Audubon

SOCIETY OF ALASKAN NATURAL HISTORY

AND ETHNOLOGY

THE MUIR GLACIER

ALASKA

BY

PROF. G. FREDERICK WRIGHT

OBERLIN, OHIO

BULLETIN NO. 2

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SOCIETY OF

Alaskan Natural History and Ethnology

Sitka, Alaska

ORGANIZED MONDAY, OCTOBER 24, 1887

INCORPORATED UNDER THE LAWS OF THE STATE OF OREGON,
WEDNESDAY, APRIL 11, 1888

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NAME.

The name of this Society is the "Society of Alaskan Natural History and Ethnology."

OBJECT.

The purpose is to collect and preserve in connection with the Sitka Industrial Training School, specimens illustrative of the Natural History and Ethnology of Alaska, and publications relating thereto.

MEMBERSHIP.

The membership of the Society shall consist of the founders, the officers and teachers of the Sitka Industrial Training School, and such others as may from time to time be elected to membership. Non-residents of Alaska interested in the work of the Society, and willing to contribute to its funds, may be elected Corresponding Members. Parties who have rendered distinguished service to Alaska may be elected Honorary Members.

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IN the summer of 1886 I organized a small party to make some investigation of glacial phenomena in Alaska. A company consisting of Rev. J. L. Patton, of Greenville, Mich., Mr. Prentiss Baldwin, of Cleveland, Ohio, and myself, took the steamer Idaho, Captain Hunter commanding, at Port Townsend, on the 24th of July. Little need be said of that portion of the journey which is taken by ordinary tourists, except to remark upon some of the glacial phenomena which I was specially prepared to observe.

In travelling from Oberlin, Ohio, to Bismarck, Dakota, via St. Paul, the marks of former glacial action were everywhere visible; but at Sim's Station, on the Northern Pacific Railroad, the signs of glacial action disappeared, and did not reappear except in isolated mountain areas until we had passed the Cascade Mountains in Oregon and Washington Territory. But the whole valley of the Willamette and of Puget Sound, in Oregon and Washington Territory, is deeply covered with glacial drift; the islands of Puget Sound being, like those to the south of the New England coast, nothing else but irregular deposits of glacial debris. In the journey from Portland to Seattle all the streams coming down from Mount Rainier betray their glacial origin in the milky-white color given to them by the supply of glacial mud furnished by the glaciers in which they originate far up upon the flanks of the mountains. These glaciers formerly extended so as to fill the whole valley, as those from the Alps once filled that between the Alps and the Juras in Switzerland.

To a practiced eye it is evident that all the intricate channels throughout the long archipelago extending from the Straits of Juan de Fuca to Glacier Bay were once filled with glacial ice. The rocky surfaces in the neighborhood of Victoria, on Vancouver's Island, exhibit remarkable evidences of glacial action. The furrows, and grooves, and scratches, characteristic of such action are scarcely excelled anywhere else in

the world. Dr. Dawson reports similar evidences running up some thousands of feet upon the sides of the fiords which indent the coasts of British Columbia. In Naha Bay, on Revilla Gigedo Island, and again at Fort Wrangell and at Sitka, the positive evidence of former glacial action is unmistakable. It is evident that the numerous glaciers still lingering at the head of the fiords of the Alexander archipelago formerly extended till they became confluent, and gave to the whole archipelago somewhat the appearance of the area now covered by the Muir glacier.

Upon consultation with Rev. Mr. Young, of Fort Wrangell, and others, it was thought that our party would further the interests of science most by concentrating attention for a month upon the Muir glacier. In conformity with this advice we engaged, upon reaching Juneau, the services of two Indians and a dug-out canoe, and with adequate camping equipment and provisions were transferred upon the steamer to the head of Muir Inlet, and were put off upon the barren strip of moraine extending for two miles and a half upon the east side of the inlet south of Muir glacier. Here we remained for twenty-nine days, being taken off by Captain Hunter on his return trip on the 3d of September. The main scientific results were contributed to the *American Journal of Science* for January, 1887, which, by request of Dr. Sheldon Jackson, United States General Agent of Education in Alaska, is hereby reproduced with some additions for the benefit of tourists.

