of 9^s. The last signs of the diagram on the northwest-southeast component are from 4^h 29^m 31^s to 4^h 39^m 19^s.

On the northwest-southwest component the diagram is much shorter than that of the preceding component and begins at 1^h 35^m 7^s; up to 1^h 45^m 40^s we find only slight and insignificant disturbances. From 1^h 45^m 40^s to 1^h 48^m 30^s there are undulations which reach an amplitude of 3 millimeters, with a simple oscillatory period of 4.5^s, a little different from that of the pendulum, which is about 5^s. From 1^h 48^m 30^s to about 2^h 10^m 58^s there is another disturbance of very little significance. The maximum phase is between 2^h 10^m 58^s and 2^h 36^m 23^s, and consists of undulations which at 2^h 14^m 25^s reach an amplitude of almost 6 millimeters, with a simple oscillatory period varying between 7^s and 9^s. From 2^h 36^m 23^s to 2^h 47^m 51^s the diagram grows smaller and ceases altogether. (Riccò.)

September 10, 1899 (the early shock).—On the northwest-southeast component the first indications, hardly visible, of the seismic registration begin at 18^h 15^m 21^s; after about the first half minute, or at 18^h 15^m 45^s, they take well-defined shape as regular undulations, of an amplitude of about 0.75 millimeter, with a simple oscillatory period in the beginning of 3^s; after that, nearly equal to that of the pendulum, that is, 5^s. At 18^h 24^m 58^s the movement increases in force, and gradually, by 18^h 28^m 32^s, the undulations attain an amplitude of about 4 millimeters, maintaining the simple oscillatory period of 5^s. From 18^h 28^m 32^s the amplitude of the undulations diminishes somewhat, and after 18^h 36^m 39^s they assume an oscillatory period of 6^s, then 7.5^s, and many of them have the tracing disturbed by interference of a movement of different period; at 18^h 54^m 20^s and at 19^h 0^m 20^s there are two secondary maxima represented by two undulations of about 5 millimeters amplitude; this continues until 19^h 15^m 2^s, at which hour the amplitude of the motion is reduced to about 2.75 millimeters. After 19^h 15^m 2^s the movement gradually grows weaker and leaves undulations with a period

[1] Translated from Notizie sui terremoti osservati in Italia durante l'anno 1899, compilate dal A. Cancani: Boll. Soc. sismol. ital., vol. 6, appendice, 1900-1901, pp. 186-187, 196-197, 203-205.

[2] Subtract one hour to reduce to Greenwich mean time.

varying between 5^s and 7.5^s; at $20^h\ 17^m\ 50^s$ the movement is reduced to a very small matter; a little after this hour there are rather flattened undulations, which are hardly visible and of a somewhat longer period; these undulations are quite well defined at about $20^h\ 33^m\ 4^s$; and up to $20^h\ 57^m\ 7^s$ we find many which reach an amplitude of 0.75 millimeter, with a simple oscillatory period of about 9^s. From $20^h\ 57^m\ 7^s$ to $21^h\ 52^m\ 12^s$ we find only very small undulations of an indeterminable period which may be attributable either to the earth movement or to the action of the strong southwest wind which was blowing that night. (Riccò.)

September 10, 1899 (the heaviest shock.)—From $21^h\ 52^m\ 12^s$ to $22^h\ 2^m$ there are very small undulations hardly visible, some of which have a simple oscillatory period of 1^s and 1.5^s; immediately after $22^h\ 2^m$ they take a well-determined and regular form and attain an amplitude of 1 millimeter, continuing until $22^h\ 24^m\ 54^s$; from this time to $22^h\ 31^m\ 34^s$ they have a long period of undulation, much obscured, the tracing of which is disturbed by the interference of other movements of different period; in this interval of time they have a simple oscillatory period, varying from 9^s to 12^s. At $22^h\ 31^m\ 34^s$ there are other undulations with a prevailing period of 6^s and an amplitude of nearly 0.75 millimeter, which continue to $21^h\ 51^m\ 29^s$. Immediately after this time there is a continuous series of undulations, for the greater part with a simple oscillatory period of 4.5^s, which toward $23^h\ 6^m\ 24^s$ attain an amplitude of nearly 5.5 millimeters; at $23^h\ 6^m\ 47^s$ the movements nearly cease, but regain strength suddenly and leave upon the chart a series of 38 complete undulations, very regular, which altogether give a fusiform figure, somewhat swollen, and which from $23^h\ 7^m\ 35^s$ to $23^h\ 8^m\ 44^s$ attain an amplitude of 21 millimeters (absolute maximum); these undulations, with a simple oscillatory period equal to that of the pendulum, namely of 5^s, cease at $23^h\ 12^m\ 39^s$; and suddenly thereafter another series of undulations begin, the tracing of which is disturbed by movements of a different period, which at $23^h\ 28^m\ 39^s$ attain another secondary maximum represented by an undulation of an amplitude of 14 millimeters; at first, that is, a little after $23^h\ 12^m\ 39^s$, these undulations have a simple oscillatory period equal to that of the pendulum, but afterwards one of 12^s, especially as they approach $23^h\ 28^m\ 39^s$. From this time the amplitude of movement and the period of oscillation begin to diminish and so continue until $0^h\ 57^m\ 8^s$ of the succeeding day, the 11th, and in this long period of time there are undulations with a period of 18^s, afterwards of 12^s, and then of 7.5^s and of 6^s nearly to the end. At $0^h\ 57^m\ 8^s$ come waves with a long period of 12^s and an amplitude not exceeding 1 millimeter; these diminish little by little as they approach $2^h\ 14^m\ 42^s$; the amplitude and period gradually decrease almost to zero. Other disturbances appear at $2^h\ 14^m\ 42^s$, but these may be due to the strong southwest wind then prevailing rather than to seismic movement.

On the northeast-southwest component there is found a small tooth nearly 0.5 millimeter in height at $18^h\ 25^m\ 15^s$; an undulation of nearly 1 millimeter amplitude with simple oscillatory period of 3^s at $18^h\ 30^m\ 16^s$. From $18^h\ 52^m\ 37^s$ to $18^h\ 59^m\ 46^s$ there occur other undulations almost equal to the preceding in amplitude and period. Another tooth 0.33 millimeter in height is found at $19^h\ 25^m\ 20^s$; and from this time to $22^h\ 52^m\ 53^s$ there is a period of repose. From $22^h\ 52^m\ 53^s$ to $23^h\ 1^m\ 2^s$ there are other undulations of nearly 2 millimeters amplitude with simple oscillatory period of about 3^s, interrupted by an interval of repose. At $23^h\ 1^m\ 2^s$ there begins the massive phase on the northeast-southwest component, which consists of undulations that at first have a simple period of 6^s and then with the development of this phase go to 12^s. At $23^h\ 35^m\ 35^s$ they have their maximum with an oscillation of 9 millimeters amplitude.

After this latter time the movement declines. The oscillatory period diminishes to less than 3^s and at $23^h\ 59^m\ 24^s$ the diagram on the northeast-southwest ends. (Riccò.)

THE SAN FRANCISCO EARTHQUAKE.

For purposes of comparison the description of the record of the San Francisco earthquake of April 18, 1906, by the same instrument at Catania is quoted here,[1] the accompanying seismograms being shown in Plate XXXII, *B*.

We notice first of all that on that day [Apr. 18, 1906] the wind was strong, the sea very rough, and the seismograph slightly perturbed, but there is some uncertainty as to the precise moment of the beginning and the ending of the seismogram which we are examining. In spite of this, on the northeast component it appears that the first indications of the seismic movement begin at $14^h\ 26^m\ 5^s$. Between that time and $14^h\ 37^m\ 27^s$ there are very small undulations, not larger than 0.5 millimeter, with an oscillatory period of 4^s to 6^s. At $14^h\ 37^m\ 27^s$ the movement becomes more perceptible, and at $14^h\ 42^m\ 26^s$ there is an undulation of the amplitude of 1 millimeter, with a period of 6^s. At $14^h\ 49^m\ 58^s$ the aforesaid undulation disappears almost entirely, to give place to others which are irregular and of slow indeterminable period up to $14^h\ 53^m\ 14^s$; after that moment the said undulations take definite shape, showing in the beginning a period of 18^s, after which it decreases, while the amplitude increases, reaching almost 9 millimeters at $15^h\ 12^m\ 51^s$; from $15^h\ 12^m\ 51^s$, at latest, the movement declines gradually, with undulations of diverse oscillatory periods varying from 5^s to 9^s; these disappear at about $17^h\ 13^m\ 41^s$.

On the northwest component between $14^h\ 26^m\ 5^s$ and $14^h\ 35^m\ 23^s$ there are quite small undulations of an oscillatory period varying from 2^s to 3^s. The said undulations become a little more perceptible between $14^h\ 35^m\ 23^s$ and $14^h\ 45^m\ 26^s$. At $14^h\ 56^m\ 22^s$ they again become very small; after $14^h\ 56^m\ 22^s$ the undulations begin again to manifest themselves in slow irregular period, and at $15^h\ 7^m\ 8^s$ reach an amplitude of 9.5 millimeters, with a period of about 9^s, and then little by little they decline toward $16^h\ 16^m\ 45^s$.

[1] From unpublished data furnished to the writers by Dr. Emilio Oddone.

MISCELLANEOUS COMMENTS.

Other seismograph records are commented on, as stated below, in the reports of the seismological committee of the British Association for the Advancement of Science and in other seismologic publications and manuscripts furnished to the writers by the observatories.

In the seismograph at Victoria, British Columbia, the nearest one to Yakutat Bay, in 1899, the amplitude recorded was so great that in one shock the pen went off the paper, the record (reproduced hree as Pl. XXVIII p. 102), being noted [1] as a "very large quake," while one of the minor shocks showed an amplitude [2] of 7.5 millimeters. John Milne [3] comments on this Victoria record of the earthquake of September 3 (Shide No. 333) as "of particular interest as indicating that the time taken for an earthquake to travel round the world or to traverse two diameters slightly exceeds 210 minutes."

On the same day the Toronto instrument [4] registered an amplitude of 24 millimeters, the total swing of the boom being, therefore, nearly 2 inches.

In South America, at Cordoba, Argentina,[5] there was an amplitude of 6.5 millimeters during this same shock, the record of which was here "followed by thickening of line and pulsations which gradually merged into the following shock," about four hours later.

The earthquake of September 3, as recorded on the seismograph at Shide, in the Isle of Wight, England, had a recorded amplitude of 15 millimeters. It is recorded [6] that "at the maximum the boom was caught by eclipse plate of the watch."

At Kew, near London, the same shock is referred to [7] as "the second largest [8] disturbance recorded during the year. (See Pl. XXIX, *A*, p. 102.) There was an interval of 17.4 minutes between the commencement of motion and the maximum phase, and 4.3 minutes between the maximum and its apparent repetition. The repeat shocks are clearly visible till $2^h\ 3^m$."

At San Fernando, Spain,[9] where the shock of September 3 was registered by an amplitude of 8.17 seconds of arc, there were "no preliminary tremors; the commencement was great motion."

At Mauritius,[10] an island in the Indian Ocean east of Africa and Madagascar, in position nearly antipodean to Yakutat Bay, the earthquake of September 3 was described as "the largest disturbance recorded at Mauritius and does not admit of description. Tracings will be published [11] in the volumes of observations for 1899." This ocean station records only about one-fourth of the shocks registered at the Isle of Wight and about a third of those registered at Bombay.

This shock and the one of September 10 showed the following times and amplitudes: [12]

Record of Yakutat Bay earthquakes as registered at the island of Mauritius.

