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MALASPINA GLACIER.

INTRODUCTION.

A DEFINITE classification of glaciers does not seem to be practicable, for the reason that various types which may be selected grade one into another through many intermediate forms. It is convenient, however, especially in teaching, to recognize three generic types termed Alpine, Piedmont and Continental glaciers; and a subordinate class designated as Tidewater glaciers, to include those which reach the ocean and give origin to bergs.

Alpine glaciers occur in many mountainous regions and have their type in the Alps where they were first studied. Several divisions dependent upon size have been recognized.

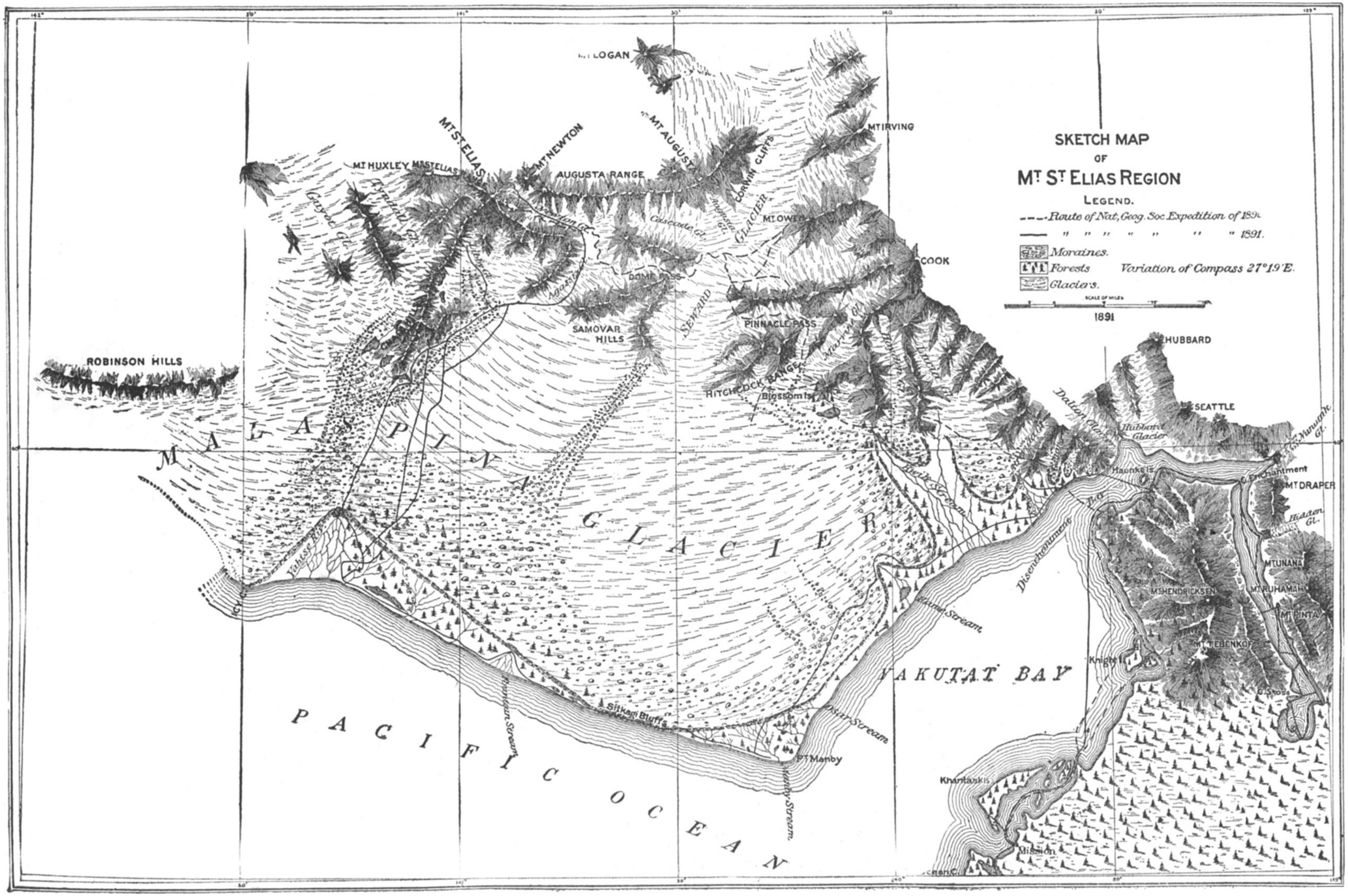
Continental glaciers as their name implies are of vast extent, and at the present time are illustrated by the ice sheets of Greenland and the Antarctic continent. The Pleistocene ice sheets of America and Europe were of this class.

Piedmont glaciers are formed on comparatively level ground at the bases of mountains where the ice is unconfined by highlands in most directions and has freedom to expand. They are fed by glaciers of the Alpine type, which spread out and unite one with another on leaving the valleys through which they descend from snow fields at higher elevations. The only known example of this class occurs in Alaska on the plain intervening between the Mt. St. Elias range and the ocean, and is the subject of this sketch.

GEOGRAPHY OF THE ST. ELIAS REGION.

The south coast of Alaska from Glacier bay on the east to the vicinity of the mouth of Copper river on the west, is bordered by a system of lofty mountains composed of many short ranges, which present steep escarpments to the south and overlook a narrow coastal-plain. At times the plain is wanting as in the vicinity of Mt. Fairweather, and the mountains rise directly from the ocean to great heights. To the north of the uplifts, facing the sea, there is an excessively rugged plateau probably about a hundred miles broad, and with a general elevation of eight or nine thousand feet. On this plateau there are hundreds of short ranges and isolated peaks rising by estimate some five or six thousand feet above the ice-filled valleys, while some of the more prominent summits have a still greater elevation. The northern border of this rugged region has been only partially explored but is known to be less precipitous than its southern face. The elevated region is destitute of both plant and animal life, and is covered with a vast névé field through which many precipitous peaks project. The southern slopes of these islands in the desert of snow are frequently bare in summer and furnish the only relief to the mantle of perpetual white. It is in this region that the ice streams supplying the Malaspina glacier have their sources.

