

Chapter 2

The Glaciers

OF the small residual glaciers mentioned in the preceding chapter, I have found sixty-five in that portion of the range lying between latitude $36^{\circ} 30'$ and 39° . They occur singly or in small groups on the north sides of the peaks of the High Sierra, sheltered beneath broad frosty shadows, in amphitheatres of their own making, where the snow, shooting down from the surrounding heights in avalanches, is most abundant. Over two thirds of the entire number lie between latitude 37° and 38° , and form the highest fountains of the San Joaquin, Merced, Tuolumne, and Owen's rivers.

The glaciers of Switzerland, like those of the Sierra, are mere wasting remnants of mighty ice-floods that once filled the great valleys and poured into the sea. So, also, are those of Norway, Asia, and South America. Even the grand continuous mantles of ice that still cover Greenland, Spitzbergen, Nova Zembla, Franz-Joseph-Land, parts of Alaska, and the south polar region are shallowing and shrinking. Every glacier in the world is smaller than it once was. All the world is growing warmer, or the crop of snow-flowers is diminishing. But in contemplating the condition of the glaciers of the world, we must bear in mind while trying to account for the changes going on that the same sunshine that wastes them builds them. Every glacier records the expenditure of an enormous amount of sun-heat in lifting the vapor for the snow of which it is made from the ocean to the mountains, as Tyndall strikingly shows.

The number of glaciers in the Alps, according to the Schlagintweit brothers, is 1100, of which 100 may be regarded as primary, and the total area of ice, snow, and *névé* is estimated at 1177 square miles, or an average for each glacier of little more than one square mile. On the same authority, the average height above sea-level at which they melt is about 7414 feet. The Grindelwald glacier descends below 4000 feet, and one of the Mont Blanc glaciers reaches nearly as low a point. One of the largest of the Himalaya glaciers on the head waters of the Ganges does not, according to Captain Hodgson, descend below 12,914 feet. The largest of the Sierra glaciers on Mount Shasta descends to within 9500 feet of the level of the sea, which, as far as I have observed, is the lowest point reached by any glacier within the bounds of California, the average height of all being not far from 11,000 feet.

The changes that have taken place in the glacial conditions of the Sierra from the time of greatest extension is well illustrated by the series of glaciers of every size and form extending along the mountains of the coast to Alaska. A general exploration of this instructive region shows that to the north of California, through Oregon and Washington, groups of active glaciers still exist on all the high volcanic cones of the Cascade Range,--Mount Pitt, the Three Sister, Mounts Jefferson, Hood, St. Helens, Adams, Rainier, Baker, and others,--some of them of considerable size, though none of them approach the sea. Of these mountains Rainier, in Washington, is the highest and iciest. Its dome-like summit, between 14,000 and 15,000 feet high, is capped with ice, and eight glaciers, seven to twelve miles long, radiate from it as a center, and form the sources of the principal streams of the State. The lowest-descending of this fine group flows through beautiful forests to within 3500 feet of the sea-level, and sends forth a river laden with glacier mud and sand. On through British Columbia and southeastern Alaska the broad, sustained mountain-chain, extending along the coast, is generally glacier-bearing. The upper branches of nearly all the main cañons and fiords are occupied by glaciers, which gradually increase in size, and descend lower until the high region between Mount Fairweather and Mount St. Elias is reached, where a considerable number discharge into the waters of the ocean. This is preëminently the ice-land of Alaska and of the entire Pacific Coast.

Northward from here the glaciers gradually diminish in size and thickness, and melt at higher levels. In

Prince William Sound and Cook's Inlet many fine glaciers are displayed, pouring from the surrounding mountains; but to the north of latitude 62° few, if any, glaciers remain, the ground being mostly low and the snowfall light. Between latitude 56° and 60° there are probably more than 5000 glaciers, not counting the smallest. Hundreds of the largest size descend through the forests to the level of the sea, or near it, though as far as my own observations have reached, after a pretty thorough examination of the region, not more than twenty-five discharge icebergs into the sea. All the long high-walled fiords into which these great glaciers of the first class flow are of course crowded with icebergs of every conceivable form, which are detached with thundering noise at intervals of a few minutes from an imposing ice-wall that is thrust forward into deep water. But these Pacific Coast icebergs are small as compared with those of Greenland and the Antarctic region, and only a few of them escape from the intricate system of channels, with which this portion of the coast is fringed, into the open sea. Nearly all of them are swashed and drifted by wind and tide back and forth in the fiords until finally melted by the ocean water, the sunshine, the warm winds, and the copious rains of summer. Only one glacier on the coast, observed by Prof. Russell, discharges its bergs directly into the open sea, at Icy Cape, opposite Mount St. Elias. The southernmost of the glaciers that reach the sea occupies a narrow, picturesque fiord about twenty miles to the northwest of the mouth of the Stikeen River, in latitude $56^{\circ} 50'$. The fiord is called by the natives "Hutli," or Thunder Bay, from the noise made by the discharge of the icebergs. About one degree farther north there are four of these complete glaciers, discharging at the heads of the long arms of Holkam Bay. At the head of the Tahkoo Inlet, still farther north, there is one; and at the head and around the sides of Glacier Bay, trending in a general northerly direction from Cross Sound in latitude 58° to 59° , there are seven of these complete glaciers pouring bergs into the bay and its branches, and keeping up an eternal thundering. The largest of this group, the Muir, has upward of 200 tributaries, and a width below the confluence of the main tributaries of about twenty-five miles. Between the west side of this icy bay and the ocean all the ground, high and low, excepting the peaks of the Fairweather Range, is covered with a mantle of ice from 1000 to probably 3000 feet thick, which discharges by many distinct mouths.

