GLACIERS OF MOUNT RAINIER,

BY

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WITH A PAPER ON

THE ROCKS OF MOUNT RAINIER,

BY

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GLACIERS OF MOUNT RAINIER.

By ISRAEL C. RUSSELL.

THE PRINCIPAL PHYSICAL FEATURES OF THE STATE OF WASHINGTON.

The State of Washington presents marked geographic and climatic diversities. The Cascade Mountains cross the State in a general north-south direction and divide it into two portions which are as different from each other in nearly all their features as two adjacent regions can well be.

The Cascade Mountains begin at the south in northern California and extend northward across Oregon and Washington and into British Columbia. In northern Washington the range is composed of granitic rocks, and its scenic features are here much more diverse than in its southern extension, where only igneous rocks, mostly andesite and basalt, have as yet been reported to occur. Many of the summit peaks of the Cascade Range in Washington are from 6,000 to 8,000 feet or more in altitude. At least five passes are known which are considered practicable for railroads. These range in elevation from 3,100 to 5,500 feet above the sea. The Columbia River, flowing from east to west, passes through the mountains, forming in part the boundary between Washington and Oregon, and dissects the range nearly to sea level. The elevation at Cascade Locks is but 106 feet above the ocean.

East of the foothills of the Cascades lies the Great Plain of the Columbia, as it is termed, which merges on the south with a vast plateau, forming southeastern Washington and extending far into Oregon. The elevation in this region ranges from about 300 feet along the Columbia to 2,500 feet near the Washington-Idaho boundary. Central and southeastern Washington, embracing a region about 20,000 square miles in area, was once a level plain of basalt formed by many successive flows of molten rock. In the neighborhood of the Cascades the once level basaltic sheets have been broken by numerous lines of fracture and the intervening blocks have been variously tilted, but in the southeastern portion of the State the lava sheets are still horizontal and form a nearly level plateau, in which there are many deeply eroded stream channels, some of which, termed coulées, are no longer lines of drainage.

The vast lava flows which covered central and southeastern Washington, and a still greater region to the southward, met the mountains of metamorphic rock of Idaho and Washington in an irregular line coinciding in general with the Washington-Idaho boundary from the Oregon line northward to Spokane River; thence westward the border of the lava is followed by the Columbia in making its westerly detour, known as the Big Bend. To the north of the Big Bend of the Columbia are rugged mountains of granite rocks which merge with the northern Cascades. When the geology and geography of Washington are more thoroughly studied it will probably be found that the granitic portion of the northern Cascades belongs in reality to the great series of highlands and mountains north of the Big Bend, which is designated in general as the Okanogan Mountains.

The Cascade Mountains are precipitous on the west and descend abruptly to a region of mild relief in which the extremely irregular basin occupied by Puget Sound is sunk. This low country, deeply covered with glacial drift, extends westward to the Olympic Mountains and to the Pacific.

As shown in this brief outline, the main geographic features of Washington are a great mountain range trending approximately N. 15° E., a roughened lava plateau on the east, and a dissected plain of glacial drift on the west.

Associated with the Cascade range in Washington, but of later date, and distinct from it both geographically and geologically, are four especially prominent volcanic mountains. About 15 miles east of the crest line of the Cascades in south-central Washington stands Mount Adams, 9,570 feet high. This is a volcanic cone much defaced by disintegration and erosion, but steam escaping from its summit reveals the fact that the rocks within the snow- and ice-covered cone are still hot. Fifty miles west of the Cascades, and near the Canadian boundary, rises Mount Baker, 10,877 feet high, also a volcanic mountain, with a well-defined crater near its summit. Similar to Mount Baker in geographical position, but in the southern part of the Puget Sound country, stands Mount St. Helens, 9,750 feet high. Mount Baker and Mount St. Helens have been in eruption in modern times, and it is believed, although perhaps not proved, that eruptions from them have occurred within the last fifty years. The fourth great volcano referred to, and the grandest of all, is Mount Rainier, to be described later, on which the glaciers forming the subject of this paper are situated.

CLIMATE.

Of special interest in the study of the glaciers of Mount Rainier is the character of the climate of Washington. The plateau country to the east of the Cascades is arid and partakes of the desert-like nature of the Great Basin region, of which in many respects it is a northern extension. The rainfall is small. Over an area of 20,000 square miles the mean annual precipitation varies from 5 to 20 inches. The summers are long and hot; the winters mild and rainy. Snow lies on the higher portions of the plateau for several weeks each year, but seldom remains more than a few days in the valleys. The plateau is treeless. In the lower valleys sagebrush and other desert shrubs impart their neutral tints to the landscape. The higher portions of the plateau in a state of nature were covered with luxuriant bunch grasses. Much of the former prairie is now under cultivation. The deep, rich soil formed by the decay of basalt absorbs the rain and retains it in such a manner as to render wheat raising possible with an annual precipitation of less than 20 inches.