The Tyndall glacier, shown on the accompanying map, is fed by the snow falling on the southwest portion of the Mt. St. Elias range, and flows southward with such a strong current that even after expanding on the plain at the base of the mountains and forming the western lobe of the Malaspina glacier, it continues its southward course and entering the sea forms Icy cape from which thousands of bergs are annually set adrift. Tyndall glacier has important tributaries, especially from the northern side of Robinson hills, but whether it is joined by a glacier from the elevated region to the north of the first range facing the coast, is not known. No break through which a glacier could flow has been observed in the mountain crest to be seen from the ocean, but future explorers may hope to discover such a pass.


SKETCH MAP
OF
Mt. St. Elias Region
LEGEND.
Route of Nat, Geog. Soc Expedition of 1890
" " " " " " " 1891.
Moraines.
Forests
Glaciers.
Variation of Compass 27°19'E.
SCALE OF MILES
1891
LOGAN
Mt. ST. ELIAS
Mt. NEWTON
Mt. AUGUST
Mt. HUXLEY
AUGUSTA RANGE
CORWIN CLIFFS
Mt. IRVING
Mt. OWEN
COOK
Cascade Gl.
GLACIER
SEWARD
SAMOVAR HILLS
PINNACLE PASS
HITCHCOCK RANGE
Blossom Is.
HUBBARD
SEATTLE
Dalton Glacier
Hubbard Glacier
ROBINSON HILLS
MALASPINA GLACIER
Yahtse R.
Sitkagi Bluffs
Pt. Manby
Manby Stream
YAKUTAT BAY
Disenchantment Bay
Haenkel Is.
C. Enchantment
Mt. DRAPER
Hidden Gl.
Mt. UNANA
Mt. HENDRICKSEN
Mt. RUHAMAH
Mt. PINTA
Mt. TEBENKOF
Knight I.
Khantaak Is.
Mission
PACIFIC OCEAN

The Agassiz glacier is formed by the union of many high-grade ice-streams on the eastern and northern slopes of the St. Elias range, and on the southern face of the equally precipitous Augusta range. All of these tributaries have been seen and are indicated in a rough way on the accompanying map.

Seward glacier is the principal feeder of the Malaspina ice sheet. Its most distant tributaries have their sources far to the north of the Augusta range, in the general névé field covering the main mountain mass. Scores, if not hundreds, of secondary glaciers unite to form the trunk stream which is fully three miles broad where best defined, and probably not less than sixty or seventy-five miles long.

Besides the great glaciers enumerated above there are several smaller ice-streams of the same type, such as the Marvine, Hitchcock, Lucia, etc., each of which is eight or ten miles in length and flows through a deep well-defined valley. Between these various trunk streams there are scores of high-grade glaciers that originate in deep cirques in the southern face of the mountains or in some instances, on the rugged slopes themselves where there are no depressions, and descend to and merge with the vast plateau of ice skirting the ocean.

Before giving special attention to the Malaspina glacier it may be well to glance at a few other geographical conditions which influence its existence.

The climate of southern Alaska adjacent to the coast is mild and uniform. The summers are cool with much fog and rain; the winters are not severe, but clear days are rare and snow falls to the depth of several feet. Among the neighboring mountains the snow-fall is excessive and occurs during every month of the year. In the névé region near Mt. St. Elias at an elevation of about 5,000 ft. it is not uncommon to see strata of compact snow without a parting, fifty feet thick exposed in the walls of crevasses. The mean annual temperature on the coast is thought to be about 40-45 deg. F., but this estimate is based on observation at a very limited number of stations. The humidity is excessive, and the mean annual rain-fall is known to be about an hundred inches. In the vicinity of Mt. St. Elias it is probably even greater than this. The prevailing winds are from the south, at least in summer, and are laden with moisture which is precipitated when the mountains are reached. To the north of the mountains the climate is far different from what it is on the coast. The summers are short and hot and the winters marked by extreme severity; the rainfall is small throughout the year and perennial snow is not seen even on mountains four or five thousand feet high and situated near and even north of the Arctic Circle.

On the mountains facing the ocean the winter snow extends down to sea level but melts during spring and summer so as to form a well defined boundary, or "snow line," which recedes from the coast as the warm season advances. In August and September it has an elevation of about 2,500 feet, corresponding on the glaciers with the lower limit of the névés. The regions below and above the snow line are in marked contrast. From the ocean up to an elevation of from 2,500 to 3,000 feet in summer, every island in the ice as well as the low lands along the coast and even the moraines on the lower border of the Piedmont ice-sheet, are covered with luxuriant vegetation, and are frequently brilliant with banks of flowers. Above the snow line except on occasional sunny slopes at comparatively low elevation, where Alpine flowers thrive, all is desolate, lifeless winter. The well known features characteristic of glacial ice and névé snow are sharply defined by the same horizon. In the higher mountains snow storms are frequent even in summer, and at elevations exceeding about 13,000 feet rain never falls and the snow is fine and dry. On the mountain tops the snow does not soften, even on hot summer days. Its indefinite accumulation is prevented by avalanches and by its being blown away.

The relief of the St. Elias region is due largely to displacements. The mountains are in many instances formed of tilted blocks bounded by faults, and the prevailing structure approaches the Great Basin type. The effects of pre-glacial stream erosion are not distinguishable and in many instances the ice drainage is consequent upon the prevailing structure. This is shown principally by the fact that large glaciers, such as the Agassiz and Seward, follow lines of displacement; in several instances, cascades occur where glaciers cross faults.

THE PIEDMONT ICE SHEET.[1]

Area.—The Malaspina glacier extends with unbroken continuity from Yakutat bay 70 miles westward, and has an average breadth of between 20 and 25 miles. Its area is approximately 1,500 square miles; or intermediate in extent between the area of the State of Rhode Island and the area of the State of Delaware.