1. Description of Glacier Bay.

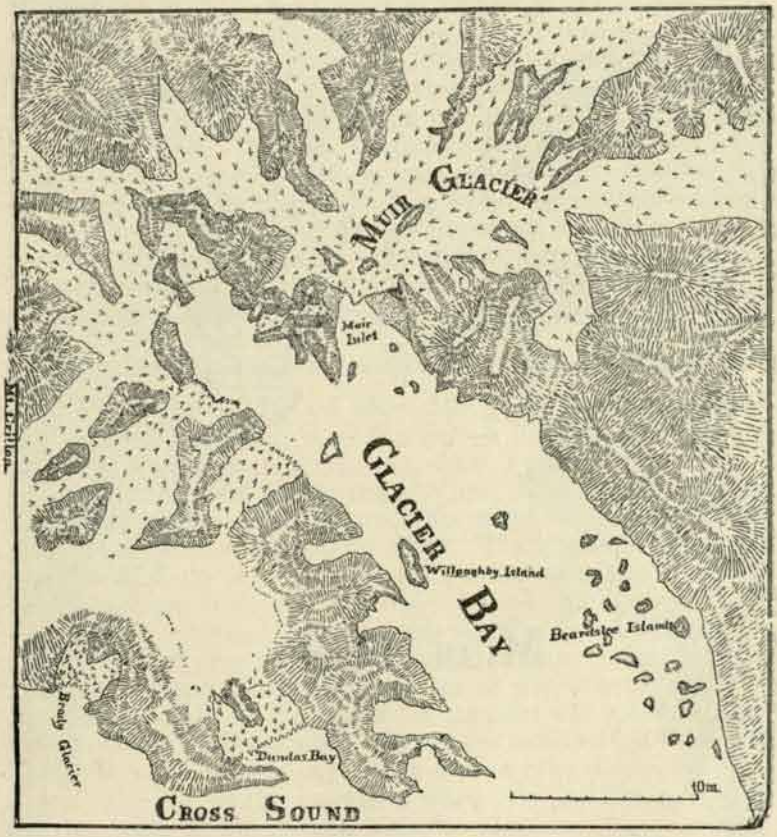
The Muir glacier enters an inlet of the same name at the head of Glacier Bay, Alaska, in latitude 58° 50′, longitude 136° 40′ west of Greenwich. (See Fig. 1.)* Glacier Bay is a body of water about thirty miles long and from eight to twelve miles wide (but narrowing to about three miles at its upper end) projecting in a northwest direction from the eastern end of Cross Sound. The peninsula inclosed between Glacier Bay, Cross Sound and the Pacific Ocean is from thirty to forty miles wide and contains numerous lofty mountain peaks. Mount Crillon, opposite the head of the bay, is 15,900 feet high, and Mount Fairweather, a little farther north, is 15,500 feet. Mounts Lituya and LaPerouse, lying on either side of Crillon, are not far from 10,000 feet above the sea. To the east, between Glacier Bay and Lynn Channel, is a peninsula extending considerably south of the mouth of the bay, and occupied by the

* The maps have been largely made from original data. They are square with the compass, which bears here, however, 28° east of north.

White Mountains, whose height I am unable to ascertain, but probably having no peaks exceeding 10,000 feet.

Near the mouth of Glacier Bay is a cluster of low islands named after Commander Beardslee, of the U. S. Navy. There are twenty-five or thirty of these, and they are composed of loose material,—evidently glacial debris,—and are in striking

1

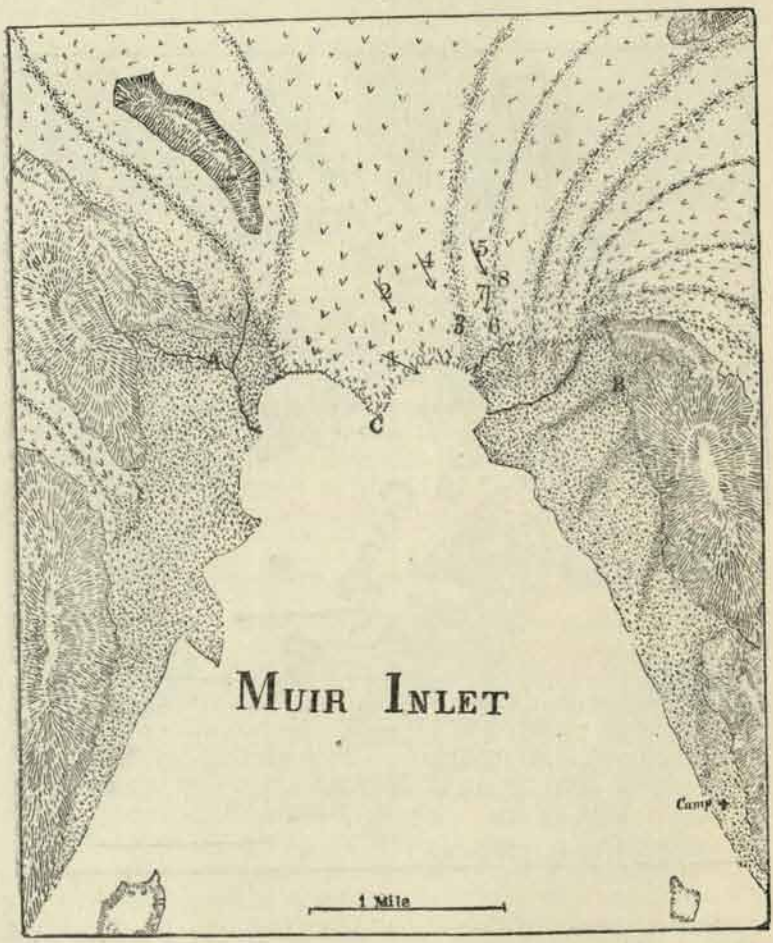


contrast to most of the islands and shores in southeastern Alaska. These, also, like all the other land to the south, are covered with evergreen forests, though the trees are of moderate size. The islands and shores in the upper part of the bay are entirely devoid of forests. Willoughby Island, near the middle of the bay, is a bare rock, about two miles long and 1500 feet high, showing glacial furrows and polishing, from the

bottom to the top. Several other smaller islands of similar character in this part of the bay show like signs of having been recently covered with glacial ice.