West of the Cascades the entire country, except certain limited areas where soil conditions are unfavorable, was originally clothed with magnificent forests. The forests of fir, cedar, spruce, etc., from which the Evergreen State derives its popular name, extend from the shore of the Pacific over the Cascade Mountains and down their eastern slopes to an elevation of about 2,000 feet, leaving the higher summits bare. The annual rainfall to the west of the mountains ranges from 50 to over 100 inches. On the higher mountains it is probable that the mean annual precipitation, mostly in the form of snow, is in excess of the heaviest precipitation observed in the valleys. The temperature throughout the year is surprisingly mild and equable. The winters are humid, but with little snow in the valleys.

The prevailing winds in Washington are from the west, and come from the Pacific charged with moisture. In passing Mount Rainier and other lofty mountains they are forced upward, rarefied, and chilled, and part with much of their humidity before reaching the plateau east of the Cascades.

Glaciers are no less dependent on climatic conditions than forests. We find them especially where high mountains rise in the paths of warm, humid winds. On the mountains of Washington, and particularly on Mount Rainier, these conditions are abundantly fulfilled.

POSITION AND ELEVATION OF MOUNT RAINIER.

Mount Rainier is situated approximately 43 miles southeast of the city of Tacoma and 11 miles west of the crest of the Cascade Mountains. As determined by the United States Geological Survey its highest summit, Crater Peak, is in latitude 46° 51′ 04.84″ and longitude 121° 45′ 28.50″, and is 14,526 feet in height.

The country intervening between Puget Sound and the foothills of Mount Rainier is low and for the most part heavily forest covered. From Tacoma, which is at tide level, the whole height of the majestic mountain is in view; that is, the visual height of the peak embraces the entire elevation of its summit above the sea. The appearance of the mountain from near Tacoma is shown in the photograph forming Pl. LXV. Although much of the detail in the sculpturing of the mountain's slopes is lost in this picture, yet it serves to show the isolation of the great peak and the manner in which it towers above all its neighbors. As seen from many points on Puget Sound, even as far north as the Straits of Fuca, the mountain is wonderfully impressive. It rises boldly into the sky as a magnificent snow-clad dome, and appears sufficiently rugged and precipitous to bid defiance to the boldest mountaineer. In fact, its northern side is so precipitous that no ascents have been attempted from that direction.

To the east of Mount Rainier, and intervening between its base and the Cascade range, there is a rugged and deeply eroded country, not yet thoroughly explored, in which the highest peaks are, by estimate, between 7,000 and 8,000 feet high. This region, in common with the lower slopes of Mount Rainier and nearly all of the adjacent country, as previously stated, is densely forest covered.

The important place that Mount Rainier occupies in the minds of all who are familiar with the charming scenery of western Washington has created a desire for more detailed information concerning its higher and more inaccessible portions, and particularly in reference to the glaciers visible on its sides from great distances.

DISCOVERY AND EARLY EXPLORATION OF MOUNT RAINIER.

Spanish explorers entered what is now known as Puget Sound in 1790, and must have been familiar with Mount Rainier as seen from a distance, but, so far as the records seem to show, they did not give a name to the mountain.

Vancouver explored and mapped Puget Sound in 1792, and named not only the waterways and their immediate shores, but several of the mountains seen in the distance as well. Mounts Baker, Rainier, and Hood were named at this time in honor of the lords of the British Admiralty whose names they still bear. In the narrative of his voyage,[1] in describing the region about Port Townsend, Captain Vancouver stated that a "very remarkable high round mountain, covered with snow, apparently at the southern extremity of the distant range of snowy mountains before noticed [the Cascades] bore S. 45° E." When farther south in Puget Sound, he recorded (p.79): "The weather was serene and pleasant, and the country continued to exhibit, between us and the eastern snowy range, the same luxuriant appearance. At its northern extremity Mount Baker bore by compass N. 22° E.; the round snowy mountain now forming its southern extremity, and which, after my friend Rear-Admiral Rainier, I distinguished by the name of Mount Rainier, bore N. 42° E."

Before the coming of Vancouver the Indians had a name for the mountain in which we are interested. To them it was known as Tacoma,

[1] Captain George Vancouver, A Voyage of Discovery to the North Pacific Ocean and Round the World, London, 1801, 8°, vol. 2, pp, 73, 79.