Date.	Time of maximum.	Half amplitude.	
		Millimeters.	Seconds.
1899.	h. m.		
Sept. 4	1 51.5	23	5.70
Sept. 10	19 1.0	1.6	.52
Do.	19 13.5	1.6	.52
Do.	23 7.2	4.5	1.47
Do.	23 15.0	4.4	1.44

1 Judd, J. W., and Milne, John, Seismol. Circ. No. 2: British Assoc. Adv. Sci., p. 38, register Nos. 71–74.
2 Half the complete range of the maximum motion.
3 Rept. British Assoc. Adv. Sci., 1900, p. 69.
4 Seismol. Circ. No. 2, British Assoc. Adv. Sci., p. 36, Toronto No. 116.
5 Idem, p. 50, Nos. 84–85.
6 Judd, J. W., and Milne, John, Seismol. Circ. No. 1, British Assoc. Adv. Sci., p. 3, Shide No. 333.
7 Idem, p. 9, Kew register, No. 142.
8 The largest being the earthquake of September 10, at Yakutat Bay.
9 Idem, p. 14, Register No. 35.
10 Idem, p. 17, Register No. 23.
11 See Rept. British Assoc. Adv. Sci., 1900, p. 96.
12 Record from director of Royal Alfred Observatory, Colony of Mauritius.

The commencement of each shock was masked by air tremors.

At Victoria, British Columbia, about 1,000 miles from the Yakutat Bay origin, the shocks of September 10 were recorded by the seismograph, but the records for that whole week were lost in the mails. Nothing more unfortunate could have occurred from the point of view of the student of these Yakutat Bay earthquakes, for this was then the instrument nearest to the faulted zone from which the shocks emanated. The Victoria observer [1] characterizes the record of September 10 as a "splendid seismogram lost in mails."

In an interview with the observer, Napier Denison,[2] these records of September 10 are discussed as follows, the discussion having been based upon a description written before the records were lost:

The first of these [shocks] occurred at 9.10 a. m. on the 10th, as a small tremor, followed three minutes later by the greatest shock ever recorded on this instrument, causing the "boom" to swing over 1 inch. A lull then ensued till 1 p. m., when a smaller shock occurred, followed at 1.45 p. m. by another severe one which lasted nearly two hours.

At Toronto, Canada,[3] the shocks of September 10 caused "vibrations across paper." At Cordoba, Argentina,[4] the amplitude (5 millimeters) was not quite as great as that recorded on the same instrument by the Yakutat shock of a week before.

The first of the seismograms recorded at Kew, England, on September 10 [5] was "a well-marked record, showing an apparent interval of 27.5^m between the commencement of the larger motions and the maximum oscillations, with three distinct groups in the time. The 'repeat' phases are fairly traceable for 25^m."

The second shock of September 10 (No. 145) was—

by far the largest disturbance yet recorded at Kew, and owing to the crossing of the photographic traces the magnitude of the maximum oscillation is a little uncertain, but it certainly exceeded 10.8 [seconds of arc]. The duration of the preliminary tremors was abnormally long, followed by an interval of 20^m before the maximum was reached, and the swings exceeded 5″ for over 2^m. The "repeat" shock, starting at 22^h 25.6^m, was also unusually prolonged, having a total duration of 5^m. The large waves ended abruptly at 22^h 47^m and the subsequent swings were small.

At San Fernando, Spain, the earthquake of September 10 was registered by an amplitude of 14.62 seconds of arc, nearly twice that of the earthquake of September 3 and three and a half times the next largest amplitude recorded at this station from July to December, 1899.

At Mauritius [6] the earthquake of September 10 was far less in amplitude than that of September 3. (See record on p. 108.)

R. D. Oldham [7] comments on the records of the earthquake of September 3 and the two on September 10 made by the seismograph at Cape Town (see Pl. XXX, *A*, *B*, p. 102), 150° from the point of origin, as follows:

In all of them the commencement is almost imperceptible and the recorded times, as compared with the times of origin, show that it was too late to represent the first phase of the original impulse, except possibly in the case of the third of these shocks, which gives an interval of 2.5 minutes. The second phase is well marked on all the records; and the times, as determined by me, on photographic copies of the original records, give intervals of 44.6, 45.7, and 45.5 minutes, respectively;[8] the true interval, therefore, may be taken as about 45 minutes or a little more.

J. Kortazzi [9] makes the following notes regarding the records of a horizontal pendulum at Nicolajew, in Russia, at the time of the Alaska shocks of September 3 and 10, 1899:

September 4. Commencing at 1^h 33^m the line suddenly disappears; its traces become visible about 3 o'clock, when the point inclines 24 millimeters (pendulum to the south); at 4^h 22^m the vibrations diminish, but feeble shocks continue until 7^h 20^m.

September 10. Commencement, 18^h 14.5^m; maximum, 18^h 24^m; the trace disappears; the shocks grow feebler at 20^h 32^m. Commencement, 21^h 57^m; maximum, 22^h 14^m; the trace disappears.

September 11. At 0^h 47^m the pendulum inclines 16 millimeters to the south; the shocks grow feebler until 2^h 7^m and end at 5^h 22^m.

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1 Seismol. Circ. No. 2, British Assoc. Adv. Sci., p. 38, No. 80

2 Victoria Semi-Weekly Colonist, Sept. 21, 1899.

3 Seismol. Circ. No. 2, British Assoc. Adv. Sci., p. 36, Toronto Nos. 126, 127.

4 Idem, No. 1, p. 51, Nos. 89, 90.

5 Judd, J. W., and Milne, John, Seismol. Circ. No. 1, British Assoc. Adv. Sci., pp. 6, 9, register Nos. 144, 145.

6 Idem, p. 14, 37 bis.

7 Quart. Jour. Geol. Soc., vol. 62, 1906, pp. 460–461.

8 In the first case the time is a little uncertain, owing to the failure of the occulting watch. See Seismol. Circ. No. 1, British Assoc. Adv. Sci. 1900.

9 Gerland's Beitr. Geophysik, vol. 4, 1900, pp. 404–405. Times given in Central European time, one hour faster than that of Greenwich.

At Jurjew (Dorpat), Russia, the earthquake of September 3 and the two on September 10 were recorded by three seismographs, producing records as follows:[1]

Records of earthquakes of Sept. 3 and Sept. 10, 1899, made at Dorpat, Russia.[a]

Earthquake of Sept. 3.

Pendulum.	Commencement of preliminary tremors.	Duration.	Maximum.	End.	One half amplitude in millimeters.
	h. m.	*h. m.*	*h. m.*	*h. m.*	
No. 1	0 33.2	.. ....	0 34.6	.. ..	$3\frac{1}{2}$
		0 36.0	0 38.3	.. ..	$4\frac{1}{2}$
		0 40.5	0 42.5	.. ..	$4\frac{1}{2}$
		0 43.9	.. ....	.. ..	....
		[b] 0 47.6	.. ....	6 59	....
No. 2	0 33.2	0 35.3	0 33.7	.. ..	3
		[c] 0 40.8	.. ....	6 23	....
No. 3	0 33.2	.. ....	0 35.0	.. ..	
			0 37.7	.. ..	} 25–30
			0 38.6	.. ..	
		[d] 0 40.4	.. ....	.. ..	
		2 23.9	3 7.8	.. ..	25
		3 59.0	.. ....	.. ..	....
		4 30.3	.. ....	.. ..	13
		5 21.2	.. ....	.. ..	$8\frac{1}{2}$
		.. ....	5 26.0	7 47	15

Earthquakes of Sept. 10.

Pendulum.	Commencement of preliminary tremors.	Duration.	Maximum.	End.	One half amplitude in millimeters.
No. 1	17 13.9	17 22.5	17 24.6	.. ..	5
		[e] 17 26.4	.. ....	.. ..	....
		18 49.0	.. ....	.. ..	....
		21 4.8	.. ....	.. ..	5
		21 50	.. ....	26 29	15
No. 2	17 13.9	[e] 17 22.6	.. ....	26 5	....
No. 3	17 13.9	17 22.6	.. ....	.. ..	$6\frac{1}{2}$
		[f] 17 24.1	.. ....	.. ..	....
		18 22.9	18 26.8	.. ..	39
		18 34.9	18 36.9	.. ..	$27\frac{1}{2}$
		18 39.7	18 43.8	.. ..	$33\frac{1}{2}$
		18 51.7	.. ....	.. ..	....
		20 52.9	.. ....	.. ..	21
		21 2.1	.. ....	.. ..	....
		21 16.8	21 20.6	.. ..	$23\frac{1}{2}$
		[g] 21 52.6	.. ....	.. ..	....

[a] Sept. 3 in Alaska, Sept. 4 at Dorpat. Times recorded in Greenwich mean time. Because of the insufficient sensibility of the papers the pictures of the vibrations of the light points are very weak.
[b] After this moment the traces of the light points on the seismogram are no longer to be distinguished because of the too powerful vibrations.
[c] Because of the weakness of the picture the traces of the light points disappear after this moment.
[d] After this moment the traces of the light points are no longer to be distinguished.
[e] Because of the weakness of traces of the light points the determination of the moments are impossible up to the following phases.
[f] Followed by rapidly increasing vibrations with amplitudes of not less than 120 millimeters.
[g] This moment is the beginning of a new, very powerful disturbance, whose phases can not be distinguished because of the weakness of the picture. Amplitudes of vibrations of not less than 200 millimeters.

J. P. van der Stok[2] compares the records of the shock of September 10 at Strassburg, Germany, and Batavia, Java (see Pl. XXIX, *D*), stating that—

From these records we may conclude that the center of the disturbance is situated at a greater distance from Batavia than from Strassburg; first, because preliminary tremors have been registered at the latter place about 21^h; second, because the epoch of the maximum disturbance at Batavia is about one hour later than at Strassburg; and, third, because the duration is considerably less at the former than at the latter station.

The last argument is, however, questionable owing to the difficulty of fixing the characterizing epochs.

The following data are provided by the seismograms:

September 10, 1899. Greenwich mean time:

	Strassburg.	Batavia.
Preliminary tremors, beginning	20^h 58.9^m	
maximum	21 8.2	
beginning	21 54.3	22^h 7.0^m
maximum	21 58.9	22 54.5
end	24 28.9	23 19.5
Duration	2 34.6	1 12.5

[1] Data supplied by Prof. G. Lewitzky, July 15, 1909.
[2] Two earthquakes registered in Europe and at Batavia: Proc. Sec. Sci. Koninkl. Akad. Wetenschappen Amsterdam, vol. 2, 1900, pp. 244-246.

E. Lagrange[1] comments on the seismogram of the earthquake of September 3 at Uccle, Belgium, as follows:

September 4,[2] 1899. The plate which accompanies this note reproduces the seismic tracing of two of the pendulums. The curves I, II, and III are given by the stationary mirror and the two west and north-south pendulums. The other curves are due to the movement of the roll in the contrary direction, each roll serving twice, and do not belong to the phenomenon which we are now considering. It may be remarked in passing that the perturbations of D are due to the wind and are therefore relatively feeble; the curves C and B are a good example of what the Germans call microsismiche unruhe (microseismic unrest).

But to return to the curves II and III. The earthquake began suddenly at $0^h 18^m$ (Uccle), on the 4th of September, or $1^h 0^m 38^s$ T. H. C. The maximum agitation, which lasts about five minutes, takes place about $1^h 31^m$ T. H. C.; then follow almost uniform oscillations, continuing for about half an hour. The seismic disturbance then diminishes little by little. It shows a marked recovery about $5^h 40^m$, which lasts about an hour; this is not represented on the plate before the reader.