The upper end of the bay is divided into two inlets of unequal lengths, the western one being about four miles wide

2



and extending seven or eight miles (estimated) in the direction of the main axis of the bay to the northwest. The eastern, or Muir, inlet is a little over three miles wide at its mouth, and extends to the north about the same distance, narrowing at the upper end to a little over one mile, where it is interrupted by

the front of the Muir glacier. The real opening between the mountains, however, is here a little over two miles wide, the upper part on the eastern side being occupied with glacial debris covering a triangular space between the water and the mountain about one mile wide at the ice-front and coming to a point three miles below, beyond which a perpendicular wall of rock 1000 feet high rises directly from the water. The mountain on the west side of Muir inlet, between it and the other fork of the bay, is 2900 feet high. That on the east is 3150 feet high, rising to about 5000 feet two or three miles back. The base of these mountains consists of metamorphic slate whose strata are very much contorted—so much so that I found it impossible, in the time at command, to ascertain their system of folds. Upon the summits of the mountains on both sides are remnants of blue crystalline limestone preserved in synclinal axes. In the terminal moraine deposited in front of the glacier on its eastern side are numerous bowlders of very pure white marble coming in medial moraines originating in mountain valleys several miles to the east. Granitic bowlders are also abundant.

2. Dimensions and Characteristics of the Muir Glacier.

The width of the ice where the glacier breaks through between the mountains is 10,664 feet—a little over two miles. But, as before remarked, the water-front is only about one mile. This front does not form a straight line, but terminates in an angle projecting about a quarter of a mile below the northeast and northwest corners of the inlet. The depth of the water 300 yards south of the ice-front is (according to the measurement of Capt. Hunter of the steamer *Idaho*) 516 feet near the middle of the channel; but it shoals rapidly toward the eastern shore. According to my measurements, taken by leveling up on the shore, the height of the ice at the extremity of the projecting angle in the middle of the inlet was 250 feet; and the front was perpendicular. Back a few hundred feet from the projecting point, and along the front nearer the shores, the perpendicular face of the ice was a little over 300 feet. A little farther back, on a line even with the shoulders of the mountains between which the glacier emerges to meet the water, the general height is 408 feet. From here the surface of the glacier rises toward the east and northeast about 100 feet to the mile. On going out in that direction on the ice seven miles (as near as I could estimate) I found myself, by the barometer, 1050 feet above the bay.

The main body of the glacier occupies a vast amphitheatre with diameters ranging from thirty to forty miles. This esti-

mate was made from various views obtained from the mountain summits near its mouth when points whose distances were known in other directions were in view. Nine main streams of ice unite to form the grand trunk of the glacier. These branches come from every direction north of the east and west line across the mouth of the glacier; and no less than seventeen sub-branches can be seen coming in to join the main streams from the mountains near the rim of the amphitheatre, making twenty-six in all. Numerous rocky eminences also rise above the surface of the ice, like islands from the sea. The two of these visited, situated about four miles back from the front, showed that they had been recently covered with ice,—their surfaces being smoothed and scored, and glacial debris being deposited everywhere upon them. Upon the side from which the ice approached these islands (the stoss side) it rose, like breakers on the seashore, several hundred feet higher than it was immediately on the lee side. A short distance farther down on the lee side, however, the ice closes up to its normal height at that point. In both instances, also, the lee side of these islands seemed to be the beginning of important sub-glacial streams of water; brooks running into them as into a funnel, and causing a backward movement of ice and moraine material, as where there is an eddy in the water. In both these cases the lee sides of these islands were those having greatest exposure to the sunshine. The surface of the ice on this side was depressed from one to two hundred feet below the general surface on the lee side.

The ice in the eastern half of the amphitheatre is moving much more slowly than that in the western half. Of this there are several indirect indications. First, the eastern surface is much smoother than the western. There is no difficulty in traversing the glacier for many miles to the east and northeast. Here and there the surface is interrupted by superficial streams of water occupying narrow, shallow channels, running for a short distance and then plunging down into "*moulins*" to swell the larger current, which may be heard rushing along in its impetuous course far down beneath and out of sight. The ordinary light-colored bands in the ice parallel with its line of motion are everywhere conspicuous, and can be followed on the surface for long distances. When interrupted by crevasses they are seen to penetrate the ice for a depth of many feet, and sometimes to continue on the other side of a crevasse in a different line, as if having suffered a lateral fault. The color of the ice below the surface is an intense blue, and over the eastern portion this color characterizes the most of the surface. Numerous holes in the ice, penetrating downward from

an inch or two to several feet and filled with water, are encountered all over the eastern portion. Sometimes there is a stone or a little dirt in the bottom of these, but frequently there is nothing whatever in them but the purest of water. In the shallower enclosures on the surface containing water and a little dirt, worms about as large around as a small knitting needle and an inch long are abundant.

3. The Moraines.

The character and course of the moraines on the eastern half of the glacier also attest its slower motion. There are seven medial moraines east of the north and south line, four of which come in to the main stream from the mountains to the southeast. (See Fig. 2.) Near the rim of the glacial amphitheatre these are long distances, in some cases miles, apart; but, as they approach the mouth of the amphitheatre, they are crowded closer and closer together near its eastern edge, until in the throat itself they are indistinguishably mingled. The three more southern moraines unite some distance above the mouth. One of these contains a large amount of pure marble. This moraine approaches the others on either side until the distance between them disappears, and its marble unites in one common medial moraine a mile or more above the mouth. The fifth moraine from the south is about 150 yards in width, five miles back from the mouth. It is then certainly as much as five, and probably eight, miles from the mountains from which the debris forming it was derived. All these moraines contain many large blocks of stone, some of which stand above the general mass on pedestals of ice, with a tendency always to fall over in the direction of the sun. One such block was twenty feet square and about the same height, standing on a pedestal of ice three or four feet high. It is the combination of these moraines, after they have been crowded together near the mouth, which forms the deposit now going on at the northeast angle of the inlet just in front of the ice. Of this I will speak more fully in connection with the question of the recedence of the glacier. Similar phenomena, though on a smaller scale, appear near the southwest angle of the amphitheatre.