This fragmentary ice-sheet, and the immense glaciers about Mount St. Elias, together with the multitude of separate river-like glaciers that load the slopes of the coast mountains, evidently once formed part of a continuous ice-sheet that flowed over all the region hereabouts, and only a comparatively short time ago extended as far southward as the mouth of the Strait of Juan de Fuca, probably farther. All the islands of the Alexander Archipelago, as well as the headlands and promontories of the mainland, display telling traces of this great mantle that are still fresh and unmistakable. They all have the forms of the greatest strength with reference to the action of a vast rigid press of oversweeping ice from the north and northwest, and their surfaces have a smooth, rounded, overrubbed appearance, generally free from angles. The intricate labyrinth of canals, channels, straits, passages, sounds, narrows, etc., between the islands, and extending into the mainland, of course manifest in their forms and trends and general characteristics the same subordination to the grinding action of universal glaciation as to their origin, and differ from the islands and banks of the fiords only in being portions of the pre-glacial margin of the continent more deeply eroded, and therefore covered by the ocean waters which flowed into them as the ice was melted out of them. The formation and extension of fiords in this manner is still going on, and may be witnessed in many places in Glacier Bay, Yakutat Bay, and adjacent regions. That the domain of the sea is being extended over the land by the wearing away of its shores, is well known, but in these icy regions of Alaska, and even as far south as Vancouver Island, the coast rocks have been so short a time exposed to wave-action they are but little wasted as yet. In these regions the extension of the sea effected by its own action in post-glacial time is scarcely appreciable as compared with that effected by ice-action.

Traces of the vanished glaciers made during the period of greater extension abound on the Sierra as far south as latitude 36° . Even the polished rock surfaces, the most evanescent of glacial records, are still found in a wonderfully perfect state of preservation on the upper half of the middle portion of the range, and form the most striking of all the glacial phenomena. They occur in large irregular patches in the summit and middle regions, and though they have been subjected to the action of the weather with its corroding storms

for thousands of years, their mechanical excellence is such that they still reflect the sunbeams like glass, and attract the attention of every observer. The attention of the mountaineer is seldom arrested by moraines, however regular and high they may be, or by cañons, however deep, or by rocks, however noble in form and sculpture; but he stoops and rubs his hands admiringly on the shining surfaces and tries hard to account for their mysterious smoothness. He has seen the snow descending in avalanches, but concludes this cannot be the work of snow, for he finds it where no avalanches occur. Nor can water have done it, for he sees this smoothness glowing on the sides and tops of the highest domes. Only the winds of all the agents he knows seem capable of flowing in the directions indicated by the scoring. Indians, usually so little curious about geological phenomena, have come to me occasionally and asked me, "What makeum the ground so smooth at Lake Tenaya?" Even horses and dogs gaze wonderingly at the strange brightness of the ground, and smell the polished spaces and place their feet cautiously on them when they come to them for the first time, as if afraid of sinking. The most perfect of the polished pavements and walls lie at an elevation of from 7000 to 9000 feet above the sea, where the rock is compact silicious granite. Small dim patches may be found as low as 3000 feet on the driest and most enduring portions of sheer walls with a southern exposure, and on compact swelling bosses partially protected from rain by a covering of large boulders. On the north half of the range the striated and polished surfaces are less common, not only because this part of the chain is lower, but because the surface rocks are chiefly porous lavas subject to comparatively rapid waste. The ancient moraines also, though well preserved on most of the south half of the range, are nearly obliterated to the northward, but their material is found scattered and disintegrated.