It is a vast, nearly horizontal plateau of ice. The general elevation of its surface at a distance of five or six miles from its outer border is about 1,500 feet. The central portion is free from moraines or dirt of any kind, but is rough and broken by thousands and tens of thousands of crevasses. Its surface, when not concealed by moraines, is broadly undulating, and recalls the appearance of the rolling prairie lands west of the Mississippi. From the higher swells on its surface one may see for many miles in all directions without observing a single object to break the monotony of the frozen plain. So vast is the glacier that, on looking down on it from elevations of two or three thousand feet above its surface, its limits are beyond the reach of vision.

Lobes.—The glacier consists of three principal lobes, each of which is practically the expansion of a large tributary ice stream. The largest has an eastward flow, toward Yakutat bay, and is supplied mainly by the Seward glacier. The next lobe to the west, is the expanded terminus of the Agassiz glacier; its current is toward the southwest. The third great lobe lies between the Chaix and Robinson hills, and its main supply of ice is from the Tyndall and Guyot glaciers. Its central current is south-

[1] This account of the Malaspina glacier has been compiled principally from the proof-sheets of a report by the writer on a second expedition to Mt. St. Elias in 1891, to appear in the Thirteenth Ann. Rep. of the U. S. Geological Survey.

ward. The direction of flow in the several lobes explains the distribution of the moraines about their borders.

The Seward lobe melts away before reaching Yakutat bay and ends with a low frontal slope, but its southern margin has been eaten into by the ocean, so as to form the Sitkagi bluffs. The Agassiz lobe is complete, and is fringed all about its outer border by broad moraines. The Guyot lobe pushes boldly out into the ocean, and breaking off forms magnificent ice cliffs.

Characteristics of the non-moraine-covered surface.—On the north border of the glacier, but below the line of perpetual snow, where the great plateau of ice has a gentle slope, the surface melting gives origin to hundreds of rills and rivulets which course along in channels of clear ice until they meet a crevasse or moulin and plunge down into the body of the glacier to join the drainage beneath. On warm summer days when the sun is well above the horizon the murmur of streams may be heard wherever the ice surface is inclined and not greatly broken, but as soon as the shadows of evening cross the ice fields melting ceases and the silence is unbroken. These streams are always of clear, sparkling water, and it is seldom that their channels contain debris. Where the surface of the glacier is nearly level, and especially when broken by crevasses, surface streams are absent, although the clefts in the ice are frequently filled with water. The moulins in which the larger of the surface streams usually disappear are well-like holes of great depth. They are seldom straight, however, as the water in plunging into them usually strikes the opposite side and causes it to melt away more rapidly than the adjacent surfaces. The water in descending is dashed from side to side and increases their irregularities. A deep roar coming from the hidden chambers to which the moulins lead frequently tells that large bodies of water are rushing along the ice caves beneath. In the southern portion of the glacier, where the ice has been deeply melted, and especially where large crevasses occur, the abandoned tunnels made by englacial streams are sometimes revealed. These tunnels are frequently 10 or 15 feet high, and occasionally one may pass through them from one depression in the glacier to another. In some instances they are floored with debris, some of which is partially rounded. As melting progresses this material is concentrated at the surface as a moraine.

The ice in the various portions of the glacier was observed to be formed of alternate blue and white bands, as is the rule in glacial ice generally. The blue bands are of compact ice, while the white bands are composed of ice filled with air cavities. The banded structure is usually nearly vertical, but the dip, when noticeable, is northward. Nearly parallel with the blue and white layers, but crossing them at low angles, there are frequently bands of hard, blue ice several hundred feet long and 2 or 3 inches in thickness which have a secondary origin, and are due to the freezing of waters in fissures.

The rapid melting of the surface produces many curious phenomena, which are not peculiar to this glacier, however, but common to many ice bodies below the line of perpetual snow. The long belts of stone and dirt forming the moraines protect the ice beneath from the action of the sun and air, while adjacent surfaces waste away. The result of this differential melting is that the moraines become elevated on ridges of ice. The forms of the ridges vary according to the amount and character of the debris resting upon them. In places they are steep and narrow, and perhaps 150 or 200 feet high. From a little distance they look like solid masses of debris, and resemble great railroad embankments, but on closer examination they are seen to be ridges of ice, covered with a thin sheet of earth and stones. The sides of such ridges are exceedingly difficult to climb, owing to the looseness of the stones, which slide from beneath one's feet and roll down the slopes. The larger bowlders are the first to be dislodged by the melting of the ice, and, rolling down the sides of the ridges, form a belt of coarse debris along their margins. In this way a marked assortment of the debris in reference to size and shape frequently takes place. In time the narrow belts of large bowlders become elevated in their turn and form the crests of secondary ridges. Rocks rolling down the steep slopes are broken into finer and finer fragments and are reduced in part to the condition of sand and clay. When the debris is sufficiently comminuted it is sometimes carried away by surface streams and washed into crevasses and moulins. Not all of the turbidity of the subglacial streams can be charged to the grinding of the glacier over the rocks on which it rests, as a limited portion of it certainly comes from the crushing of the surface moraines during their frequent changes of position.

Isolated blocks of stone lying on the glacier, when of sufficient size not to be warmed through by the sun's heat in a single day, also protect the ice beneath and retain their position as the adjacent surface melts, so as to rest on pedestals frequently several feet high. These elevated blocks are usually flat, angular masses, sometimes 20 feet or more in diameter. Owing to the greater effect of the sun on the southern side of the columns which support them, the tables are frequently inclined southward, and ultimately slide off their pedestals in that direction. No sooner has a block fallen from its support, however, than the process is again initiated, and it is again left in relief as the adjacent surface melts. The many falls which the larger blocks receive in this manner cause them to become broken, thus illus trating another phase of the process of comminution to which sur face moraines are subjected. On Malaspina glacier the formation of glacial tables is confined to the summer season. In winter the surface of the glacier is snow-covered and differential melting can not be marked. The fact that glacial tables are seldom seen just after the snows of winter disappear suggest that winter melting takes place to some extent, but in a different manner from what it does in the summer. Just how the blocks are dislodged from the pedestals in winter has not been observed.