4. Indirect Evidences of Motion.

The dominant streams of ice in the Muir glacier come from the north and the northwest. These unite in the lower portion to form a main current, about one mile in width, which is moving toward the head of the inlet with great relative rapidity. Were not the water in the inlet deep enough to

float the surplus ice away, there is no knowing how much farther down the valley the glacier would extend. The streams of ice from the east and southwest have already spent the most of their force on reaching the head of the inlet; and, were it not for this central ice-stream, a natural equilibrium of forces would be established here independent of the water, and no icebergs would be formed. The surface of this central current of motion is extremely rough, so that it is entirely out of the question to walk far out upon it. On approaching this portion of the glacier from the east the transverse crevasses diagonal to the line of motion increase in number and size until the whole surface is broken up into vast parallelograms, prisms and towers of ice, separated by yawning and impassable chasms scores and hundreds of feet in depth. Over this part of the ice the moraines are interrupted and drawn out into thinner lines, often appearing merely as patches of debris on separate masses of ice. This portion of the ice-current presents a lighter colored appearance than other portions, and the roughened lines of motion can be followed, as far as the eye can reach, through distant openings in the mountains to the north and northwest.

The comparative rapidity of the motion in this part of the ice is also manifest where it breaks off into the water at the head of the inlet. As already said, the perpendicular front of ice at the water's edge is from 250 to 300 feet in height. From this front there is a constant succession of falls of ice into the water, accompanied by loud reports. Scarcely ten minutes either day or night passed during the whole month without our being startled by such reports, and frequently they were like thunder-claps or the booming of cannon at the bombardment of a besieged city, and this though our camp was two and a half miles below the ice-front. Sometimes this sound accompanied the actual fall of masses of ice from the front, while at other times it was merely from the formation of new crevasses or the enlargement of old ones. Repeatedly I have seen vast columns of ice, extending up to the full height of the front, topple over and fall into the water. How far these columns extended below the water could not be told accurately, but I have seen bergs floating away which were certainly 500 feet in length. At other times masses would fall from near the summit breaking off part way down, and splashing the spray up to the vey top of the ice, at least 250 feet. The total amount of ice thus falling off could not be directly estimated, but it is enormous. Bergs several hundred feet long and nearly as broad, with a height of from twenty to sixty feet, were numerous and constantly floating out from the inlet. The

steamer met such one hundred miles away from the glacier The smaller pieces of ice often so covered the water of the inlet miles below the glacier that it was with great difficulty that a canoe could be pushed through. One of the bergs measured was sixty feet above water and about four hundred feet square. The portion above water was somewhat irregular, so that probably a symmetrical form thirty feet in height would have contained it. But even at this rate of calculation, the total depth would be two hundred and forty feet. The cubical contents of the berg would then be almost 40,000,000 feet. Occasionally, when the tide and wind were favorable, the inlet would for a few hours be comparatively free from floating ice; at other times it would seem to be full.

5. Subglacial Streams.

The movements of the glacier in its lower portions are probably facilitated by the subglacial streams issuing from the front. There are four of these of considerable size. Two emerge in the inlet itself, and come boiling up, one at each corner of the ice-front, making a perceptible current in the bay. There are also two emerging from under the ice where it passes the shoulders of the mountains forming the throat of the glacier. These boil up, like fountains, two or three feet, and make their way through the sand and gravel of the terminal moraine for about a mile, and enter the inlet 250 or 300 yards south of the ice-front. These streams are perhaps three feet deep and from twenty to forty feet wide, and the current is very strong, since they fall from 150 to 250 feet in their course of a mile. It is the action of the subglacial streams near the corners of the inlet which accounts for the more rapid recession of the glacier front there than at the middle point projecting into the water south of the line joining the east and west corners. It was also noticeable that the falls of ice were much more frequent near these corners, and the main motion of the ice as afterwards measured was, not toward the middle point projecting into the inlet, but toward these corners where the subglacial streams emerged below the water.

6. Direct Measurement of the Velocity.

No small difficulty was encountered in securing direct measurements of the motion; and, as the results may be questioned, I will give the data somewhat fully. As it was impossible to cross the main current of the glacier, we were compelled to take our measurement by triangulation. But even then it seemed at first necessary to plant flags as far out on the

ice as it was safe to venture. This was done on the second day of our stay, and a base-line was established on the eastern shore, about a mile above the mouth, and the necessary angles were taken. But on returning to repeat the observations three or four days afterwards it was found that the ice was melting from the surface so fast that the stakes had fallen, and there were no means at command to make them secure. Besides they were not far enough out to be of much service. It appeared also that the base-line was on a lateral moraine, which was, very likely, itself in motion. But by this time it had become evident that the masses of ice uniting to compose the main stream of motion retained their features so perfectly from day to day that there was no difficulty in recognizing many of them much farther out than it was possible to venture to plant stakes. Accordingly another base-line was established on the east side opposite the projecting angle of ice in the inlet. From this position eight recognizable points in different portions of the ice-field were triangulated,—the angles being taken with a sextant. Some of the points were triangulated on five different times, at intervals from the eleventh of August to the second of September. Others were chosen later and triangulated a fewer number of times. In all cases given the angles were taken independently by Mr. Prentiss Baldwin, of Cleveland, and myself and found to agree.