All this period from the 1st to the 10th of September is extremely agitated; from the 2d to the 8th the curves register nine tremors and a light shock, on September 6, at $3^h 41^m$ T. H. C., perceived also at Quarto (Florence).

According to the newspapers, on the 3d of September 53 shocks were felt on the coast of Alaska during five hours. At the head of Yakutat Bay a chasm opened suddenly, into which the sea poured. In India, as we are informed from Darjiling, the same day there were very strong shocks, which caused the fall of dwellings and many injuries; considerable displacements occurred in the mountains. It is probable that the period of agitation which we noted at Uccle is not unrelated to these distant phenomena.

At Grenoble, France,[3] the seismograph record of the heavy disturbance of September 10, 1899, consisted of a light shock northeast at $22^h 3^m 40^s$.

Seismograms from Göttingen, Germany, sent us by Dr. L. Geiger, show the shocks of September 3 and 10, 1899, as recorded at the Geophysikalisches Institut.

At Hamburg, Germany, seismographs at the Hauptstation für Erdbebenforschung am Physikalischen Staats-Laboratorium show records with the triple horizontal Rebeur-Ehlert pendulum (undamped) on September 4 and 10, 1899, as follows:[4]

September 4, 1899: Beginning of the tremor (sharp, powerful shock) at $0^h 33.4^m$, mean Greenwich time.

Further information is impossible, as, in consequence of the rather large dimension of impact, the lines of the recorder became weak and soon left the recording sheet.

September 10, 1899: Beginning of the tremors (sharp, powerful shock) at $17^h 13.7^m$, mean Greenwich time. Beginning of the second tremor:

North pendulum	$17^h 22.8^m$, mean Greenwich time.
Middle pendulum	$17^h 22.5^m$, mean Greenwich time.
South pendulum	$17^h 22.8^m$, mean Greenwich time.

During the period of the second tremor the recording became so weak that it was impossible to take correct measurements. The north pendulum left the paper about an hour after the beginning of the quake.

The record of the middle and the south pendulum indicates between 21^h and 22^h, mean Greenwich time, a new powerful shock, but the beginning of this can not be traced, as the final record of the previous quake covers the lines. Also further information seems impossible because of this large shock and the faintness of the recording lines. Indications of the middle pendulum disappear entirely from the sheet at $22\frac{1}{2}^h$, mean Greenwich time. The south pendulum comes to rest September 11, about 2^h, mean Greenwich time.

At Strassburg, Germany,[5] these earthquakes showed the following at the Kaiserliche Hauptstation für Erdbebenforschung:

Record of Rebeur-Ehlert horizontal recording pendulum at Strassburg. At this time the sources of light were very weak and the curves consequently very faint. Only one of the three pendulums gives a significant record. The hours given are in middle European time, or that of one hour east of Greenwich.

Record of middle pendulum, east-west:

September 4, beginning of first disturbance, $1^h 5.1^m$; beginning of second disturbance, $1^h 15.0^m$.

Further readings are impossible because the lines of the pendulum become confused with lines of the south pendulum.

September 10, beginning of first disturbance, $17^h 46.3^m$; beginning of second disturbance, 17^h, 56.2^m.

September 10, beginning of first tremor [of the heaviest earthquake], $22^h 23^m$, 22.5^s. The recording time here breaks off abruptly.

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[1] Les mouvements sismiques en Belgique en 1899: Bull. Soc. belge d' astronomie, 5e année, No. 2, 1901, p. 4.
[2] September 3. Difference in time with difference in longitude.
[3] Reboul, Paul, communication dated December, 1908.
[4] Schütt, R., communication dated December, 1908.
[5] Rudolph, A., communication dated May, 1909.

At Kremsmünster, Austria, the shock of September 3, two on September 10, and one each on September 15, 23, and 26, gave seismograph records which P. F. Schwab [1] has described.

At Trieste, Austria, the shocks of September 3, 10, 17, 23, and 26 were recorded by a Rebeur-Ehlert horizontal pendulum seismograph, the records being made by Mazelle.[2]

These shocks were also recorded at Laibach, Krain, Austria, and described by Belar.[3]

At Batavia, Java, the seismograph at the Koninklijk magnetisch en meteorologisch Observatorium did not permit the identification of the shock of September 3 because of disturbance by air tremors. Both shocks on September 10 were clearly recorded, however.[4] (See Pl. XXIX, *C*, *D*, p. 102.) R. D. N. Verbeek [5] characterizes the record of the second shock, which had a duration of 134 minutes, as "a very remarkable disturbance." F. H. Staverman [6] states that the printed records of these shocks in volume 22 of the observatory record cited above are erroneous in some particulars and should read as follows:

September 10, 1899, Greenwich mean time:

First preliminary tremor.	Second preliminary tremor.	Principal portion.
$17^h\ 15.8^m$	$17^h\ 28.7^m$	$17^h\ 43.1^m$
$21^h\ 54.5^m$	$22^h\ 7.4^m$	$22^h\ 21.8^m$

(Batavia observatory $7^h\ 7.3^m$ east of Greenwich.)

No. 164 copy should be the same as No. 114 in the printed report; No. 165 copy as No. 115; Nos. 164 and 165 are taken from the original register. On No. 164 no first preliminary tremor can be seen.

The duration of the preliminary tremors given in the printed report (2.9^m) must be erroneous; I suppose $13^m \pm$ for the first preliminary tremor agrees very well with copy No. 165.

This correction is of interest in view of the fact that C. G. Knott,[7] writing respecting the propagation of the large waves nine years before, suggested that there might be some error in the Batavia record of the earthquakes of 1899 in Alaska because the time records at this observatory were almost the only ones that failed to come in their proper place in relation to neighboring records.

INTERVALS AND TIMES OF MAXIMA COMPUTED BY OLDHAM.

From some of the best of these distant records, R. D. Oldham [8] has computed the intervals and times of maxima of the three severest Yakutat shocks, as follows:

Intervals and times of maxima of three heavy shocks at Yakutat Bay.

Place of observation.	Distance from epicentra.	Calculated interval at 3 kilometers per second.	Recorded time of maxima after origin.		
			No. 333.[a]	No. 337.[a]	No. 338.[a]
	Degrees.	*Minutes.*	*Minutes.*	*Minutes.*	*Minutes.*
Victoria	14.2	8.8	12.0		
Toronto	39.0	24.2	23.5	23.8	23.6
Tokyo	55.5	34.4	28.5		29.5
Do.			30.0		
Kew	64.4	39.9	42.5	48.6	41.1
Shide	65.1	40.4	41.0	46.3	44.0
Do.			41.2		
Trieste	73.0	45.3	68.4	54.0	48.5
Do.		45.3	71.0	48.6	46.4
Do.		45.3	51.0	46.3	46.9
Padua	73.1	45.4	54.5	50.5	47.5
Do.		45.4	60.5	55.5	46.5
Do.		45.4	54.5	50.0	45.5
Do.		45.4	60.5		47.5

[a] No. 333 is the hard shock of Sept. 3; Nos. 337 and 338 those of Sept. 10, the last being the heaviest shock of all.

NOTE.—For a slightly different result, with some of the same data, see Rept. British Assoc. Adv. Sci., 1900, p. 77.

[1] Berichte über Erdbebenbeobachtungen in Kremsmünster: Mitt. Erdbeben-Comm. K. Akad. Wiss. Wien, vol. 15, 1900, pp. 42–45.

[2] Mazelle, Eduard, Erdbebenstörungen zu Triest: Mitt. Erdbeben-Komm., Sitzungsber. K. Akad. Wien 17 Bd. 109 Abth. 1, Feb., 1900, pp. 116–123.

[3] Belar, A., Boll. Soc. Seism. Ital., vol. 6, 1900–1901, pp. 190, 208, 227.

[4] Nos. 114 and 115, Obs. Magn. Meteorol. Observatory Batavia, vol. 22, pt. 1, 1899.

[5] Communication dated Dec. 3, 1908.

[6] Communication dated Jan. 7, 1909.

[7] Fifth Rept. Comm. Seismol. Invest.: Seventieth Rept. British Assoc. Adv. Sci., 1900, pp. 74–75

[8] Unpublished manuscript loaned to the writers.

Intervals and times of maxima of three heavy shocks at Yakutat Bay—Continued.

Place of observation.	Distance from epicentra.	Calculated interval at 3 kilometers per second.	Recorded time of maxima after origin.		
			No. 333.	No. 337.	No. 338.
	Degrees.	*Minutes.*	*Minutes.*	*Minutes.*	*Minutes.*
Quarto	74.3	46.1	49.5	47.5	46.2
Do		46.1	49.5	47.5	60 5
Do		46.1	48.5		
Rome	76.5	47.4		53.8	42.5
Do				51.5	44.5
Rocca di Papa			47.5	54.1	46.3
Do			65.1	54.1	45.3
Do			52.5	48.7	
Do			51.3		
Do			52.7		
San Fernando	76.8	47.6	56.5	48.2	45.4
Ischia	77.7	48.2	52.5		55.5
Do			66.0		
Catania	81.3	50.7	53.1	52.8	49.1
Do			54.1	58.8	56.1
Bombay	97.5	60.5	58.0	57.3	58 6
Batavia	107.5	66.6		71.7	76.8
Cordoba	109.3	67.8		69.3	83.3
Mauritius	138.0	85.6	91.0		87.7
Cape Town	149.6	92.8	91.0	90.5	84.7
Do	210.4		111.5	107.5	102.0
San Fernando	283.2		169.0		
Rocca di Papa	283.5		169.5		
Trieste				131.5	
Toronto	321.0		214.5		194.5
Victoria	345.8		219.5		

COMPARISON OF SEISMOGRAPH RECORDS AND LOCAL ACCOUNTS.

The seismograph records made in various parts of the world, of which the writers have seen descriptions, indicate profound seismic disturbances on several dates in September beside the 3d and 10th, notably on the 17th, 20th, 23d, 26th–27th, and 29th, nearly all being recorded at Victoria, Toronto, Cordoba, Shide, Kew, the Italian observatories, San Fernando, Madras, Colaba (Bombay), Mauritius, Batavia, Tokyo, Cape Town, and doubtless elsewhere.

The record of September 20 belongs to the destructive earthquake at Aidin (Smyrna), in Asia Minor; no disturbance was reported at Yakutat or on the Copper River delta on that date. On September 29 there was a violent shock in Ceram, East Indies, but a notable shock is also recorded on the Copper River delta that day, so the seismograph records might belong either to Alaska or to the East Indies; but the smallness of amplitude (2.5 millimeters) of the record of September 29 at Victoria (then the nearest seismograph to Alaska), compared with that of the other Yakutat shocks, leads us to suspect that the record written by the world's seismographs is that of an earthquake in the East Indies, with which a small aftershock of the Yakutat Bay earthquakes, felt on the Copper River delta and elsewhere, happened to coincide in date. The exact time of the observation on the Copper River delta is not available for settling this question. The coincidence of the other dates, notably September 23 and 26 to 27, in world-wide seismograph records and local observations at Yakutat, Copper River delta, Skagway, etc., marks these as world-shaking Alaskan earthquakes.

The earthquake of September 26 [1] had an amplitude of 7.4 millimeters at Victoria and 4.1 millimeters at Toronto; that of September 23 first had an amplitude of 17 millimeters at Victoria and then went clear across the paper. The shock of September 15, though severe at Yakutat and Skagway, rather unexpectedly failed to record itself on the distant seismographs. The shock of September 17, the only remaining one of those everywhere recorded on the seismographs during this month, is not apparently of Yakutat origin or satisfactorily correlated with the disturbances in Alaska, although C. L. Andrews states that shocks occurred at Skagway on

[1] Seismol. Circ. No. 2, British Assoc. Adv. Sci., pp. 37-39

"three Sundays consecutively," perhaps September 3, 10, and 17, and a shock is reported at Juneau on September 17. The shock on the 17th may have had its origin elsewhere in the mountains, therefore, and have been a local shock, sensible at Skagway and Juneau but not at Yakutat. The evidence on this question is not conclusive because of the incompleteness of the Alaska time records.