While large objects lying on the surface of the glacier are elevated on pedestals in the manner just described, smaller ones, as is well known and especially those of dark color, become heated by the sun, and, melting the ice beneath, sink into it. When small stones and dirt are gathered in depressions on the surface of the glacier, or, on a large scale, when moulins become filled with fine debris and the adjacent surface is lowered by melting, the material thus concentrated acts as do large bowlders, and protects the ice beneath. But as the gravel rises in reference to the adjacent surface, the outer portion rolls down from the pedestal on all sides, and the result is that a sharp cone of ice is formed, having a sheet of gravel and dirt over its surface. These sand cones, as they are called, sometimes attain a height of ten or twelve feet, and form conspicuous and characteristic features of the glaciers over large areas.

The surface of Malaspina glacier over many square miles, where free from moraine, is covered with a coral-like crust which results from the alternate melting and freezing of the surface. The crevasses in this portion of the vast plateau are seldom of large size, and, owing to the melting of their margins, are broad at the surface and contract rapidly downward. They are in fact mere gashes, sometimes ten or twenty feet deep, and are apparently the remnants of larger crevasses formed in the glaciers which flow down from the mountains. Deeper crevasses occur at certain localities about the border of the glacier, where the ice at the margin falls away from the main mass, but these are seldom conspicuous, as the ice in the region where they occur is always heavily covered with debris and the openings become filled with stones and bowlders. The generally level surface of the glacier and the absence of large crevasses indicate that the ground on which it rests is comparatively even. Where the larger of the tributary glaciers join it, however, ice falls occur, caused by steep descents in the ground beneath. These falls are just at the lower limit of perpetual snow and are only fully revealed when melting has reached its maximum and the snows of the winter have not yet begun to accumulate.

Moraines.—From any commanding station overlooking Malaspina glacier one sees that the great central area of clear, white ice is bordered on the south by a broad, dark band formed by bowlders and stones. Outside of this and forming a belt concentric with it is a forest-covered area, in many places four or five miles wide. The forest grows on the moraine, which rests upon the ice of the glacier. In a general view by far the greater part of the surface of the glacier is seen to be formed of clear ice, but in crossing it one comes first to the forest and moraine-covered border, which, owing to the great obstacles it presents to travel, impresses one as being more extensive than it is in reality.

The moraines not only cover all of the outer border of the glacier, but stream off from the mountain spurs projecting into it on the north. As indicated on the accompanying map, one of these trains starting from a spur of the Samovar hills crosses the entire breadth of the glacier and joins the marginal moraine on its southern border. This long train of stones and bowlders is really a highly compound medial moraine formed at the junction of the expanded extremities of the Seward and Agassiz glaciers.

All of the glaciers which feed the great Piedmont ice-sheet are above the snow line, and the debris they carry only appears at the surface after the ice descends to the region where the annual waste is in excess of the annual supply. The stones and dirt previously contained in the glacier are then concentrated at the surface owing to the melting of the ice. This is the history of all of the moraines on the glacier. They are formed of the debris brought out of the mountains by the tributary Alpine glacier, and concentrated at the surface by reason of the melting of the ice.

Malaspina glacier in retreating has left irregular hillocks of coarse debris which are now densely forest-covered. These deposits do not form a continuous terminal moraine, however, but a series of irregular ridges and hills having a somewhat common trend. They indicate a slow general retreat without prolonged halts. The heaps of debris left as the ice front retreated have a general parallelism with the present margin of the glacier and are pitted with lake basins, but only their higher portions are exposed above the general sheet of sand and gravel spread out by streams draining the glacier.

The blocks of stone forming the moraines now resting on the ice are of all sizes up to twenty or thirty feet in diameter, but those of large dimensions are not common. The stones are rough and angular except when composed of material like granite, which on weathering forms oval and rounded boulders of disintegration. So far as has been observed, very few of the stones on the glacier have polished or striated surfaces. The material of which the moraines are composed is of many kinds, but individual ridges frequently consist of fragments of the same variety of rock, the special kind in each case depending on the source of the thread in the great ice current which brought the fragments from the mountains.

In many instances, particularly near the outer border of the ice sheet, there are large quantities of tenacious clay, filled with angular stones, which is so soft, especially during heavy rains, that one may sink waist deep in the treacherous mass. Sometimes blocks of stone a foot or more square float on the liquid mud and lure the unwary traveler to disaster.

On the eastern margin of the ice sheet adjacent to Yakutat bay, where the frontal slope is low, there are broad deposits of sand and well rounded gravel which has been spread out over the ice. On the extreme margin of the glacier this deposit merges with hillocks and irregular knolls of the same kind of material, some of which rise a hundred feet above the nearest exposure of ice and are clothed with dense forests. The debris is so abundant and the ice ends in such a low slope that it is frequently impossible to determine where the glacier actually terminates. The water-worn material here referred to as resting on the glacier, has been brought out of tunnels in the ice, as will be noticed further on.

Surface of the fringing moraines.—A peculiar and interesting feature of the moraine on the stagnant border of Malaspina glacier is furnished by the lakelets that occur everywhere upon it. These are found in great numbers both in the forest-covered moraine and in the outer border of the barren moraine. They are usually rudely circular, and have steep walls of dirty ice which slope toward the water at high angles, but are undercut at the bottom, so that the basins in vertical cross section have something of an hour-glass form. The walls are frequently from 50 to 100 feet high, with a slope of 40° to 50°, and sometimes are nearly perpendicular. Near the water's edge the banks are undercut so as to leave a ridge projecting over the water. The upper edge of the walls is formed of the sheet of debris which covers the glacier, and the melting of the ice beneath causes this material to roll and slide down the ice slopes and plunge into the waters below. The lakes are usually less than 100 feet in diameter, but larger ones are by no means uncommon, several being observed which were 150 or 200 yards across. Their waters are always turbid owing to the mud which is carried into them by small avalanches and by the rills that trickle from their sides. The rattle of stones falling into them is frequently heard while traveling over the glacier, and is especially noticeable on warm days, when the ice is melting rapidly, but is even more marked during heavy rains. The crater-like walls inclosing the lakes are seldom of uniform height, but frequently rise into pinnacles. Between the pinnacles there are occasionally low saddles, through which in some instances the lakes overflow. Frequently there are two low saddles nearly opposite to each other, which suggests that the lakes were formed by the widening of crevasses. The stones and dirt which fall into them, owing to the melting of the walls, gradually fill their bottoms. Instances are numerous where the waters have escaped through crevasses or openings in the bottom of the basin, leaving an exceedingly rough depression, with a heavy deposit of debris at the bottom.