The base-line finally chosen (marked B on Fig. 2) was at the foot of the mountain exactly east by the compass from the projecting angle of ice in the inlet. The elevation of the base-line was 408 feet above tide—corresponding to that of the ice-front. The distance of this projecting point of ice (marked C on Fig. 2) from the base-line was 8534 feet, and it remained very nearly stationary during the whole time—showing that the material breaking off from the ice-front was equal to that pushed along by the forward movement. Satisfactory observations were made upon eight other points numbered and located on Fig. 2.

No. 1 was a pinnacle of ice 1476 feet N. by 30° E. from C. The movement from August 14th to August 24th was 1653 feet E. by 15° S. After this date the pinnacle was no longer visible, having disappeared along the wasting line of front between C and the subglacial stream at the northeast corner of the inlet.

No. 2 was a conspicuous pinnacle of ice 2416 feet N. by 16° E. of C. Observations were continued upon this from August 11th to September 2d. The total distance moved during that time was 1417 feet, or about sixty-five feet per day. From August 14th to August 24th the movement was

715 feet, or about seventy-one feet per day. The difference is, however, perhaps due to the neglect to record the hours of the day when the observations were taken. As these observations were wholly independent of each other, their substantial concordance demonstrates that there was no serious error in the observations themselves. The direction of movement of this point of ice was very nearly the same as that of the preceding, namely, E. 16° S. This also is towards the subglacial stream emerging from the northeast corner of the inlet.

No. 3 was observed only from August 20th to August 24th. It was situated 3893 feet N. by 62° E. of C, and moved 105 feet in a westerly direction. The westerly course of this movement probably arose from its being near where the easterly and northeasterly currents joined the main movement.

No. 4 was 5115 feet N. 42° E. of C, and moved from August 20th to August 24th, 143 feet in a southeasterly direction.

No. 5 was 5580 feet N. 48° E. of C, and moved 289 feet from August 20th to 24th in a direction E. by 39° S.

No. 6 was 5473 feet N. 70° E. of C, and moved 232 feet from August 11th to September 2d in a direction S. 66° E.

No. 7 was 6903 feet N. 59° E. of C, and moved 89 feet between August 14th and August 24th in a direction S. 3° E., about nine feet per day.

No. 8 was 7507 feet N. 62° E. of C, and moved 265 feet from August 14th to August 24th in direction S. 56° E. These last three points lay in one of the moraines on the east side of the line of greatest motion and parallel with it. These moraines are much interrupted in their course by gaps.

Not having a logarithmic table with me in camp these points brought under observation proved much nearer the eastern side than I supposed at the time. But the distances are so great that nothing better could be done from the base-line chosen. I should also have established another base-line on the western side, but stormy weather, and the difficulty of crossing at the times set for doing so, interfered. As the problems are worked out it is observable that the points chosen were all east of the centre of the main line of most rapid motion, and are tending with varying velocity toward the northeast corner of the inlet, where the powerful subglacial stream emerges from below the water level. Doubtless on the other side of the centre of motion, and at the same relative distance from the front, the ice would be found tending toward the southwest corner, where a similar subglacial stream emerges. I could but wish that some of the points observed had been farther back from the front, but must take the facts as they are.

I supposed some of them were farther away, but as they were projected on the distant background the true position could not be told until the actual working out of the problems.

From these observations it would seem to follow that a stream of ice presenting a cross-section of about 3,500,000 square feet (5000 feet wide by about 700 feet deep) is entering the inlet at an average rate of forty feet per day (seventy feet in the centre and ten feet near the margin of movement), making about 140,000,000 of cubic feet per day during the month of August. The preceding remarks upon the many indirect evidences of rapid motion render the calculation perfectly credible. What the rate may be at other times of the year there are at present no means of knowing.

7. The Retreat of the Glacier.

The indications that the Muir glacier is receding, and that its volume is diminishing, are indubitable and numerous. Little regard need to be paid to the record of Vancouver a hundred years ago, for he did not attempt to enter the bay at all, finding it so full of ice near its mouth as to deter him from it; hence his testimony that the opening was full of ice is so indefinite that it has little bearing upon the condition of the upper portions of the bay at that period of time. Nor need any reliance be placed on the traditions of the Indians to the effect that within the memory of their grandfathers the ice extended several miles farther down than at the present time. The Indians now rarely visit the head of the inlet, and the quantity of ice floating on the surface varies so much from day to day, and presumably from month to month, that great diversity of impressions might be received at times separated by even short intervals. The convincing evidence of the recent retreat of the glaciers of this bay from ground formerly occupied by them is of a physical character.

The islands of Southern Alaska are ordinarily covered with forests of cedar, hemlock and fir up to the level of perpetual snow. To this rule the shores and islands of the upper part of Glacier Bay are a striking exception. Near the mouth of the bay forests continue to occur as in other parts, only on a diminished scale; but in the upper half of the bay all shores and islands are perfectly bare of forests, and the rocks retain in the most exposed situations fresh grooves and striæ of glacial origin. It would be impossible for rocks so exposed in such a climate, to retain these for an indefinite length of time. Far up on the mountains, also, there are remnants of glacial debris in situations such that the material could not have resisted erosive agencies for any great length of time. The