TABLES OF SEISMOGRAPHIC DATA ON YAKUTAT EARTHQUAKES.

In the following tabular statement we have put together enough data from the available seismograph records [1] to show the progression to distant parts of the world of the earth tremors set in motion by the Yakutat Bay faulting and earthquakes. This has been done for the three most severe earthquakes, one on September 3 and two on September 10, the seismograph records of the other Alaskan shocks of September, 1899, being neglected.

No attempt is made to analyze these records further or to show which time records belong to the direct, fast waves that traverse the earth's interior (preliminary tremors), and which belong to the slower waves that follow the earth's crust. This analysis could have been made in more detail from the seismograms themselves. The study of the unfelt shocks whose autographs are written on the world's seismograms is interesting, but it is one in which we lack training for going further, as experienced seismologists quoted elsewhere in these pages have done. The local time records are too meager to permit our going much further even if we would. It is sufficient to point out that the tables show an orderly progression in time, duration, and intensity as the earthquake waves moved from their point of origin in Alaska outward to the antipodes, where the waves cross and return to the point of origin, as Oldham has shown in another table (pp. 112–113).

These tables are based on old calculations and, as a result of recent seismological studies, trained seismologists might now determine the times and occurrences of some of the shocks with slightly greater accuracy. Prof. H. F. Reid has called the attention of the authors to the fact that the recorded maxima on seismographs with little damping are largely instrumental and do not correspond to the greatest movement of the earth.

Progress of shock of September 3–4.

[All time records reduced to Greenwich mean time.]

Place of observation.	Commencement of preliminary tremors.[a]	Duration (minutes).	Maximum.	End.	Amplitude.		Total duration.
					Millimeters.	Seconds of arc.	
Disenchantment Bay, Alaska	[b] $0^{h}\ 21^{m}\ 40^{s}$						
Cape Whitshed, Alaska	[b] [c] 0 23 38						
Victoria, British Columbia	0 26 13		$0^{h}\ 35^{m}\ 9^{s}$	$8^{h}\ 0^{m}\ 0^{s}$	Off paper.		
Toronto, Canada	0 30 14		0 48 19		24.0		$7^{h}\ 54^{m}\ 19^{s}$
Tokyo, Japan	[d] 0 30 65				[e] 1.35		1 17
Kew, England	0 33.6	8.3	[f] 1 3.0			7.49	2 49.2
Shide, England	[g] 0 35.0	53.8	1 1.5		[h] 15.0		
San Fernando, Spain	0 33.6		1 7.1			8.17	3 19.9
Bombay (Colaba), India	0 45 25		1 18 34	3 9 51		4.66	
Cordoba, Argentina	[i] 0 40.8	16	1 52.4		6.5		3 14.6
Mauritius, Indian Ocean			[j] 1 51.5			5.70	
Cape Town, South Africa	0 46.2	60	[k] 1 51.5			2.5	

[a] Times at Alaskan localities placed in this column for convenience though the records are not seismographic and the time given may not be exact.
[b] Not seismographic, but based on careful local time observations.
[c] Computed by R. D. Oldham from seismograph records as $0^{h}\ 20^{m}\ 30^{s}$.
[d] $0^{h}\ 31^{m}\ 52^{s}$.
[e] Amplitude of principal portion given elsewhere as 15.2 millimeters.
[f] First maximum, $1^{h}\ 3.0^{m}$; second maximum, $1^{h}\ 7.3^{m}$.
[g] Or $23^{h}\ 49.1^{m}$.
[h] Boom caught at maximum by eclipse plate of watch.
[i] Given as $20^{h}\ 40.8^{m}$ September 4; probably error for $0^{h}\ 40.8^{m}$:
[j] Beginning and end lost in air tremors.
[k] Or $2^{h}\ 0.9^{m}$ or $2^{h}\ 12.0^{m}$. Times recorded roughly on account of failure of occultation watch.

[1] Chiefly from Seismol. Circs. 1 and 2, British Assoc. Adv. Sci., because the shocks are noted uniformly in that series of records and were recorded by Milne horizontal pendulums of the same general type, and the magnification of amplitude is the same, so that these records may be roughly compared.

Progress of early shock on September 10.

[All time records reduced to Greenwich mean time.]

Place of observation.	Commencement of preliminary tremors.[a]	Duration (minutes).	Maximum.	Amplitude.		Total duration.
				Millimeters.	Seconds of arc.	
Disenchantment Bay, Alaska	[b]17h 01m 30s					
Cape Whitshed, Alaska	(b)					
Victoria, British Columbia	(c)					
Toronto, Canada	17 11 56		17h 25m 19s	(d)	(d)	
Kew, England	17 15.3	7.3	[e]17 50.1		2.18	1h 39m
Shide, England			17 48.0			
San Fernando, Spain	17 9.9	14.7	17 47.1		2.58	2 12.2
Bombay (Colaba), India			17 58 47		.78	
Madras, India	17 28.3	2	[f]18 {3.2, 12.5}		1.0 .7	
Batavia, Java	17 30.2		18 8.2		2.0	1 16
Cordoba, Argentina	17 32.8	27	18 10.8	2.0		2 12
Cape Town, South Africa	17 36.2	28	18 {32.1, 34.6}		.5	2 0

[a] Times at Alaskan localities placed in this column for convenience.
[b] The time of origin given above for Disenchantment Bay was computed by Oldham from seismograph records at a distance. The first shock perceptible or at least recorded at this station without instruments came 23m 10s later (p. 121).
[c] Seismogram lost in the mails.
[d] Vibrations across paper.
[e] First maximum, 17h 50.1m; second maximum, 17h 53.5m.
[f] Clock stopped at 18h 36m.

Progress of heavy shock on September 10.

[All time records reduced to Greenwich mean time.]

Place of observation.	Commencement of preliminary tremors.[a]	Duration (minutes).	Maximum.	Amplitude.		Total duration.
				Millimeters.	Seconds of arc.	
Yakutat (Disenchantment) Bay, Alaska	[b c]21h 40m 13s					
Cape Whitshed, Alaska	[b]21 42 11					
Atlin, British Columbia	21 39 20					
Eagle, Alaska	21 40					
Victoria, British Columbia	(d)			(e)	(e)	
Toronto, Canada	20 42 14		22h 3m 6s			5h 36m 55s
Kew, England	21 1.6	58.9	[f]22 20.21		10.8	3 0
Shide, England	21 23.0		22 23.5			
San Fernando, Spain	21 3.9		22 24.9		14.62	4 11.8
Bombay (Colaba), India			22 38 9		1.78	
Batavia, Java	22 0.0		22 56.3		9.3	2 11
Cordoba, Argentina	21 56.8	35	23 2.8	5		
Mauritius, Indian Ocean	(g)		23 {7.2, 15.0}		1.47 1.44	
Cape Town, South Africa	22 1.4	24	23 {0.4, 4.2, 9.1, 13.3, 21.5}		2.4	3 30

[a] Times at Alaskan localities placed in this column for convenience.
[b] Not seismographic, but based on careful local time records.
[c] The apparent anomaly of the shock being felt at Toronto, etc., before it was recorded at the point of origin is probably due to the fact that the extremely delicate first movements which separate into the preliminary tremors were well started on their way before the more severe motion perceptible to the senses of persons nearer the point of origin was recorded. Oldham computes this same origin as 21h 39m 30s.
[d] Seismogram lost in the mails.
[e] "Over an inch" vibrations across paper.
[f] First maximum, 22h 20.21m; second maximum, 22h 25.6m.
[g] Air tremors marked beginning and end.

MAGNETOGRAPH RECORDS.

On both September 3 and September 10 the magnetographs (instruments for the measurement of terrestrial magnetism) were affected by the seismic disturbances. John Milne[1] has recorded that on September 3 and 10 "these shocks disturbed the declinometer, duplex, and vertical-force magnetographs in Toronto."

[1] Milne, John, Fifth Rept. Committee on Seismological Investigations, British Assoc. Adv. Sci., 1900, p. 83. Personal communication from R. F. Stupart.

At Wilhelmshaven, Germany, the magnetic instruments showed the following responses to the earthquakes:[1]

Magnetograph record at Wilhelmshaven, Germany.

[Mean Greenwich time recorded from midnight to midnight.]

1899.	Declination.	Horizontal intensity.	Vertical intensity.
	h. m. m.	h. m. m.	h. m. m.
Sept. 4	.. ..	.. ..	0 32.5 35.5 } .... Two very weak waves.
			40.5–41.0 { Largest wave followed by two smaller waves.
Sept. 10	22 23.0–27.5 28.0–30.0	22 21.0–23.0 23.0–24.0 24.5–27.0	21 53.0–53.5 Small wave. 54.5–55.5 Larger wave 57.0 Smaller wave. 22 1.0– 2.5 Largest wave. 3.5 Larger wave. 7.5 Smaller wave. 20.5 Larger wave. 22.5 Smaller wave. 25.0 Smaller wave.

The instruments for registering variations of terrestial magnetism at the Koninklijk Nederlandsch Meteorologisch Instituut at De Bilt, near Utrecht, clearly show both the shock of September 3 and the heaviest shock of September 10,[2] the times which correspond with seismograph data in England and Belgium, near by, being as follows: September 4, from $0^h 34^m$ to $0^h 50^m$; September 10, from $21^h 52^m$ to $22^h 22^m$ (mean Greenwich time). The disturbance consists in a slight enlarging of the curve. About the amplitude or beginning of the different phases sure particulars can not be given.

Other magnetographs in western Europe, as in the Danish Meteorological Institute at Copenhagen,[3] the French observatories at Parc St. Maur[4] and Perpignan, the English observatories at Greenwich and Falmouth, and the observatory at Manila, Philippine Islands, show no disturbance during these earthquakes.

TABULATION OF INSTRUMENTAL RECORDS.

The following tables have been compiled to summarize the distribution of places of observation of these earthquakes and to show the types of instruments used and the wide observation and study made by seismologists of this series of world-shaking seismic disturbances. Many of the instrumental records are derived from circulars 1 and 2 of the Seismological Committee of the British Association for the Advancement of Science (Prof. J. W. Judd, chairman; Mr. John Milne, secretary). Some are from the publications of other observatories; others are derived from unpublished materials furnished for this report.

Instrumental records of the earthquake.

North America.

Place.	Type of seismograph.	Described by—	Published in—
Victoria, British Columbia	Milne	Seismological Committee	Circular 2, B. A. A. S., 1900, pp. 38–39.
Toronto, Ontario	Milne	Seismological Committee	Circular 2, B. A. A. S., 1900, pp. 36–37.
Toronto (Agincourt), Ontario	(Magnetograph)	R. F. Stupart	Personal communication.
		J. Milne	B. A. A. S., 5th Rept. Seismological Committee, 1900, p. 83.
City of Mexico, Mexico	Milne		

South America.

Place.	Type of seismograph.	Described by—	Published in—
Cordoba, Argentina	Milne	Seismological Committee	Circular 2, B. A. A. S., 1900, pp. 50–51.

[1] Information furnished by Capt. Hans Capelle, June 5, 1909.

[2] Van Dyk, G., communication dated December, 1908.

[3] Harboe, G. G., communication dated December, 1908.