As the general surface of the glacier is lowered by melting, the partially filled holes gradually disappear and their floors, owing to the deep accumulation of debris on them, which protects the ice from melting, become elevated above the surrounding surface, in the same manner that glacial tables are formed. The debris covering these elevations slides down their sides as melting progresses, and finally a rugged pyramid of ice, covered with a thin coating of debris, occupies the place of the former lake. These pyramids frequently have a height of 60 or 80 feet, and are sometimes nearly conical in shape. They resemble "sand cones," but are of much greater size and are sheathed with coarser debris. The sand cones are usually, if not always, formed and melted away during a single season, while the debris pyramids require several seasons for their cycle of change.

Like the lakelets to which they owe their origin, the debris pyramids are confined to the stagnant portions of the glacier and play an important part in the breaking up and comminution of the material forming the marginal moraines. Owing to the sliding of the bowlders and stones into the lakelets and their subsequent fall from the sides of the pyramids, they are broken and crushed so that the outer portion of the glacier, where the process has been going on longest, is covered with finer debris and contains more clay and sand than the inner portions.

Just how the holes containing glacial lakelets originate it is difficult to say, but their formation seems to be initiated, as already suggested, by the melting back of the sides of crevasses. Breaks in the general sheet of debris covering the glacier expose the ice beneath to the action of the sun and rain, which causes it to melt and the crevasses to broaden. The openings become partially filled with water and lakelets are formed. The waves wash the debris from the ice about the margin of the lakelets, thus exposing it to the direct attack of the water, which melts it more rapidly than higher portions of the slopes are melted by the sun and rain. It is in this manner that the characteristic hourglass form of the basins originates. The lakelets are confined to the outer or stagnant portion of the glacier, for the reason that motion in the ice would produce crevasses through which the water would escape. Where glacial lakelets occur in great numbers it is evident that the ice must be nearly or quite stationary, otherwise the basins could not exist for a series of years. The lakelets and the pyramids resulting from them are the most characteristic features of the outer border of the glacier. The number of each must be many thousand. They occur not only in the outer portion of the barren moraine, but also throughout the forest-covered area still nearer the outer margin of the glacier. Large quantities of trees and bushes fall into them with the debris that slides from their sides, and tree trunks, roots and soil, thus become buried in the moraines.

Forests on the moraines.—The outer and consequently older portions of the fringing moraines are covered with vegetation, which in places, particularly near the outer margin of the belt, has all the characteristics of old forests. It consists principally of spruce, alder and cottonwood trees, and a great variety of shrubs, bushes and ferns. In many places the ice beneath the dense forest is not less than a thousand feet thick. The vegetation is confined principally to the border of the Seward lobe. Near Yahtse river the belt is 5 miles broad, but decreases toward the east, and is absent at the Sitkagi bluffs, where the glacier is being eaten away by the sea. It is only on the stagnant borders of the ice sheet that forests occur. Both glacial lakelets and forests on the moraines are absent where the ice has motion. The forest-covered portion is by estimate between 20 and 25 square miles in area.

Outer margin.—The southern margin of Malaspina glacier, between the Yahtse and Point Manby, is abrupt and forms a bluff that varies in height from 140 to 300 feet or more. The bluff is so steep in most places and is so heavily incumbered with fallen trees and boulders, that it is with difficulty one can climb it. Many times the trouble in ascending is increased by land slides which have piled the superficial material in confused heaps, and in other instances the melting of the ice beneath the vegetation has left concealed pit-falls into which one may drop without warning. The bluff formed by the margin of the glacier when not washed by the sea, is boldest and steepest where the covering of vegetation is most dense. Where the covering consists of stones and dirt without vegetation, however, the margin may still be bold. This is illustrated between the mouth of the Yahtse and Icy cape, where the ice is concealed beneath a general sheet of debris, but has a bold convex margin which rises abruptly from the desolate torrent-swept waste at its base.

When the glacier meets the sea the ice is cut away at the water-level, and blocks fall from above, leaving perpendicular cliffs of clear ice. At Icy cape there is a bold headland of this nature from which bergs are continually falling with a thunderous roar that may be heard fully twenty miles away. On the crest of the cliffs of clear blue ice there is a dark band formed by the edge of the sheet of debris covering the glacier, and showing that the moraine which blackens its surface along its outer margin is entirely superficial. At Sitkagi bluffs the glacier is again washed by the sea but the base of the ice is there just above the water-level and recession is slow. The bluffs are heavily covered with stones and dirt, and icebergs do not form.

At the heads of the gorges in the margin of the glacier leading to the mouths of tunnels, the dirt-covered ice forms bold cliffs which are most precipitous at the heads of the reëntrant angles. The eastern margin of the ice sheet, facing Yakutat bay, is low and covered to a large extent with water-worn debris. The ridges on the glacier formed by moraines are there at right angles to the margin of the ice and are bare of vegetation. The reason for the exceptionally low slope of the eastern margin of the ice sheet seems to be that the current in the ice is there eastward and the glacier is melting back without leaving a stagnant border.