triangular shaped terminal moraine on the eastern side, just below the ice-front, presents some interesting features bearing on the same point. This extends three miles below the glacier, and in its lower portions is thinly covered with vegetation. This covering becomes less and less abundant as the glacier is approached, until, over the last mile, scarcely any plants at all can be found. Apparently this is because there has not been time for vegetation to spread over the upper portion of the moraine since the ice withdrew, for on the mountains close by, where the exposure has been longer, there is a complete matting of grass, flowering plants, and shrubs. Again, in this triangular moraine-covered space, there are five distinct transverse ridges marking as many stages in the recession of the ice-front. (See Fig. 2.) These moraines of retrocession run parallel with the ice-front on that side, and at about equal distances from each other, each one rising from the water's edge to the foot of the mountain, where they are 408 feet above tide. An inspection of the upper moraine ridge shows the manner of its formation. This transverse ridge is one-half mile below the ice-front, and is still underlaid in some portions with masses of ice thirty feet or more in thickness, which are melting away on their sides and allowing the debris covering them to slide down about their bases. Kettle-holes are in all stages of formation along this ridge. The sub-glacial stream emerging from the southeast corner of the glacier next the mountain rushes along just in the rear of this moraine ridge and in front of a similar deposit in process of formation on the very edge of the ice where the medial moraines spoken of terminate. Eventually this stream will break out in the rear of that deposit, also, and leave another ridge similar to the one now slowly settling down into position south of it. This first ridge south of the sub-glacial stream, with its ice still melting in exposed positions under its covering of gravel, cannot be many years old.

Still another sign of the recent date of this whole moraine appears at various places where water courses coming down from the mountain are depositing superficial deltas of debris upon the edge of the older glacial deposit. These deltas are very limited in extent, though the annual deposition is by no means insignificant. At the southern apex of the moraine, three miles below the ice-front, and but one or two hundred yards from our camp, great quantities of debris came tearing down in repeated avalanches during a prolonged season of rain. Twenty-five years would be ample time for the formation of the cone of debris at the foot of this line of avalanches. Thus there can be no reasonable doubt that during the earlier

part of this century the ice filled the inlet several miles farther down than now. And there can be scarcely less doubt that the glacier filled the inlet, as recently as that, 1000 or 1500 feet above its present level near the front. For the glacial debris and striæ are very marked and fresh on both mountains flanking the upper part of the inlet up to 2500 feet, and the evidences of an ice movement in the direction of the axis of the bay are not wanting as high as 3700 feet on the eastern mountain, upon which I found fresh striæ running north by south and directly past the summit, which rises 1000 or 1500 feet still higher just to the east.

8. A Buried Forest.

All this is necessary to a comprehension of one of the most interesting of problems, presented by the buried forests near the southwest corner of the glacier. (See A, fig. 2.) Below this corner, and extending for about a mile and a half, there is a gravel deposit, similar to that on the eastern side, except that it is not marked by transverse ridges, but is level-topped, rising gradually from about 100 feet at its southern termination to a little over 300 feet where it extends north and west of the ice-front. (See fig. 2.) The sub-glacial stream entering the inlet just below the southwest corner of the ice emerges from the ice about a mile farther up, on the north side of the projecting shoulder of the western mountain which forms that side of the gateway through which the ice enters the inlet. This stream comes principally from the decaying western branch of the glacier before alluded to, and, after winding around the projecting shoulder of the mountain (this shoulder is 315 feet A. T.), has worn a channel through the gravel deposit lying between the lower mile of the glacier and the mountain a short distance to the southwest. About half-way down, a small brook, coming from between this latter mountain and that whose shoulder forms the western part of the gateway just north of it, joins the main stream issuing from the glacier on this side. Where these streams unite at A they are now uncovering a forest of cedar trees in perfect preservation, standing upright in the soil in which they grew, with the humus still about their roots. An abundance of their cones, still preserving their shape, lies about their roots; and the texture of the wood is still unimpaired. One of these upright trunks measured ten feet in circumference about fifteen feet above the roots. Some of the smaller upright trees have their branches and twigs still intact, preserving the normal conical appearance of a recently dead cedar tree. These trees are in various stages of exposure. Some of them are uncovered to the roots, some

are washed wholly out of the soil, while others are still buried and standing upright, in horizontal layers of fine sand and gravel, some with tops projecting from a depth of twenty or thirty feet, others being doubtless entirely covered. The roots of these trees are in a compact, stiff clay stratum, blue in color, without grit, intersected by numerous rootlets as long as a knitting needle, which is, in places, twenty feet thick. There is also, occasionally in this substratum of clay a small fragment of wood, as well as some smooth pebbles from an inch to two feet in diameter. The surface of this substratum is at this point 85 feet above the inlet. The deposit of sand and gravel covering the forest rises 115 feet higher, and is level-topped at that height, but rising toward the north till it reaches the shoulder of the mountain at an elevation of 300 feet. The trees are essentially like those now growing on the Alaskan mountains, Many of them have been violently broken off from five to twenty feet above their roots. This has been done by some force that has battered them from the upper side at the point of fracture. Evidently cakes of ice brought down by the streams indicated in the map, when flowing at various higher levels than now, have accomplished this result. For the trunks in the main stream were battered on the north side, while those in the gully worn by the lateral stream were battered from the west side.