[4] Moureaux, C. E., communication dated December, 1908.

Instrumental records of the earthquake—Continued.

Europe.

Place.	Type of seismograph.	Described by—	Published in—
Shide, Isle of Wight	Milne	John Milne	Circular 1, B. A. A. S., 1900, p. 3.
Kew, England	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, pp. 6–7, 9.
Uccle, Belgium	Rebeur-Ehlert	E. Lagrange	Bull. Soc. Belge d'Astron., 5e année, 1901, No. 2, p. 4.
Utrecht (de Bilt), Holland	(Magnetograph)	G. van Dyk	Personal communication.
Hamburg, Germany	Rebeur-Ehlert	R. Schült	Personal communication.
Wilhelmshaven, Germany	(Magnetograph)	H. Capelle	Personal communication.
Göttingen, Germany		L. Geiger	Personal communication.
Strassburg, Germany	Rebeur-Ehlert	A. Rudolph	Personal communication.
		J. P. van der Stok	Konink. Akad. Wetens. Amsterdam, vol. 2, 1900, pp. 244–246.
Grenoble, France		Paul Reboul	Personal communication.
San Fernando, Spain	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, p. 64.
Rome (Rocca di Papa), Italy	Agamennone and Vicentini vertical pendula and two horizontal pendula.	G. Agamennone	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 178–182, 194–196, 199–202, 224.
Catania, Italy		A. Riccò	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 186–187, 197, 204–205, 225.
Naples (Casamicciola), Italy	Six instruments	G. Grablovitz	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 183–186, 202–204, 224–225.
Naples (Portici), Italy			
Rome, Italy		S. S. del Coll. Rom	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 182–183, 194, 199, 223.
Florence (Quarto Castello), Italy	Vicentini and others	A. Bastogi, D. R. Stiattesi	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 187–189, 197–198, 205–207, 225–226.
Padua, Italy			
Pavia, Italy		E. Oddone	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 189, 198, 207, 226–227.
Siena, Italy	Vicentini		Boll. Soc. Sism. Ital., vol. 6, 1900–1901, p. 205.
Turin, Italy		R. Osserv. Astron	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 189–190, 207–208.
Trieste, Austria	Rebeur-Ehlert	E. Mazelle	Mitt. Erdb. Komm. K. Akad. Wiss. Wien, Bd. 109, 1900, pp. 28–31, 34–35.
Kremsmünster, Austria		P. F. Schwab	Mitt. Erdbeben Komm. K. Akad. Wiss. Wien, 15, 1900, pp. 42–45.
Laibach, Austria	Vicentini	A. Belar	Boll. Soc. Sism. Ital., vol. 6, 1900–1901, pp. 190, 208, 227.
Nicolajew, Russia		J. Kortazzi	Beiträge Geophysik, vol. 4, 1900, pp. 404–405.
Jurjew (Dorpat), Russia	Zollner-Repsold, Rebeur-Paschwitz.	G. Lewitzky	Personal communication.

Asia.

Place.	Type of seismograph.	Described by—	Published in—
Tokyo (Hongo), Japan	Omori	F. Omori	Pubs. E. I. C. (foreign languages), No. 6, 1901, pp. 48–51.
Tokyo (Hitotsubashi), Japan	Omori	F. Omori	Pubs. E. I. C. (foreign languages), No. 13, 1903, pp. 96–99; No. 21, 1905, pp. 46–49.
Tokyo, Japan	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, pp. 24–25.
Batavia, Java	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, p. 20.
		R. D. M. Verbeek	Konink. Magn. en Met. Obs., Batavia, vol. 22, 1899, part 1.
Bombay (Colaba), India	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, p. 13.
Madras, India	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, p. 12.

Africa.

Place.	Type of seismograph.	Described by—	Published in—
Mauritius, Indian Ocean	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, p. 17.
Cape Town, South Africa	Milne	Seismological Committee	Circular 1, B. A. A. S., 1900, p. 22.

TIME OF THE SHOCKS OF 1899.

DETERMINATION OF TIMES OF ORIGIN BY OLDHAM.

R. D. Oldham[1] refers to these Yakutat earthquakes as shocks "the time of origin of which is only known by inference from distant records." These times he gives as September 4, 0^h 20.5^m; September 10, 17^h 1.5^m and 21^h 39.5^m. These are given in Greenwich mean time, the earthquake of September 3 having the date of September 4 on account of the difference in time between the longitude of Greenwich and that of Yakutat Bay.

Oldham's method of determining these times is of some interest. The seismograph records referred to as Shide No. 333 are from instruments at six cities in Italy bearing the standard number of an observatory in the Isle of Wight and automatically written by the Yakutat Bay

[1] Quart. Jour. Geol. Soc., vol. 62, 1906, p. 459.

earthquake of September 3. Shide No. 337 is one of the early shocks on September 10 and No. 338 the heaviest shock of September 10. Oldham says: [1]

The times of origin of these shocks can be determined with an error of not more than 1 minute of time by the use of the curves reproduced in my previous paper.[2] In applying this method I propose to use only the records of the Italian seismographs and adopt this course for the two reasons (1) that, as shown in the paper referred to, the heavily weighted pendula with mechanical records give much more concordant results for the first two phases than light pendula with a slow-moving photographic record, and (2) because the curves having been deduced from the records of instruments of the type used in Italy, it is logical to use the data obtained from instruments of this type in applying them to obtain the time of origin of an earthquake.

In the case of the Alaskan earthquakes the Italian observatories are distant from 73° in the case of Padua to 81° in the case of Catania. The mean-time interval, as deduced from the curves, is consequently about 13.5 minutes for the first and 23.5 minutes for the second phase. I have consequently extracted from the published accounts the times of commencement and, where recorded, of the first marked increase of movement, representing the second phase; these are tabulated below and the resulting time of origin deduced. The times so obtained are doubtless subject to a slight error, but this probably does not exceed 1 minute of time, an error which becomes insignificant when dealing with the comparatively slow traveling waves of the third phase. The times tabulated have been obtained, in the case of Padua, directly from the diagrams obtained there, which Prof. Viccutini very kindly allowed me to examine; in the case of the observatory at Quarto (Florence) from the publication of that observatory, and in the case of the other Italian observatories, from the details published in part 2 of the Bollettino della Società sismologica italiana.

Time of earthquake of September 4, 1899. (Shide No. 333.)

Observatory.	Distance (degrees).	First phase.	Second phase.
Padua	73.1	0h 34.3m	0h 44 m
		34.3	45
		34.3	
Quarto	74.3	33.8	
		33.8	
		34.5	
		33.8	
		33.8	
Rome	76.5	34.6	46.5
		34.7	
Rocca	76.5	33.3	43.6
		35.5	
		34.5	45.0
		34.6	
		34.25	
Ischia	77.7	34.5	44.5
		34.5	44.5
		34.6	44.5
		34.5	44.3
		34.5	44.3
		34.7	44.3
		34.6	45.5
		34.6	44.4
Catania	81.3	34.7	45.7

The mean time for the first phase may be taken as about $0^h\ 34^m$ and for the second phase as about $0^h\ 44^m$, giving the time of origin as $0^h\ 20.5^m$ Greenwich mean time.

Time of earthquake of September 10, 1899. (Shide No. 337.)

Observatory.	Distance (degrees).	First phase.	Second phase.
Padua	73.1	17h 15.1m	17h 24.7m
		15.2	
		15.1	
Quarto	74.3	15.0	24.5
		14.7	
		14.7	
Rome	76.5	15.6	25.8
Rocca	76.5	15.2	25.0
			25.1
Ischia	77.7	15.7	25.6
Catania	81.3	15.3	25.0

The mean time for the first phase is $17^h\ 15^m$ and for the second phase $17^h\ 25^m$, giving $17^h\ 1.5^m$ Greenwich mean time as the time of origin.

[1] Unpublished manuscript loaned to the authors.

[2] On the propagation of earthquake motion to great distances: Philos. Trans. Royal Soc. London, ser. A, vol. 194, 1900, pp. 135–174.

Time of earthquake of September 10, 1899. (*Shide No. 338.*)

Observatory.	Distance (degrees).	First phase.	Second phase.
Padua	73.1	21^h 53.1^m	22^h 2.7^m
		53.1	2.3
		53.0	
Quarto	74.3	....	9.8
			9.8
			2.7
Rome	76.5	50.5	
Rocca	76.5	....	3.2
		53.4	3.6
		53.4	3.4
Ischia	77.7	53.5	3.5
Catania	81.3	52.9	1.0

The resulting mean time for the first phase is about 21^h 53^m and for the second phase 22^h 3^m. which give a corrected time of 21^h 39.5^m Greenwich mean time as the time of origin.

TIME RECORDS OBTAINED FROM ALASKA.

The time of the principal shocks, as recorded at the two nearest points in Alaska, Yakutat village (lat. 59° 33′ N., long. 139° 45′ W.) and Cape Whitshed (lat. 60° 27′ 34″ N., long. 145° 54′ 35″ W.), are shown below:

Records of shocks at Yakutat village and Cape Whitshed.

Date.	Yakutat village.[a]	Cape Whitshed.[b]
Sept. 3	3^h 30^m p. m.	2^h 40^m p. m.
Aftershock		3^h 22^m 30^s p. m.
Do		(c)
Do		6^h 45^m p. m.
Do		7^h 10^m p. m.
Do		7^h 44^m p. m.
Sept. 10 [d]	7^h 40^m a. m.	7^h 43^m a. m.
Aftershock		8^h 01^m a. m.
Do		10^h 03^m 34^s a. m.
Do		10^h 53^m 45^s a. m.
Do		10^h 59^m 55^s a. m.
Do		11^h 05^m 05^s a. m.
Sept. 10 [e]	12^h 15^m p. m.	11^h 58^m 33^s a. m.
Aftershock		12^h 07^m 08^s p. m.
Do		5^h 36^m 08^s p. m.
Do		5^h 44^m 02^s p. m
Do		5^h 51^m 41^s p. m.
Sept. 15	7^h 15^m p. m.	(f)
Sept. 17 [g]		
Sept. 23	(c)	1^h 22^m a. m.
Aftershock		1^h 28^m 09^s a. m.
Do		1^h 33^m 09^s a. m.
Do		1^h 40^m 09^s a. m.
Do		1^h 41^m 51^s a. m.
Sept. 26	(c)	2^h 49^m a. m.
Do		12^h 05^m 38^s p. m.
Do		2^h 46^m p. m.
Sept. 29	(c)	During night.

[a] Observed at Yakutat village by R. W. Beasley. Irregularly regulated "sun time" of local meridian.
[b] Observed in Coast Survey camp by H. P. Ritter, with good and well-rated chronometer showing solar time of local meridian.
[c] Shock noticed, but time not recorded.
[d] The early shock.
[e] The great earthquake.
[f] Shocks were felt between Sept. 12 and 16, but not precisely recorded because of general uproar of storm then raging. This shock of Sept. 15 was felt with great intensity at Skagway as well as at Yakutat.
[g] If observed at Yakutat or Cape Whitshed this shock was not recorded.

Obviously from the local records of the Yakutat Bay shocks of 1899 no isoseismal lines could be drawn, or careful deductions made concerning the depth of focus, speed of transmission, or acceleration, etc., of the several shocks. The difficulty arises from the lack of data, due to the paucity of population in the area affected, and the unreliability of the time records in practically all except one or two localities where observations were made, owing to the absence of standard time and the long periods during which even careful observers are unable to check and correct their timepieces in this wilderness.