Marginal lakes. — The water bodies here referred to are called "marginal lakes" for the reason that they are peculiar to the margins of glaciers. Where rocks border an ice field or project through it they become heated, especially on southern exposures, and, radiating heat to the adjacent ice, cause it to melt. A depression is thus formed along the margin of the ice, which becomes a line of drainage. Water flowing through such a channel accelerates the melting of the ice, at least until a heavy coating of debris has accumulated. When a steep mountain spur projects into an ice field the lines of drainage on each side converge and frequently unite at its extremity, forming a lake, from which the water usually escapes through a tunnel in the ice. Typical instances of lakes of this character occur at Terrace point, at the south end of the Hitchcock range, and again about the base of the Chaix hills.

When a stream flows along the side of a glacier a movement in the ice or the sliding of stone and dirt from its surface sometimes obstructs the drainage and causes the formation of another variety of marginal lakes. In such instances the imprisoned waters usually rise until they can find an outlet across the barrier and then cut a channel through it.

A glacier in flowing past the base of a mountain frequently obstructs the drainage of lateral valleys and causes lakes to form. These usually find outlets, as in the case of lakes at the end of mountain spurs, through a subglacial or englacial tunnel, and are filled or emptied according as the tunnel through which the waters escape affords free drainage or is obstructed. Several examples of this variety of marginal lakes occur on the west and north sides of the Chaix hills. They correspond in the mode of their formation with the well-known Merjelen See of Switzerland.

Other variations in the manner in which glaciers obstruct drainage might be enumerated, but those mentioned cover all of the examples thus far observed about Malaspina glacier. The conditions which lead to the formation of the marginal lakes are unstable, and the records which the lakes leave in the form of terraces, deltas, etc., are consequently irregular. When streams empty into one of these lakes, deltas and horizontally stratified lake beds are formed, as in ordinary water bodies, but as the lakes are subject to many fluctuations, the elevations at which the records are made are continually changing, and in instances like those about Malaspina glacier, where the retaining ice body is constantly diminishing, may occupy a wide vertical interval.

Drainage begins on the southeast side of Chaix hills at Moore's Nunatak, where during the time of our visit there were two small lakes, walled in on nearly all sides by the moraine covered ice of Malaspina glacier. The water filling these basins comes principally from the high ice fall at the north, where the glacier descends over a projecting spur running east from

Moore's Nunatak. The water escaped from the first lake across a confused mass of debris which had slid from the ice bluff bordering the stream and formed a temporary dam. Below the dam the water soon disappeared beneath deeply crevassed and heavily moraine - covered ice and came to light once more at the mouth of a tunnel about a mile to the southwest. The second lake, at the time of our visit, had almost disappeared, but its former extent was plainly marked by a barren sand flat many acres in extent, and by terraces along its western border. The lake occupied a small embayment in the hills, the outlet of which had been closed by the ice flowing past it. Below the second lake the stream flows along the base of densely wooded knolls and has a steep moraine - covered bluff of ice for its left bank. About a mile below it turns a sharp projection of rocks and cuts deeply into its left bank, which stands as an overhanging bluff of dirty ice over 100 feet high. The stream then flows nearly due west for some 3 miles to Crater lake. On its right bank is a terrace about 150 feet high which skirts the base of the Chaix hills and marks the position of the stream at a former stage. The terrace is about 100 yards broad, and above it are two other terraces on the mountain slope, one at an elevation of 50 feet and the other at 75 feet above the broad terrace. The upper terraces were only observed at one locality, and were probably due to deposits formed in a marginal lake at the end of a mountain spur.

The terraces left by streams flowing between a moraine-covered glacier and a precipitous mountain slope are peculiar and readily distinguishable from other similar topographic features. The channels become filled principally with debris which slides down the bank of ice. This material is angular and unassorted, but when it is brought within the reach of flowing waters soon becomes rounded and worn. On the margin of the channel, adjacent to the glacier, there is usually a heavy deposit of unassorted debris which rests partly upon the ice and forms the actual border of the stream. When the glacier is lowered by melting, the steam abandons its former channel and repeats the process of terrace building at a lower level. The material forming the terrace at the base of Chaix hills is largely composed of blue clay filled with both angular and rounded stones and bowlders, but its elevated border is almost entirely of angular debris. The drainage from the mountain slope above the terrace is obstructed by the elevated border referred to, and swamps and lagoons have formed back of it. In the material forming the terraces there are many tree trunks, and growing upon its surface there is a forest of large spruce trees.

At the extreme southern end of the Chaix hills the drainage from the northeast, which we have been tracing, joins another stream from the northwest and forms Lake Castani. This lake, like the one at Terrace point, is at the south end of a precipitous mountain ridge projecting into the glacier and drains through a tunnel in the ice. The stream flowing from it is known as the Yahtse and flows for six or eight miles beneath the ice before emerging at its southern margin. Large quantities of both coarse and fine material are being carried into Lake Castani by tributary streams and is there deposited as deltas and lake beds. When the lake is drained, as sometimes happens, vast quantities of this material must be carried into the tunnel through which the waters escape.

On the west side of Chaix hills are several other marginal lakes of the same general character as those just described. The one next northwest of Lake Castani occupies a long narrow valley between two outstanding mountain ridges, and is retained by the glacier which blocks the end of the recess thus formed. This lake was clear of ice July, 1891, and of a dark blue color, showing that it received little drainage from the glacier. Other lakes on the northwest side of the Chaix hills are of a similar nature, and during my visit were heavily blocked with floating ice. On the north side of Chaix hills there are other small water bodies occupying embayments and retained by the glacier which flows past their entrances. The water from all these lakes escapes through tunnels.

The lakes to which attention has been directed are especially interesting, as they illustrate one phase of deposition depending upon glaciation, and suggest that a great ice sheet like that which formerly covered New England very likely gave origin to marginal lakes, the records of which should be found on steep mountain slopes.

Drainage.—The drainage of the Malaspina glacier is essentially englacial or subglacial. There is no surface drainage excepting in a few localities, principally on its northern border, where there is a slight surface slope, but even in such places the streams are short and soon plunge into a crevasse or a moulin and join the drainage beneath.