From this description the explanation of this buried forest would seem to be evident enough. At some period, when the ice occupied only the upper part of the valley to the north of this point, forests grew all over the space lying southwest of the present ice-front. As the ice advanced to near its present position, the streams carrying off the surplus water from the western half of the advancing glacier were suddenly turned into the protected space occupied by this forest, where they deposited their loads of sand and gravel. A cause very likely combining to facilitate deposition in this spot has not yet been spoken of, but is evident when on the ground, and from a glance at the map. A transverse valley passes just below this point from Muir inlet to the western inlet into which Glacier Bay divides. This transverse valley is at present occupied by a decaying glacier opening into both inlets, and sending a sub-glacial stream, through a long, narrow series of moraines, into Muir inlet about two miles to the south. Now, when a general advance of the ice was in progress, this transverse stream probably pushed itself down into the inlet across the path of the ice moving from the north, and so formed an obstruction to the water running from the southwest corner of the main glacier, thus favoring the rapid deposition which so

evidently took place. When this enclosed place was filled up, and the advancing ice had risen above and surmounted the projecting shoulder of the mountain just to the north, that rocky barrier protected a portion of the forest from the force of the ice movement, causing the ice to move some distance over the top of the superincumbent gravel before exerting its full downward force. Thus sealed up on the lee side of this protecting ridge of rock, there would seem to be no limit to the length of time the forest might be preserved. I see no reason why this forest may not have antedated the Glacial period itself.

The existence of other forests similarly preserved in that vicinity is amply witnessed to by many facts. One upon the island near the west shore, four miles south, is now exposed in a similarly protected position. Furthermore, the moraine, already described on the east side of the inlet, contains much wood ground up into slivers and fragments. Indeed, our whole dependence during the month for fuel was upon such fragments lying exposed in the moraine. Occasional chunks of peat or compact masses of sphagnum formed a part of the debris of this moraine. These also occurred on some of the medial moraines on the eastern side. I did not go up them far enough to learn directly their origin. But, as no forests were visible anywhere in that direction, it is presumable that they had been recently excavated from preglacial forests similar in situation to that now exposed on the west below the ice-front.

The capacity of the ice to move, without disturbing them, over such gravel deposits as covered the forests, is seen in the present condition of the southwestern corner of the glacier itself. As the ice-front has retreated along that shore, large masses of ice are still to be seen lapping over upon the gravel. These are portions of the glacier still sustained in place by the underlying gravel while the water of the inlet has carried the ice from the perpendicular bank clear away. This phenomenon, and that of the general perpendicular front presented by the ice at the water's edge, accords with the well-known fact that the surface of the ice moves faster than the lower portions. Otherwise the ice columns at the front would not fall over into the water as they do.

9. Kames and Kettle-holes.

The formation of kames, and of the knobs and kettle-holes characteristic both of kames and of terminal moraines, is illustrated in various places about the mouth of Muir glacier, but especially near the southwest corner just above the shoulder of the mountain where the last lateral branch comes in from

the west. This branch is retreating, and has already begun to separate from the main glacier at its lower side, where the sub-glacial stream passing the buried forest emerges. Here a vast amount of water-worn debris covers the ice, extending up the glacier in the line of motion for a long distance. It is evident from the situation that, when the ice-stream was a little fuller than now, and the sub-glacial stream emerged considerably farther down, a great mass of debris was spread out on the ice at an elevation considerably above the bottom. Now that the front is retreating, this sub-glacial stream occupies a long tunnel, twenty-five or thirty feet high, in a stratum of ice that is overlaid to a depth in some places of fifteen or twenty feet with water-worn glacial debris. In numerous places the roof of this tunnel has broken in, and the tunnel itself is deserted for some distance by the stream, so that the debris is caving down into the bed of the tunnel as the edges of ice melt away, thus forming a tortuous ridge, with projecting knolls where the funnels into the tunnel are oldest and largest. At the same time, the ice on the sides at some distance from the tunnel, where the superficial debris was thinner, has melted down much below the level of that which was protected by the thicker deposit; and so the debris is sliding down the sides as well as into the tunnel through the centre. Thus three ridges approximately parallel are simultaneously forming. When the ice has fully melted away, this debris will present all the complications of interlacing ridges, with numerous kettle-holes and knobs characterizing the kames; and these will be approximately parallel with the lines of glacial motion. The same condition of things exists about the head of the sub-glacial stream on the east side, also near the junction of the first branch glacier on the east with the main stream, as also about the mouth of the independent glacier shown on the map lower down on the west side of the inlet. (See fig. 2.) The formation of kettle-holes in the terminal ridges has already been referred to. (See p. 15.)

10. Transportation and waste by Water.

Considerable earthy material is carried out from the front by the bergs. Pebbles and dirt were frequently seen frozen into them as they were floating long distances away. Just how many of the bergs were formed from ice that originally rested on the bottom of the inlet I have no means of telling. That some were so formed seems exceedingly probable, if for no other reasons because of the great amount of debris that was sometimes seen frozen into them. It is by no means certain that the sub-glacial streams boiling up near the upper corners of the inlet were beneath the lowest stratum of ice. Some

small streams were seen pouring out from the face of the ice half way up from the water. It seems likely that a great amount of sediment becomes incorporated in cavities in the center of the glacier through the action of these sub-glacial streams; and so is ready for transportation when the masses break loose.

There were two pretty distinct lines of motion in the currents of the inlet, corresponding to those originating in the sub-glacial streams, so that ordinarily the ice-floes arranged themselves in the inlet along definite lines. But the tides were so high as sometimes to cause much irregularity. Frequently large icebergs would be seen moving up the lines of current or diagonal to them. The upper part of the inlet was filled with the muddy water coming from the sub-glacial streams. The line separating this muddy water from the clear water of the bay was driven now one way and now another, according to the influence of the tide. The steamer's screw brought up much muddy water from below the surface some distance down the bay, and where the surface was clear. The sediment forming over the bottom of the bay must resemble the loess of the Missouri and Mississippi valleys.