The places in this region where accurate time records were made are so few that they can be easily enumerated. (See Pls. II, p. 14; XXXIII, in pocket.) (*a*) At Cape Whitshed, near the Copper River delta, the Coast Survey observer, Mr. Ritter, made a series of most valuable time records, reading in correct mean local time, taken from a good and well-rated chronometer; (*b*) near Atlin, east of Skagway, a Canadian geologist, Prof. Gwillim, recorded the September 10 shock by what is probably almost absolutely correct solar time; (*c*) at Eagle, Alaska, Judge Myers, a United States Weather Bureau observer, made a single record based on fairly correct local solar time.

After these three come a series of records whose times are subject to a greater error. In the Chugach Mountains an Army lieutenant made a time record that is probably close to the truth, for he was engaged in topographic work, and it might be possible to correct his reading for mean local time with assurance of at least approximate accuracy. The same statement applies to the records made by the United States Geological Survey party under Brooks and Peters in the Tanana Valley and the topographers accompanying Schrader's party on the Koyukuk. At Skagway and a few other telegraph stations correct time should have been obtainable, but this has not yet been verified. Mr. Beasley's time records at Yakutat village are fairly accurate, as comparison with the more precise time records shows, but not accurate enough for use in these computations. The observed times of the shocks at other towns, in camps, on trails, and especially in the prospectors' camp in Disenchantment Bay are practically valueless for precise computations.

Of these various time records those by the Coast Survey party, the Canadian geologist, and the Weather Bureau observer are therefore the only ones which we regard as capable of serving for accurate comparison with distant seismograph records and for conclusions as to the times of origin of the shocks and their rates of transmission to various points.

The discussion of the local time records is therefore reduced to this: We know that the first earthquake on September 3 was recorded at Camp Whitshed, the Coast Survey camp near the Copper River delta, at 2.40 p. m. Camp Whitshed is in 145° 54′ 35″ west longitude, 60° 27′ 34″ north latitude; Disenchantment Bay is in 139° 33′ 0″ west longitude, 59° 58′ 20″ north latitude. Allowing for a correction of 25^{m} 26.3^{s} of time for 6° 21′ 35″ of longitude, and a correction of 1^{m} 58^{s} of time for transmission about 220 miles, at the arbitrary rate of 3 kilometers (1.86 miles) per second, we determine the time of origin of the shock in Disenchantment Bay as about 3.03½ p. m. September 3 (3^{h} 03^{m} $28\frac{1}{3}^{s}$ local time at Yakutat, or 0^{h} 21^{m} $40\frac{1}{3}^{s}$ a. m. September 4, Greenwich mean time). If the earthquake of September 3 originated near Yakataga (as seems possible) and not at Disenchantment Bay (p. 76) this calculation should be revised.

The first shock recorded on September 10 at Camp Whitshed came at 7.43 a. m. When this is corrected for longitude and transmission as above, it is found that the shock would have been felt at Disenchantment Bay at 8.06½ a. m. (8^{h} 06^{m} $28\frac{1}{3}^{s}$ local time at Yakutat, or 17^{h} 24^{m} $40\frac{1}{3}^{s}$ Greenwich mean time). This is about 23 minutes later than the shock which the seismograph records show (see p. 115) should have originated and forces us to conclude that either the first shaking at the Coast Survey camp was mild and not recorded because it came just at or near the time of rising, or else this shock was not central in Disenchantment Bay, but originated somewhere in the mountains near by. The intensity of the first shock felt by the prospectors in Disenchantment Bay is against this hypothesis, but their time record is valueless for settling this question, which must accordingly be left unanswered. We have therefore adopted the seismograph time record for the origin of this shock, as is shown in the table below.

A similar correction for longitude and transmission fixes the time of origin of the heaviest shock on September 10, which was recorded at the Coast Survey camp at 11^{h} 58^{m} 33^{s}, as about 12.22 p. m. (12^{h} 22^{m} $1\frac{1}{3}^{s}$ local time in Disenchantment Bay, or 21^{h} 40^{m} $13\frac{1}{3}^{s}$ Greenwich mean time).

The times of each of the remaining shocks may be worked out on the same basis, the result being the following corrected times of origin for the whole series:

Corrected times of origin of the earthquakes.

Date.	Time at Yakutat Bay.	Same in Greenwich mean time.
Sept. 3	$3^h\ 03^m\ 28^s$ p. m	[a] $0^h\ 21^m\ 40^s$.
10	$8^h\ 06^m\ 28^s$ a. m	$17^h\ 24^m\ 40^s$.
10	$12^h\ 22^m\ 01^s$ p. m.	$21^h\ 40^m\ 13^s$.
15	$7^h\ 15^m\ 00^s$ a. m	$16^h\ 33^m\ 12^s$.
17		
23	$1^h\ 45^m\ 28^s$ a. m	$11^h\ 03^m\ 40^s$.
26	$3^h\ 12^m\ 30^s$ a. m	$12^h\ 40^m\ 42^s$.
29		

[a] Sept. 4 rather than Sept. 3, the difference in time being due to difference in longitude.

No time record is available for the possible initial shock on August 27, 1899, but no great shock seems to have been recorded by seismographs that day. All the seismograph records known to the writers show world-shaking earthquakes on September 3 and twice on September 10 at most of the observatories where instruments were then installed.

There seems to have been no seismograph record of the shock of September 15, although it was reported as severe at Yakutat, Skagway, and other places.

The shock of September 17, though widely recorded by seismographs, was not felt at Yakutat or Cape Whitshed. Its observation at Skagway and Juneau is uncertain. Prof. Milne has computed, however, that this shock originated in Alaska.[1]

The shock of September 23 was recorded throughout the world, the record having an amplitude of 17 millimeters at Victoria, and then going clear off the paper.

The shock of September 26 was recorded throughout the world, but was less violent than that of September 23. Its amplitude was 7.4 millimeters at Victoria and 4.1 millimeters at Toronto.

The shock of September 29, the final one of the series, happens to coincide in date with the Ceram earthquake in the East Indies. The Victoria seismogram, with an amplitude of 2.5 millimeters, might possibly belong to the Alaskan series, but the exact time of the shock felt in the night at Cape Whitshed is not available for determining this conclusively.

COMPARISON OF LOCAL TIME RECORDS AND SEISMOGRAPHIC TIME RECORDS.

A comparison of the local time records just quoted with those worked out by Oldham (p. 119) from the seismograph records is given below, showing the times of origin determined for Disenchantment Bay for the three chief shocks. All are given in both Greenwich and local time.

Local and seismograph records of times of origin of Yakutat Bay earthquakes.

September 3.

	Local solar time.	Greenwich mean time.
Local record	$3^h\ 03^m\ 28\frac{1}{3}^s$ p. m.	$0^h\ 21^m\ 40\frac{1}{3}^s$ September 4.
Seismograph record	3 02 18	0 20 30

First shock September 10.

	Local solar time.	Greenwich mean time.
Local record	$8^h\ 06^m\ 28\frac{1}{3}^s$ a. m.	$17^h\ 24^m\ 40\frac{1}{3}^s$.
Seismograph record	7 43 18	17 01 30.

Heavy shock September 10.

	Local solar time.	Greenwich mean time.
Local record	$12^h\ 22^m\ 1\frac{1}{3}^s$ p. m.	$21^h\ 40^m\ 13\frac{1}{3}^s$.
Seismograph record	12 21 18	21 39 30

[1] Nature, vol. 60, 1899, p. 545.

A comparison of these records shows a close agreement in two out of the three sets. The records of the heavy final shock of September 10 agree within 43 seconds, and those of the shock of September 3 check within 70 seconds, coming very close to the possible error of "1 minute of time," which Oldham allows himself (p. 119). So close a determination must be a source of gratification to Dr. Oldham, as this was probably the first attempt ever made to determine times of origin from distant seismograph records. The disagreement of $23^m 10^s$ in the first record of September 10 is probably due to the deficient local record or to another origin rather than to an error in Oldham's computations based on the seismograph records. The agreement of the two sets of records also accords well with our assumption that the chief shocks on September 3 and September 10 had their principal points of origin in or very near to Yakutat Bay.

SPEED OF TRANSMISSION.

It should be remembered that the rate of transmission assumed by us, on which the local time records are based, 3 kilometers per second, is wholly arbitrary. The most recent studies of velocity of propagation near the origin suggest that a rate of 7 or 8 kilometers per second may be attained in this part of the path of the earthquake waves.

An attempt has been made to check this rate of transmission by comparison of the time of occurrence at Yakutat Bay with the only other local time records of any accuracy. Comparison with Gwillim's observation on September 10 near Atlin, a place almost exactly as far east of Disenchantment Bay as Cape Whitshed is west of it, results as follows: Time of observation $12^h 45^m 0^s$ p. m., local solar time near Atlin. Place of observation near Atlin, 59° 24′ 30″ north latitude, 133° 35′ 0″ west longitude. Disenchantment Bay, 59° 58′ 20″ north latitude, 139° 33′ 0″ west longitude. Correcting this observation for a difference of $23^m 52^s$ of time with 5° 58′ of longitude, we find that the shock appears to have been felt by Gwillim at $12^h 21^m 8^s$ Yakutat Bay time, or 53 seconds before it was generated at Yakutat.

Similarly a correction of the supposedly accurate local solar time observation at Eagle (64° 13′ north latitude, 141° 15′ west longitude, about 340 miles north-northwest of Disenchantment Bay), where the earthquake was felt in the Weather Bureau observatory at $12^h 15^m$ p. m., results as follows: A correction of $6^m 48^s$ of time for 1° 42′ of longitude shows that the shock was felt by Myers at $12^h 21^m 48^s$ Yakutat Bay time, apparently 13 seconds before it was generated at Yakutat.

It might be either that (*a*) the time of origin given for Yakutat Bay is a minute more or less too late, as it would be if we assumed too fast a rate of transmission from Yakutat to the Coast Survey camp at Cape Whitshed; or (*b*) the determinations of local time by Gwillim and Myers are in slight error; or (*c*) the chronometer at the Coast Survey camp was not exactly right; or (*d*) there may have been a complex of synchronous origins at other places in the mountains beside Disenchantment Bay. One of the first two explanations is believed to account for the discrepancies. The whole matter is stated thus fully in order to show the futility of any attempt at closer computations based on the records at hand.

The speed of transmission for a longer distance, Yakutat Bay to Victoria, British Columbia, is as follows, as indicated by the data for the shock of September 3: Disenchantment Bay, latitude 59° 58′ 20″ N., longitude 139° 33′ W.; Victoria, latitude 48° 23′ N., longitude 123° 19′ W. Distance in miles along surface, computed from an 18-inch globe, about 1,000 miles. Time at place of origin, $0^h 21^m 40^s$, Greenwich mean time; time at Victoria, $0^h 35^m 9^s$, Greenwich mean time; interval for transmission, 13 minutes and 29 seconds, or 809 seconds. One thousand miles in 809 seconds gives a speed of 1.23 miles, or 2.1 kilometers, per second.

The rate at which the earthquake tremors moved for greater distances is shown in the following table, which is based upon computations made by Prof. John Milne[1] on the assumption of an origin in the ocean west of Yukatat, and therefore subject to a slight error.

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[1] Fifth Rept. on Seismological Investigations, Brit. Assoc. Adv. Sci., 1900, Plate III, opposite p. 77.

Speed of large waves of three of the Yakutat Bay earthquakes in kilometers per second.