On the lower portions of the Alpine glaciers, tributary to the main ice-sheet, there are sometimes small streams coursing along in ice channels, but these are short lived. On the borders of the tributary glaciers there are frequently important streams flowing between the ice and the adjacent mountain slope, but when these come down to the Malaspina glacier they flow into tunnels and are lost to view.

Along the southern margin of the glacier, between the Yahtse and Point Manby, there are hundreds of streams which pour out of the escarpment formed by the border of the glacier, or rise like great fountains from the gravel and bowlders accumulated at its base. All of these are brown and heavy with sediment and overloaded with bowlders and stones. The largest and most remarkable of these springs is the one indicated on the accompanying map as Fountain stream. This comes to the surface through a rudely circular opening, nearly 100 feet in diameter, surrounded in part by ice. Owing to the pressure to which the waters are subjected they boil up violently, and are thrown into the air to the height of 12 to 15 feet, and send jets of spray several feet higher. The waters are brown with sediment, and rush seaward with great rapidity, forming a roaring stream, fully 200 feet broad, which soon divides into many branches, and is spreading a sheet of gravel and sand right and left into the adjacent forest. Where Fountain stream rises, the face of the glacier is steep and covered with huge bowlders, many of which are too large for the waters to move. The finer material has been washed away, however, and a slight recession in the face of the ice bluff has resulted. The largest stream draining the glacier is the Yahtse. This river, as already stated, rises in two principal branches at the base of the Chaix hills, and flowing through a tunnel some six or eight miles long, emerges at the border of the glacier as a swift brown flood fully one hundred feet across and fifteen or twenty feet deep. The stream, after its subglacial course, spreads out into many branches, and is building up an alluvial fan which has invaded and buried several hundred acres of forest.

In traversing the coast from the Yahtse to Yakutat bay, we crossed a large number of streams which drain the ice fields of the north, some of which were large enough to be classed as rivers. When the streams on flowing away from the glacier are large they divide into many branches, as do the Yahtse and Fountain, and enter the sea by several mouths. When the streams are small, however, they usually unite to form large rivers before entering the ocean. The Yahtse and Fountain, as we have seen, are examples of the first, while Manby and Yahna streams are examples of the second class. Manby stream rises in hundreds of small springs along the margin of the glacier which flow across a desolate torrent-swept area and unite just before reaching the ocean into one broad, swift flood of muddy water much too deep for one to wade.

On the border of the glacier facing Yakutat Bay, however, the drainage is different. The flow of the ice is there eastward, although the margin is probably stagnant, and instead of forming a bold, continuous escarpment, ends irregularly and with a low frontal slope. The principal streams on the eastern margin in 1891 were the Osar, Kame and Kwik. Each of these issues from a tunnel and flows for some distance between walls of ice. Of the three streams mentioned the most interesting is the Kame, which issues as a swift brown flood partially choked with broken ice, from the mouth of a tunnel and flows for half a mile in an open cut between precipitous walls of dirty ice 80 to 100 feet high. This is the longest open drainage channel that I have yet seen in the ice. It is about 50 feet broad where the stream rushes from the glacier, but soon widens to several times this breadth. Its bottom is covered with rounded gravel and sand, and along its sides are sand-flats and terraces of gravel resting upon ice. The swift, muddy current was dotted with small bergs stranded here and there in the center of the stream, showing that the water was shallow. Evidently the stream has a long subglacial course and carries with it large quantities of stones which are rounded as in ordinary rivers. Gravel and sand are being rapidly deposited in the ice channel through which it flows after emerging from its tunnel. Broad sand-flats are being spread out in the lakes and swamps two or three miles to the east. The stream is some four or five miles in length and near Yakutat bay meanders over a barren area perhaps a mile broad. I have called it Kame stream because of a ridge of gravel running parallel with it which was deposited during a former stage when the waters flowed about 100 feet higher than now and deposited a long ridge of gravel on the ice which has all the characteristics of the kames in New England. In the more definite classification of glacial sediments now adopted, this would more properly be called an osar.

Near the shore of Yakutat bay the streams from the glacier spread out in lagoons and sand-flats, where much of the finer portion of the material they carry is deposited. Sometimes this debris is spread out above the ice, and forms level terraces of fine sand and mud which become prominent as the glacier wastes away.

Osars.—The drainage of the glacier has not been investigated as fully as its importance demands, but the observations already made seem to warrant certain conclusions in reference to deposits made within the glacier by subglacial or englacial streams.

When the streams from the north reach the glacier they invariably flow into tunnels and disappear from view. The entrances to the tunnels are frequently high arches, and the streams flowing into them carry along great quantities of gravel and sand. About the southern and eastern borders of the glacier, where the streams emerge, the arches of the tunnels are low, owing principally to the accumulation of debris which obstructs their discharge. In some instances, as at the head of Fountain stream, the accumulation of debris is so great that the water rises through a vertical shaft in order to reach the surface, and rushes upward under great pressure. The streams flowing from the glacier bring out large quantities of well rounded sand and gravel, much of which is immediately deposited in alluvial cones. This much of the work of subglacial streams is open to view and enables one to infer what takes place within the tunnels and to analyze to some extent the processes of subglacial deposition.