My estimates concerning the amount of sediment carried out by sub-glacial streams from the Muir glacier are as follows:—

The amount of sediment contained in each U. S. gallon (231 cubic inches) of water collected from the sub-glacial streams is, as determined by Professor H. C. Foote, of Cleveland, 708.48 grains. Estimating the total area occupied by the glacial amphitheatre to be 1,200 square miles, and the annual precipitation the same as at (Sitka which is not far from 96 inches), the total amount of water which must in some form annually pass into the inlet from this area is 267,632,640,000 cubic feet.

Of this amount I estimate that 77,088,000,000 cubic feet would pass out as ice; or, reducing this to water, about 67,000,000,000 cubic feet of liquid water. (This part of the calculation is based on the fact approximately ascertained that a section of ice one mile wide and 1,000 feet deep is moving into the inlet at a rate of 40 feet per day.) Subtracting the ice from the total amount and making a calculation for evaporation, which would probably diminish the amount one-eighth, the total amount of water which must issue in all the subglacial streams from this glacier is 200,000,000,000 cubic feet. Estimating the specific gravity of the sediment (which is chiefly some compound of alumina and silica) at 2½, we have, as the total amount of sediment transported thus, 37,274,804

cubic yards. This equals not far from one-third of an inch per year, which is eroded from the total area (1,200 square miles) occupied by the glacier. This would equal one inch of sediment per year carried by this single glacier over Glacier Bay.

And there are two other large glacial areas emptying the product of their erosion into it. This confirms the statements concerning the recent recession of the glacier from the lower portion of the bay. And it does not differ essentially from results recently published by Danish investigators in Greenland.

11. Other Glaciers reaching the Bay.

Besides the Muir glacier there are four others of large size entering the longer inlet to the west. (see fig. 1.) These have their origin on the flanks of Mounts Crillon and Fairweather. They have never been studied, but are apparently as accessible as the Muir. Professor Muir and Rev. Mr. Young are the only well-informed persons who have visited them, and their stay was brief. I went about half way up the inlet, on its east side, and took some photographs from points where the whole outlines could be seen. I also saw them from the mountains on the east side. The general appearance does not differ materially from that of the Muir glacier. To complete the study one needs a small steam launch, and more ample time and preparation than we could command.

The moisture of the climate is a serious drawback to investigations in all that region, though this is very favorable to the growth of glaciers. The annual precipitation over southeastern Alaska averages from eighty to one hundred inches. The average number of days per annum on which rain or snow has fallen at Sitka during the last fifty years is 198, while some years it has been as high as 264. Fifteen of the twenty-nine days we were in Glacier Bay (from Aug. 4 to Sept. 2) were so rainy as to render observation impossible. The other days were, however, clear and beautiful beyond description. The absence of forests also renders it easy to climb the mountains and observe from them. It is to be hoped that other expeditions better fitted than ours, and prepared to spend a longer time, will soon make a more complete study of this now easily accessible and most fruitful field for glacial investigation.

12. Temperature.

I append the record of the thermometer from Aug. 20 to Aug. 31, giving the mean of three readings each day taken at 8 A. M., 2 P. M., and 8 P. M. The temperature of the water in the upper part of the inlet was uniformly 40° F.

Aug. 20 . . .	49·4° F.	Aug. 26 . . .	51·9° F.
Aug. 21 . . .	48·9° F.	Aug. 27 . . .	46·1° F.
Aug. 22 . . .	46·1° F.	Aug. 28 . . .	50·5° F.
Aug. 23 . . .	44·6° F.	Aug. 29 . . .	45° F.
Aug. 24 . . .	49·8° F.	Aug. 30 . . .	54·8° F.
Aug. 25 . . .	52·7° F.	Aug. 31 . . .	50·5° F.

13. Flora.

The following is the list of plants, as identified by Professor Asa Gray, found in bloom about Muir inlet during the month of August. Where the altitude is not given they were found near the tide.

Arabis ambigua, Brong.	Aug. 26	1600 A. T.
Arenaria peploides, L.	28	
Astragalus alpinus, L.	7	
Hedysarum boreale, Nutt.	28	
Sanguisorba Canadensis	6	
Lutkea sibbaldioides, Brong.	27	
Saxifraga Lyalli, Engl.	26	1600 A. T.
stellaris, L.	27	3000 A. T.
Parnassia fimbriata, Small	27	3000 A. T.
palustris, L.	6	
Epilobium latifolium, L.	6	1600 A. T.
origanifolium, Lam. [?] . .	28	
Solidago multiradiata, Ait.	27	
Erigeron salsuginosus, Gray, arctic form	27	3000 A. T.
Antennaria margaritacea, arctic form .	27	
Achillea millefolium, L., arctic var. .	27	
Arnica obtusifolia, Les.	27	1200 A. T.
Campanula rotundifolia, L., v'r. Alaskana	28	
Gentiana platypetala [?]	27	
" Menziesii [?]	27	
Mertensia maritima	7	
Castilleja parviflora, Brong.	28	
Salix vestita, Pursh.	6	
Habenaria hyperborea, R. Br. . . .	27	2650 A. T.
Luzula parviflora, Meyer		
Poa alpina, var. vivipara	26	1500 A. T.
Poa alpina, L.	26	1600 A. T.
Poa laxa, Hænke	26	1500 A. T.
Phleum alpinum, L.	26	1600 A. T.
Elymus mollis	6	
Hordeum, sp. [?]	6	

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