From Milne's assumed origin southwest of Yakutat to—	Sept. 3. (Shide, No. 333.)	Sept. 10, early shock. (Shide, No. 337.)	Sept. 10, the great earthquake. (Shide, No. 338.)
Victoria	....	....	....
Toronto	3.4	....	....
Mexico	....	2.3	2.7
Shide	3.2	2.7	2.9
San Fernando	3.1	3.1	3.1
Bombay	3.6	3.6	3.4
Batavia	....	2.9	2.3
Cape Town	3.4	3.5	3.7
Average speed	3.3	3.0	3.0

Average speed of all 17 observations, with origin assumed by Prof. Milne, 3.1 kilometers (almost 2 miles) per second.

Prof. Milne has also shown that the time necessary for one of these shocks (that of Sept. 3) to traverse the earth's circumference, or two diameters, slightly exceeds 210 minutes.[1] This is a rate of about 1.9 miles, or 3 kilometers, per second. Dr. Omori made a similar calculation for the waves of September 10,[2] which traveled around the earth with a velocity of 3.6 kilometers per second.

Prof. C. G. Knott[3] has analyzed the relationship of speed of transmission to the location of the paths of the three chief Yakutat earthquakes as follows, on the assumption that the path is not along the chord but more nearly along the arc. The paths lie as follows:

Victoria	Under sea.
Toronto	Half sea, half land.
Mexico	Half sea, half land.
Shide	Mostly sea, polar archipelago, Greenland?
San Fernando	Half sea and land, largely polar.
Bombay	Mostly land, Siberia, Tibet.
Batavia	Deep sea, east of Asia.
Mauritius	Siberia, India, Indian Ocean.
Cape of Good Hope	Polar sea, Europe, Africa.

Still assuming what we know now to be a slightly erroneous origin and assuming constant speed for small distances and nine minutes as the time from the origin to Victoria, he made the following table:

Arc.	Degrees.	Chord.	Time of passage in minutes.			Speed.		
						Arc degrees.	Chord.	Arc radians.
						Minutes.	*Minutes.*	*Minutes.*
Victoria	16	0.28	9	..	..	1.8	0.031	0.031
Toronto	40	.68	22	22	22	1.8	.31	.31
Mexico	49	.83	..	29	28	1.7	.29	.30
Shide	70	1.15	39	42	41	1.8	.29	.31
San Fernando	77	1.25	44	44	44	1.75	.28	.305
Bombay	105	1.59	55	55	57	1.9	.28	.33
Batavia	108	1.62	..	65	75	{ 1.66 1.44 }	.23	....
Mauritius	145	1.91	90	..	88	1.63	.215	.284
Cape of Good Hope	165	1.98	88	89	83	1.9	.226	.33

In the above table $\frac{\text{chord}}{\text{minutes}}$ and $\frac{\text{arc radians}}{\text{minutes}}$ may be reduced to $\frac{\text{kilometers}}{\text{seconds}}$ by multiplying by 1.06; $\frac{\text{arc degrees}}{\text{minutes}}$ may be reduced to $\frac{\text{kilometers}}{\text{seconds}}$ by multiplying by 1.84.

[1] Fifth Rept. Committee on Seismological Investigations, Brit. Assoc. Adv. Sci., 1900, p. 69.
[2] Publications Earthquake Investigation Committee in Foreign Languages, No. 13, 1903, pp. 121-124.
[3] Fifth Rept. Committee on Seismological Investigations, Brit. Assoc. Adv. Sci., 1900, p. 77.

Computing these velocities by the above formulæ he found the speed of transmission of the surface waves of the Yakutat Bay earthquakes for long distances to vary between 3.1 and 3.3 kilometers per second, or nearly 2 (1.95) statute miles per second, a rate agreeing substantially with those reached independently from the several computations cited above.

DISTURBANCES OF THE EARTH'S SURFACE.

The seismic disturbances traversed the rocks of the earth's crust from their place of origin in Yakutat Bay, where, according to Prof. John Milne's estimate, 1 or 2 cubic miles of rocky material[1] were disturbed during the faulting, to all other parts of the world. No seismograph known to have been in operation in September, 1899, failed to record the shocks which that type of instrument was capable of registering.

The disturbances may be divided into classes—(1) those that seismologists infer to have gone directly through the earth and (2) those that followed the earth's outer crust. These are indistinguishable at distances less than 650 miles. Beyond that distance—for example, at Victoria—the seismograph records show slight disturbances arriving very soon (preliminary tremors) and great motion after a longer time (principal portion, or large waves). The preliminary tremors came directly through the earth, along chords. They are generally thought to be longitudinal compressional vibrations. They have a shorter distance to go and also move at a faster rate than the large surface waves. On September 3, 1899, these direct waves traversed the chord from Yakutat to Victoria in 3½ to 4 minutes, the large waves, moving presumably along the arc, taking 13 minutes and 29 seconds to reach Victoria through the earth's outer crust.

These large waves of the principal portion of the shock are thought to vibrate transverse to the line of propagation. They were formerly thought to make the earth's crust actually rise in long undulating earth waves. For example, it was estimated[2] that the large waves of the Yakutat Bay earthquake of September 3 passed through Shide, England, as earth waves about 28 miles in length and 11⅝ inches high (45 km. by 29 cm.). The earth waves of the great shock of September 10 at Shide were computed as about 74 miles long and 15⅝ inches high (120 km. by 29 cm.) and were followed by waves computed as about 28 miles long and 17 inches high (45 km. by 43 cm.).

SUMMARY OF INSTRUMENTAL RECORDS.

It must remain for some trained seismologist to summarize adequately the seismographic record of the Yakutat Bay earthquakes, and in the hope that this may eventually be done we have gathered in this chapter such of the published and unpublished materials dealing with this group of seismic disturbances as have come to our notice.

The earthquake was one of the first great shocks that came after the establishment of instruments for the recording of earth tremors at stations throughout the world. Seismologists over all the world therefore studied and commented on these seismic disturbances, recorded by all seismographs and many magnetographs then in operation, as noted in the preceding pages, a few perhaps reaching conclusions that were more broadly generalized than later studies, with more seismograms of world-shaking earthquakes available, have justified.

From the seismograph records above they located the origin very accurately indeed, considering the methods devised up to that time. One seismologist predicted that great topographic changes would be found, such as we discovered. Another computed within a minute the time of the earthquake at its place of origin. Still others showed that the waves in the earth's crust moved about 3 kilometers (2 miles) a second. The records also show that the disturbances exceeded in magnitude those at San Francisco in 1906. The local time records are of less use in comparison with the seismographic records than those for earthquakes in more thickly inhabited regions, yet the Alaskan time records serve to check the distant seismograph records. One set of local records, that at Cape Whitshed, is of the utmost value, and several

[1] Nature, vol. 75, 1907, p. 224.

[2] J. Milne, Fifth Rept. on Seismological Investigations, Brit. Assoc. Adv. Sci., 1900, p. 83.

others are of use. This shows how important it is for all observers of an earthquake in a wilderness region to make the closest time records possible and to check their timepieces as soon as possible for correction to local solar time.

This group of shocks is abnormal, departing from the normal sequence of (1) prelude, (2) great shock, and (3) aftershocks, as Gilbert has stated.[1] The Yakutat Bay earthquakes of September, 1899, possibly had no prelude (August 27?); there were at least four great shocks (September 3, 10, 10, 23), perhaps several other important shocks (September 15, 17, 26), and a long series of aftershocks. As Gilbert points out in the preface of this volume (p. 9), this seismic disturbance "ranks high in the scale of energy, the position of its origin has been determined with unusual precision, and its initial time is known with close approximation." These facts and the detailed information furnished in the early chapters of this volume regarding great surface changes accompanying these earthquakes may commend the Yakutat Bay shocks to seismologists for further study.

[1] Gilbert, G. K., Earthquake *forecasts: Science, new series*, vol. 29, 1909, pp. 126–127.

CHAPTER VIII.

MAGNITUDE OF YAKUTAT BAY EARTHQUAKES OF SEPTEMBER, 1899.

AREA DISTURBED.

AREA MAPPED.

Plate XXXIII (map, in pocket) shows the places where it is known that shocks were felt, the places where it is known that shocks were not felt, the area of earthquake origin where visible surface faults and changes of level of the coast and evidences of vigorous shaking were seen, the large area of more moderate but nevertheless strong enough movement to be sensible to persons, and detached areas of shaking. This map shows the area affected by changes in level at Yakutat Bay, but not that at Yakataga, which the authors have not seen.

If so much of this region had not been an almost empty wilderness in 1899, and if the investigation could have been commenced immediately, instead of after an interval of eight to nine years, much more complete data might have been obtained. These would result in modifications of the map, for we could have located more of the prospectors, army officers, revenue-cutter employees, Coast Survey officials, geologists, engineers, missionaries, cannery employees, Fish Commission inspectors, Northwest mounted policemen, Hudson Bay Co.'s agents, masters of vessels, and Canadian and American marshals and commissioners who were within the area shaken or just outside its limits. This would undoubtedly result in an extension of the area rather than a decrease.

As it is, we have put down on the map nothing that depends on hearsay evidence. Each symbol is located at a place where some reliable person whom we have interviewed, or with whom we have been in correspondence, or whose printed description we have seen has recorded that he himself felt or did not feel the earthquakes in September, 1899. We have plotted together all the earthquake observations recorded, whether they were made on September 3 or September 10, because the shocks were felt in many places on both dates.

The area disturbed on September 10 was larger than that of sensible shocks on September 3, and the junior author has published elsewhere[1] maps showing the areas disturbed on the two dates.

The location of some observers from whom information was received after the map was completed is not shown on the map, though brief statements of their observations have been inserted in the text. None of these added observations greatly modify the estimate of the area of sensible shocks in September, 1899, but a few suggest that it should be slightly larger.

By plotting the actual places of well-established observations we have drawn on the map a minimum area within which the shocks were sensible to persons on September 3 and September 10. The shaken area is no doubt far greater than the map shows, for it is only on the southeast beyond Sitka and Sumdum, on the north near Rampart, Circle, and Dawson, and on the west near Seldovia and Kodiak that we had even scattered evidence from which to determine an outer limit for the sensible shocks. The outermost observations north of Skagway along the Klondike trail, beyond which the region was in 1899 and in the main still is an empty wilderness, suggest that in a much greater area to the east the earthquake shocks may have been sensible. The same statement applies to the area northwest of the upper Copper River Valley, Cook Inlet, and the Alaska Range, the outermost observations being at places where

[1] Martin, Lawrence, Alaskan earthquakes of 1899: Bull. Geol. Soc. America, vol. 21, 1910, fig. 3, p. 347, and fig. 4, p. 357.

chance prospectors, explorers, etc., happened to be, and beyond which there is little hope of learning whether the shocks were sensible or not.

One reason for the incompleteness of the data as to the outer limits of the sensible shocks is that at distances of 250 to 480 miles from Yakutat Bay the earthquake waves were so weak as to be imperceptible to some persons though quite evident to others. At Sitka, about 260 miles southeast of Yakutat Bay, for example, the heavy shock of September 10 was felt by Bishop Rowe, who was lying down, and by teachers and children sitting in a school building, but not by Dr. Georgeson, who was walking out of doors. Northwest of Yakutat Bay the shock of September 3 was not felt by A. H. Brooks and W. J. Peters, who were traveling, having crossed Tanana River that day, although they heard its avalanches in the mountains at the correct time. It was observed by a prospector equally distant from Yakutat Bay near Mentasta Pass, however. Near the south fork of Fortymile Creek the earthquakes of September 10 were not sensible to these geologists, probably because they were on the march, although they are trained scientific observers; yet these weak tremors were observed at this time at a greater distance in the same direction by several prospectors near Wade Creek, in the Fortymile district, and even at Eagle, 60 miles farther away along the same line. These two shocks were sensible to persons not traveling and severe enough in the Weather Bureau observer's office to jar his apparatus, cause lamps to swing, etc., but were insensible to men on the march.