A similar blurred condition of the superficial records of glacial action obtains throughout most of Oregon, Washington, British Columbia, and Alaska, due in great part to the action of excessive moisture. Even in southeastern Alaska, where the most extensive glaciers on the continent are, the more evanescent of the traces of their former greater extension, though comparatively recent, are more obscure than those of the ancient California glaciers where the climate is drier and the rocks more resisting.

These general views of the glaciers of the Pacific Coast will enable my readers to see something of the changes that have taken place in California, and will throw light on the residual glaciers of the High Sierra.

Prior to the autumn of 1871 the glaciers of the Sierra were unknown. In October of that year I discovered the Black Mountain Glacier in a shadowy amphitheater between Black and Red Mountains, two of the peaks of the Merced group. This group is the highest portion of a spur that straggles out from the main axis of the range in the direction of Yosemite Valley. At the time of this interesting discovery I was exploring the *névé* amphitheaters of the group, and tracing the courses of the ancient glaciers that once poured from its ample fountains through the Illilouette Basin and the Yosemite Valley, not expecting to find any active glaciers so far south in the land of sunshine.

Beginning on the northwestern extremity of the group, I explored the chief tributary basins in succession, their moraines, roches moutonnées, and splendid glacier pavements, taking them in regular succession without any reference to the time consumed in their study. The monuments of the tributary that poured its ice from between Red and Black Mountains I found to be the most interesting of them all; and when I saw its magnificent moraines extending in majestic curves from the spacious amphitheater between the mountains, I was exhilarated with the work that lay before me. It was one of the golden days of the Sierra Indian summer, when the rich sunshine glorifies every landscape however rocky and cold, and suggests anything rather than glaciers. The path of the vanished glacier was warm now, and shone in many places as if washed with silver. The tall pines growing on the moraines stood transfigured in the glowing light, the poplar groves on the levels of the basin were masses of orange-yellow, and the late blooming goldenrods added gold to gold. Pushing on over my rosy glacial highway, I passed lake after lake set in solid basins of granite, and many a thicket and meadow watered by a stream that issues from the amphitheater and links the lakes together; now wading through plushy bogs knee-deep in yellow and purple sphagnum; now passing over bare rock. The main lateral moraines that bounded the view on either hand are from 100 to

nearly 200 feet high, and about as regular as artificial embankments, and covered with a superb growth of Silver Fir and Pine. But this garden and forest luxuriance was speedily left behind. The trees were dwarfed as I ascended; patches of the alpine bryanthus and cassiope began to appear, and arctic willows pressed into flat carpets by the winter snow. The lakelets, which a few miles down the valley were so richly embroidered with flowery meadows, had here, at an elevation of 10,000 feet, only small brown mats of carex, leaving bare rocks around more than half their shores. Yet amid this alpine suppression the Mountain Pine bravely tossed his storm-beaten branches on the ledges and buttresses of Red Mountain, some specimens being over 100 feet high, and 24 feet in circumference, seemingly as fresh and vigorous as the giants of the lower zones.

Evening came on just as I got fairly within the portal of the main amphitheater. It is about a mile wide, and a little less than two miles long. The crumbling spurs and battlements of Red Mountain bound it on the north, the somber, rudely sculptured precipices of Black Mountain on the south, and a hacked, splintery *col*, curving around from mountain to mountain, shuts it in on the east.

I chose a camping-ground on the brink of one of the lakes where a thicket of Hemlock Spruce sheltered me from the night wind. Then, after making a tin-cupful of tea, I sat by my camp-fire reflecting on the grandeur and significance of the glacial records I had seen. As the night advanced the mighty rock walls of my mountain mansion seemed to come nearer, while the starry sky in glorious brightness stretched across like a ceiling from wall to wall, and fitted closely down into all the spiky irregularities of the summits. Then, after a long fire side rest and a glance at my note-book, I cut a few leafy branches for a bed, and fell into the clear, death-like sleep of the tired mountaineer.

Early next morning I set out to trace the grand old glacier that had done so much for the beauty of the Yosemite region back to its farthest fountains, enjoying the charm that every explorer feels in Nature's untrodden wildernesses. The voices of the mountains were still asleep. The wind scarce stirred the pine-needles. The sun was up, but it was yet too cold for the birds and the few burrowing animals that dwell here. Only the stream, cascading from pool to pool, seemed to be wholly awake. Yet the spirit of the opening day called to action. The sunbeams came streaming gloriously through the jagged openings of the *col*, glancing on the burnished pavements and lighting the silvery lakes, while every sun-touched rock burned white on its edges like melting iron in a furnace. Passing round the north shore of my camp lake I followed the central stream past many cascades from lakelet to lakelet. The scenery became more rigidly arctic, the Dwarf Pines and Hemlocks disappeared, and the stream was bordered with icicles. As the sun rose higher rocks were loosened on shattered portions of the cliffs, and came down in rattling avalanches, echoing wildly from crag to crag.