The streams issuing from the ice are overloaded, and, besides, on emerging, frequently receive large quantities of coarse debris from the adjacent moraine-covered ice cliffs. The streams at once deposit the coarser portion of their loads, thus building up their channels and obstructing the outlets of the tunnels. The blocking of the tunnels must cause the subglacial streams to lose force and deposit sand and gravel on the bottom of their channels ; this causes the water to flow at higher levels, and coming in contact with the roofs of the tunnels, enlarges them upwards ; this in turn gives room for additional deposits within the ice as the alluvial cones at the extremities of the tunnels grow in height. In this way narrow ridges of gravel and sand, having perhaps some stratification due to periodic variations in the volume of the streams, may be formed within the ice. When the glacier melts, the gravel ridges contained within it will be exposed at the surface, and as the supporting walls melt away, the gravel at the top of the ridge will tend to slide down so as to give the deposit a pseudo-anticlinal structure. Ridges of gravel deposited in tunnels beneath the moraine-covered portion of the Malaspina glacier, would have bowlders dropped upon them as the ice melts, but where the glacier is free from surface debris there would be no angular material left upon the ridges when the ice finally disappeared. Such a system of deposition as is sketched above would result in the formation of narrow, winding ridges of cross-bedded sand and gravel, corresponding, seemingly, in every way to the osars of many glaciated regions. The process of subglacial deposition pertains especially to stagnant ice sheets of the Malaspina type, which are wasting away. In an advancing glacier it is evident that the conditions would be different, and subglacial erosion might take place instead of subglacial deposition.

Alluvial cones.—Below the outlets of the tunnels through which Malaspina glacier is drained, there are immense deposits of bowlders, gravel, sand, and mud which have the form of segments of low cones. These deposits are of the nature of the "alluvial cones," or "alluvial fans" so common at the bases of mountains in arid regions, and are also related to the "cones of dejection," deposited by torrents, and to the subaërial portion of the deltas of swift streams. As deposits of this nature have not been satisfactorily classified, I shall for the present call them "alluvial cones."

As stated in speaking of osars, the streams issuing from tunnels in Malaspina glacier at once begin to deposit. The larger bowlders and stones are first dropped, while gravel, sand and silt are carried farther and deposited in the order of their coarseness. The deposits originating in this way have a conical form, the apex of each cone being at the mouth of a tunnel. As the apexes of the cones are raised by the deposition of coarse material, their peripheries expand in all directions, and as the region is densely forest covered, great quantities of trees become buried beneath them. As the ice at the head of an alluvial cone recedes, the alluvial deposit follows it by deposition on the upstream side. The growth of the alluvial cones will continue so long as the glacier continues to retreat, or until the streams which flow over them have their subglacial courses changed. The material of the alluvial cones is as heterogeneous as the material forming the moraines on the border of the glacier, about which they form, but the greater and practically the entire accumulation is more or less rounded and waterworn. Cross stratification characterizes the deposits throughout, and on the surface of many of the cones, and probably in their interior, also, there are large quantities of broken tree trunks and branches. The coarse deposits first laid down on a growing alluvial cone are buried beneath later deposits of finer material in such a way that a somewhat regular stratification may result. A deep section of one of these deposits should show a gradual change from fine material at the top to coarse stones and subangular bowlders at the bottom. Their outer borders are of fine sand and mud, and when the distance of the ocean is sufficient, the streams flowing from them deposit large quantities of silt on their flood plains. The very finest of the glacial mud is delivered to the ocean and discolors its water for many miles from land.

The formation of alluvial cones about the border of a stagnant ice sheet, and the deposition of ridges of gravel within it, have an intimate connection and are in fact but phases of a single process. The growth of an alluvial cone tends to obstruct the mouth of the tunnel through which its feeding stream discharges; this causes the stream to deposit within the tunnel ; this, again, raises the stream and allows it to build its alluvial cone still higher. In the case of Malaspina glacier where this process has been observed, the ice sheet is stagnant, at least on its border, and is retreating. The ground on which it rests is low, but is thought to be slightly higher on the southern margin of the glacier than under its central portion. The best development of alluvial cones and osars would be expected in a stagnant ice sheet resting on a gently inclined surface, with high lands on the upper border from which abundant debris could be derived. These ideal conditions are nearly reached in the example described.

Glacial and ocean records.—Much has been written concerning the character of the deposits made by glaciers when they meet the ocean, but so far as can be judged from the conditions observed about the borders of Malaspina ice sheet, the sea is much more powerful than the ice. Where the two unite their action, the sea leaves the more conspicuous records. The waters are active and aggressive, while the glacier is passive. Where the glacier enters the ocean its records are at once modified and to a great extent obliterated. The presence of large bowlders in marine sediments, or in gravels and sands along the coast is about all the evidence of glacial action that can be expected under the conditions referred to. Where the swift streams from the Malaspina glacier enter the ocean the supremacy of the waves, tides, and currents is even more marked. The streams are immediately turned aside by the accumulation of sand bars across their mouths, and nothing of the nature of stream-worn channels beneath the level of the ocean can exist. All of the deposits along the immediate shore between the Yahtse and Yakutat bay have the characteristic topographic features resulting from the action of waves and currents and do not even suggest the proximity of a great glacier.

Recent advance.—On the eastern margin of Malaspina glacier, about four miles north of Point Manby, there is a locality where the ice has recently advanced into the dense forest and cut scores of great spruce trees short off and piled them in confused heaps. After this advance the ice retreated, leaving the surface strewn with irregular heaps of bowlders and stones and inclosing many basins which, at the time of our visit, were full to the brim. The glacier during its advance plowed up a ridge of blue clay in front of it, thus revealing in a very satisfactory manner the character of the strata on which it rests. The clay is thickly charged with sea-shells of living species, proving that the glacier, during its former great advance, probably extended to the ocean, and that a rise of the land has subsequently occurred. This is in harmony with many other observations which show that the coast adjacent to Malaspina glacier is now rising. The blue color of the subglacial strata is in marked contrast with the browns and yellows of the moraines left on its surface by the retreating ice, which, in common with the fringing moraines still resting on the glacier, show considerable weathering. Among the shells collected in the subglacial clay Dr. W. H. Dall has identified the following;

Cardium gronlandicum, Gronl.
Cardium islandicum, L.
Kennerlia grandis, Dall.
Leda fossa, Baird.
Macoma sabulosa, Spengler.

Similar shells, all of living species, were previously found at an elevation of five thousand feet on the crest of a fault scarp at Pinnacle pass, showing that recent elevations of land much greater than the one recorded in the marine clay just noticed have taken place. In fact there are several indications that the coast in the vicinity has been rising and that the same process is still continuing.

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