Another reason for observation or failure to observe the shocks at great distances is found in local topographic or geologic conditions. For instance, in the Koyukuk and Yukon regions, 670 and 730 miles, respectively, from Yakutat, there may have been amplification of the tremors in unconsolidated Pleistocene silts. Unfortunately the vigorously shaken area within a radius of 150 miles of Yakutat afforded very few observations, because there are practically no settlements in this wilderness.

NUMBER OF SQUARE MILES SHAKEN.

As all places within 250 miles from which observations were obtained were shaken, we might assume that the shocks were felt throughout a circular region within a 250-mile radius from Yakutat Bay. This would include nearly 200,000 square miles. Outside of this circle, however, the shocks were felt with some intensity at distances of 275, 290, 300, 340, 375, 380, 390, 410, 430, and 480 miles. These are the points beyond which the boundaries of the disturbed area have been drawn upon the map (Pl. XXXIII, in pocket). This minimum area has 216,297 square miles of land alone, and may be regarded as about half the known shaken area, as the place of origin is on the seacoast and the other half lies in the Pacific Ocean. The minimum shaken area already proved, therefore, includes 432,500 square miles by the most conservative measurement.

The points of observation by Mr. Schrader and Father Amcan, 670 and 730 miles, respectively, from Yakutat Bay, shown on the map as detached areas (fig. 4 and Pl. XXXIII), and the incompleteness of data already mentioned, suggest that the shocks might have been felt in the intervening region had observers been there in 1899 to note them, and that the disturbed area is even larger than we have mapped. The east and northwest boundaries of the area, colored on Plate XXXIII as sensibly disturbed, have been placed where they are because of lack of evidence, for the most part, rather than because of specific information, such as we had to the southeast, that the shock went no farther. A circle with a 670-mile or 730-mile radius would include an area of 1,410,000 or 1,674,000 square miles; or, to take the average of these last two distances, a radius of 700 miles would give a circular area containing 1,539,000 square miles.[1] It seems quite likely that other observations as far distant as those on the Koyukuk and Yukon might be brought to light, if all the people who were in this region in 1899, and were favorably located for observing weak shocks, could be reached. It is to be noted, however, that people in Alaska are so accustomed to earthquakes that few of

[1] This estimate does not include a disturbed area near Lake Chelan, Washington, 1,200 miles from Yakutat Bay.

them would pay attention to or remember slight tremors such as are recorded at great distances. During the Charleston earthquake in the United States the outermost observations, as in New York, Boston, and La Crosse, Wis., were in high office buildings,[1] where there was natural amplification of weak tremors insensible to persons near the ground.

The inclusion of the disturbed area within a circle assumes that the Yakutat Bay area was the center of disturbance and that little or no movement occurred outside this circular area. In the absence of other evidence this hypothesis seems warranted, and the platting of the minimum shaken area (Pl. XXXIII, in pocket) bears it out well. We are aware of an alternate hypothesis that the tectonic disturbances extended for long distances in the direction of the axis of the St. Elias chain, both to the northwest and to the southeast. Observations are too scattered to permit the absolute establishment of either of these hypotheses. Moreover, it is not possible now to say whether Yakutat Bay was the area of maximum disturbance of all the shocks. It seems most certainly to have been so in the second and most destructive of the severe shocks of September 10; but those that preceded and succeeded this one may well have been central at other localities in this mountainous region. The scantiness of our data makes further discussion of this point of little value.

COMPARISON WITH OTHER GREAT EARTHQUAKES.

The following is a list of areas affected by some of the larger tectonic earthquakes of historic times:

Great earthquakes of historic times.

Center.	Date.	Approximate area affected.	Extent.
		Sq. miles.	
Lisbon, Portugal	1755	[a]2,240,000	Felt in Great Britain, throughout western Europe, and in northern Africa. Maximum radius of propagation, 700 to 1,200 miles.
New Madrid, Mo	1811–1812	1,250,000	Felt at Charleston, S. C.; Richmond, Va.; Washington, D. C.; Louisville, Ky.; Fort Duquesne (Pittsburgh), Pa.; Detroit, Mich.; Fort Dearborn (Chicago), Ill.; etc.
Charleston, S. C	1886	2,800,000	Felt at Boston, Mass.; La Crosse, Wis., and in Cuba and Bermuda. Maximum radius of propagation, 700 to 950 miles.
Riviera	1887	219,000	Radius of propagation, 264 miles.
Sonora, Mexico	1887	500,000	Felt at Durango, Mexico; Fort Davis, Tex.; Las Vegas and Santa Fe, N. Mex.; Prescott and Yuma, Ariz.; and generally within about 400 miles.
Japan	1891	330,000	Radius of propagation, 323 miles.
Assam, India	1897	1,750,000	900-mile radius of propagation.
Yakutat Bay, Alaska	1899	1,539,000	700 (670 to 730) mile radius of propagation.
Kangra, India	1905	1,500,000	
San Francisco, Cal	1906	372,700	Felt in Coos Bay, Oreg.; Los Angeles, Cal.; and Winnemucca, Nev. Radius of propagation, 350 to 400 miles.

[a] Perhaps 500,000 square miles less; Oldham (Mem. Geol. Survey India, vol. 29, 1899, p. 376) says perhaps only 1,000,000 square miles.

No similar data are available for the South American earthquakes of 1822, 1835, and 1837, for the New Zealand earthquake of 1855, or for several of the other severe earthquakes of historic times.

It will be seen that the Yakutat Bay earthquakes rank among the great tectonic earthquakes in area disturbed. The scant population of the area affected brings up a point of decided contrast with the other earthquakes cited, all of which are in areas of rather dense population. In Japan 7,279 people were killed and 17,393 injured and 197,000 buildings were destroyed and 84,000 damaged in the earthquake of 1891. In the Charleston earthquake 27 persons lost their lives and 56 others perished by cold, exposure, etc., out of a city of 50,000 to 55,000; many houses were destroyed, many more damaged, and 13,000 chimneys thrown down. In the first of the great earthquakes in India (Assam, 1897) practically all the buildings in 145,000 square miles were laid in ruins; in the second (Kangra, 1905) 18,815 lives were lost and the destruction of property was enormous, 112,477 buildings being destroyed. In California, in 1906, 100,000 to 200,000 people were made homeless, but only 709 lives were lost directly by the earthquake; there was, however, great destruction of buildings, largely due

[1] Dutton, C. E., The Charleston earthquake of August 31, 1886: Ninth Ann. Rept. U. S. Geol. Survey, 1889, pp. 203–528.

to consequent fire, their estimated value being between $139,000,000[1] and $500,000,000.[2] In the Riviera earthquake, in 1887, 640 people were killed and over 570 injured; 155 houses were rendered uninhabitable in Mentone, 61 in Nice, and many others elsewhere, so that the property loss was over $5,000,000. Lyell says that 60,000 people were killed in six minutes in the historic Lisbon earthquake of 1755, practically the whole city being thrown down. About 20,000 lives were lost in the Calabrian earthquake of 1688, about 43,000 in 1693, between 32,000 and 60,000 in 1783, 800 in 1905, while the loss of life in 1908 was stated as 100,000.

In contrast with all this, there was no recorded loss of life[3] as a result of the Yakutat Bay earthquakes; and the most serious property damage known to us, aside from the loss of a rowboat, some tents, provisions, and clothing by the eight prospectors in Disenchantment Bay, was the shifting of the roof of an uninhabited log cabin in outer Yakutat Bay and the cracking of a few chimneys and slight damage to a wharf in Skagway. Some of the great earthquakes of South America and New Zealand, likewise in thinly populated districts, have doubtless been much like the Alaskan shocks in inflicting but slight damage to the human race.

Another contrast is in the absence, so far as shown by any report we have seen, of the noises which accompanied many of the other heavy shocks cited—not the noise accompanying shaking buildings, sliding avalanches, crashing water waves, and breaking glaciers, but the heavy earth roll said to accompany some seismic disturbances. It may have occurred in Yakutat Bay, but it has not been reported, and many if not all of the noises noticed at a distance from Yakutat Bay were apparently due to avalanches.

W. H. Hobbs[4] has recently compiled an extensive list of tectonic shocks accompanied by surface faulting between 1783 and 1906. The earthquakes cited in his paper form some interesting comparisons with the shocks and effects here described.

It is unfortunate that so little is yet known concerning the physical phenomena accompanying faulting, earthquakes, and changes of level of the land. Some such changes of level are of the slow secular character of movement that is accompanied by little visible change because extending over such broad areas. Others are fairly definite in character, the time and amount of uplift being closely determined. So far as is known, no other uplift as great as 47⅓ feet is proved to have occurred at one time.

In some other respects the Yakutat Bay uplifts suggest interesting comparisons with other earthquake uplifts. In the uplifts occurring on the west coast of South America in connection with the earthquakes of 1822, 1835, and 1839, described by Darwin, elevated beaches, sea cliffs, rock benches, and sea caves with attached marine shells, in view of the human testimony as to the cause, are comparable with the effects of the Alaska uplift here described. In New Zealand, in the earthquake of 1855, there was surface faulting and new reefs were formed by uplift, as in Alaska in 1899. In Jamaica in 1692 and 1907 and in India in 1819 an earthquake resulted in elevation in one place and depression in another, as in Alaska. There was surface faulting, as in Calabria, Italy, in 1783; New Madrid, in the Mississippi Valley, in 1811-12; Owens Valley, Cal., in 1872; Sonora, Mexico, in 1887; Japan in 1891; Iceland in 1896; India in 1897 and 1905; and California in 1906. There was disturbance of surface and underground drainage, with formation of sand vents and craterlets, as at Charleston, S. C., in 1885, as well as at several other places listed above. There were destructive water waves, or tsunami, as at Lisbon, Portugal, in 1755; in Japan in 1896; and at several other localities during other earthquakes. Nevertheless this Alaskan uplift forms a striking contrast to these uplifts, combining as it does all these criteria of changes of level, adding the new types of evidence

[1] Gilbert, G. K., Science, new ser., vol. 29, 1909, p. 137.

[2] Humphrey, R. L., and Soulé, Frank, The San Francisco earthquake and fire; Bull. U. S. Geol. Survey No. 324, 1907, pp. 61, 138; McAdie, A. G., Catalogue of earthquakes on the Pacific coast, 1897 to 1906, Smithsonian Misc. Coll., vol. 49, 1907, p. 47; The California earthquake of April 18, 1906, Rept. State Earthquake Commission, Carnegie Institution of Washington, 1908.

[3] There were probably not more than 20,000 persons in the area of sensible shocks in 1899 and only a few hundreds in the central area shaken by the earthquakes.

[4] On some principles of seismic geology: Gerland's Beitr. Geophysik, vol. 7, pt. 2, Leipzig, 1907, pp. 236-253.

afforded by dissected alluvial fans and uplifted shore lines of glacial till, and furnishing completely corroborative evidence of all sorts.

Finally, it may be said that this is the first seismic disturbance that has been proved to be the direct cause of a great advance and complete breaking up of glaciers. The substitution of this idea, under appropriate conditions, for the current conception that changes of altitude or of climate cause fluctuations of glaciers can doubtless be made for many mountain regions, such as the Himalaya, with its glaciers, faulting, and frequent earthquakes. The new conception may help to explain the series of glacial advances and recessions in the St. Elias Range itself, and in the Lynn Canal, Glacier Bay, Copper River, and Prince William Sound regions, especially as we know that these mountains have long been growing by similar uplifts and may fairly assume that their growth was necessarily accompanied by earthquakes and, ever since the mountains were high enough for glaciation, by glacial oscillations.

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