The main lateral moraines that extend from the jaws of the amphitheater into the Illilouette Basin are continued in straggling masses along the walls of the amphitheater, while separate boulders, hundreds of tons in weight, are left stranded here and there out in the middle of the channel. Here, also, I observed a series of small terminal moraines ranged along the south wall of the amphitheater, corresponding in size and form with the shadows cast by the highest portions. The meaning of this correspondence between moraines and shadows was afterward made plain. Tracing the stream back to the last of its chain of lakelets, I noticed a deposit of fine gray mud on the bottom except where the force of the entering current had prevented its settling. It looked like the mud worn from a grind stone, and I at once suspected its glacial origin, for the stream that was carrying it came gurgling out of the base of a raw moraine that seemed in process of formation. Not a plant or weather-stain was visible on its rough, unsettled surface. It is from 60 to over 100 feet high, and plunges forward at an angle of 38°. Cautiously picking my way, I gained the top of the moraine and was delighted to see a small but well characterized glacier swooping down from the gloomy precipices of Black Mountain in a finely graduated curve to the moraine on which I stood. The compact ice appeared on all the lower portions of the glacier, though gray with dirt and stones embedded in it. Farther up the ice disappeared beneath coarse granulated snow. The surface of the glacier was further characterized by

dirt bands and the outcropping edges of the blue veins, showing the laminated structure of the ice. The uppermost crevasse, or "bergschrund," where the *névé* was attached to the mountain, was from 12 to 14 feet wide, and was bridged in a few places by the remains of snow avalanches. Creeping along the edge of the schrund, holding on with benumbed fingers, I discovered clear sections where the bedded structure was beautifully revealed. The surface snow, though sprinkled with stones shot down from the cliffs, was in some places almost pure, gradually becoming crystalline and changing to whitish porous ice of different shades of color, and this again changing at a depth of 20 or 30 feet to blue ice, some of the ribbon-like bands of which were nearly pure, and blended with the paler bands in the most gradual and delicate manner imaginable. A series of rugged zigzags enabled me to make my way down into the weird under-world of the crevasse. Its chambered hollows were hung with a multitude of clustered icicles, amid which pale, subdued light pulsed and shimmered with indescribable loveliness. Water dripped and tinkled overhead, and from far below came strange, solemn murmurings from currents that were feeling their way through veins and fissures in the dark. The chambers of a glacier are perfectly enchanting, notwithstanding one feels out of place in their frosty beauty. I was soon cold in my shirt-sleeves, and the leaning wall threatened to engulf me; yet it was hard to leave the delicious music of the water and the lovely light. Coming again to the surface, I noticed boulders of every size on their journeys to the terminal moraine--journeys of more than a hundred years, without a single stop, night or day, winter or summer.

The sun gave birth to a network of sweet-voiced rills that ran gracefully down the glacier, curling and swirling in their shining channels, and cutting clear sections through the porous surface-ice into the solid blue, where the structure of the glacier was beautifully illustrated.

The series of small terminal moraines which I had observed in the morning, along the south wall of the amphitheater, correspond in every way with the moraine of this glacier, and their distribution with reference to shadows was now understood. When the climatic changes came on that caused the melting and retreat of the main glacier that filled the amphitheater, a series of residual glaciers were left in the cliff shadows, under the protection of which they lingered, until they formed the moraines we are studying. Then, as the snow became still less abundant, all of them vanished in succession, except the one just described; and the cause of its longer life is sufficiently apparent in the greater area of snow-basin it drains, and its more perfect protection from wasting sunshine. How much longer this little glacier will last depends, of course, on the amount of snow it receives from year to year, as compared with melting waste.

After this discovery, I made excursions over all the High Sierra, pushing my explorations summer after summer, and discovered that what at first sight in the distance looked like extensive snow fields, were in great part glaciers, busily at work completing the sculpture of the summit-peaks so grandly blocked out by their giant predecessors.

On August 21, I set a series of stakes in the Maclure Glacier, near Mount Lyell, and found its rate of motion to be little more than an inch a day in the middle, showing a great contrast to the Muir Glacier in Alaska, which, near the front, flows at a rate of from five to ten feet in twenty-four hours.

Mount Shasta has three glaciers, but Mount Whitney, although it is the highest mountain in the range, does not now cherish a single glacier. Small patches of lasting snow and ice occur on its northern slopes, but they are shallow, and present no well marked evidence of glacial motion. Its sides, however, are scored and polished in many places by the action of its ancient glaciers that flowed east and west as tributaries of the great glaciers that once filled the valleys of the Kern and Owen's rivers.