MOUNT RAINIER FROM STEILACOOM PLAINS, NEAR TACOMA.

as nearly as their pronunciation can be rendered in English. Personally, I am strongly in favor of retaining the aboriginal name, but as the United States Board on Geographic Names has decided that the name which Vancouver gave shall be used on Government maps and in official publications, I have no choice in this paper but to accept their decision.

The first ascent of Mount Rainier was made by Gen. Hazard Stevens and P. B. Van Trump in August, 1870. An exceedingly graphic and entertaining account of this pioneer climb was published by Stevens in the Atlantic Monthly, Vol. XXXVIII, 1876. This ascent was made on the south side of the mountain, by the way of what are now known as Paradise Park and Gibraltar, which is practically the route followed in recent years by many tourists. After spending a night in the crater at the summit, they made the descent by the same route.

In October, 1870, Messrs. S. F. Emmons and A. D. Wilson, of the United States Geological Exploration of the Fortieth Parallel, ascended Mount Rainier, taking essentially the same route as that followed about two months before by Stevens and Van Trump. During this excursion much valuable information concerning the geology of the mountain, and especially in relation to the numerous glaciers on its sides, was obtained, and this will be presented later.

During the past ten years the south side of Mount Rainier, between the Nisqually and Cowlitz glaciers, has become a favorite and much frequented resort for camping parties. The park-like region near timber line presents unusual attractions on account of the cool summer temperature, bracing air, and magnificent scenery, and also furnishes a convenient starting point for persons desiring to climb the great peak. An especially beautiful portion of the southern slope, known as Paradise Park, is one of a number of open, meadow-like tracts, strewn in profusion with charming flowers during the short summer and diversified by thrifty groves of firs, to which much of its beauty is due. From Paradise Park the way to the summit of Mount Rainier is easily found, and the climb, considering the elevation attainable, is by no means difficult.

CHARACTERISTICS OF MOUNT RAINIER.

Mount Rainier is an extinct volcano. The residual heat of its once molten rocks still gives origin to steam jets, slightly impregnated with sulphurous gases in a few instances, which escape from crevices in the now partially snow-filled craters at the summit.

As has been determined by Bailey Willis, the mountain stands on a slanting peneplain, which consists of granites, schists, and coal-bearing Tertiary rocks; that is, the region where Mount Rainier is situated was eroded during late Tertiary times until it was reduced practically to a plain at sea level. Such a plain is known among geographers as a peneplain. This peneplain was then upraised and tilted so as to slope gently westward. Since the plain was elevated it has been deeply dissected by erosion, and the land masses between the sunken stream channels have been worn into mountain forms. The general level of the summits which mark approximately the position of the tilted peneplain, in the region adjacent to Mount Rainier on the north, is about 6,500 feet. The streams that have roughened the plain by excavating deep channels in the rocks composing it were guided westward by the slope produced by the uplifting; that is, their courses were determined by the slope of the land, due to tilting, and for this reason they are classed as consequent streams. Several rivers have their sources in the glaciers of Mount Rainier, and flow away from the mountain in all directions, and have deeply eroded its sides. These, too, are consequent streams; that is, their courses were determined by the original slopes of the mountain.

The latest marked eruption of Mount Rainier ceased before the work of erosion, now evidenced by such conspicuous results on its lower slopes and in the platform on which it stands, was far advanced. The rocks all about the base of the volcano are mainly Tertiary sediments and the products of ancient volcanic eruptions. Of older date than the Tertiary, and apparently rising through the rocks of that age at a few localities, are isolated areas of light-colored granite. Outcrops of granite were noted on the south side of Mount Rainier, near the extremity of the Nisqually Glacier, by Kautz in 1857, and also by Emmons in 1870. Similar granite, forming bold, rounded knobs and mountain-like masses on the north side of the mountain, between Carbon and Winthrop glaciers, was discovered in 1896 during the reconnaissance which formed the basis of this paper. A line connecting the granite outcrops on the two sides of the mountain bears slightly east of north, and possibly indicates the direction of the line of fracture that admitted of the extrusion of the lavas of which Mount Rainier is built. An hypothesis suggested by the observations made by myself last summer is that the granite was raised by faulting after the adjacent Tertiary rocks were deposited but previous to their being worn down to a peneplain. No opportunity was found, however, for testing this suggestion.

The main mass of Mount Rainier is composed of andesite and basalt, which were ejected to a considerable extent in a fragmental condition as scoria, pumice, lapilli, bombs, etc. Lava flows were not abundant during the later stages of eruption. The mountain ranks as a composite cone, but so far as its structure is revealed in the canyons and amphitheaters sculptured in its sides, and as is indicated also by the profiles of the great cone, it was built largely of material thrown out by explosions from a summit crater. The profiles of the mountain and the character of its summit show that at the time of its greatest perfection and beauty it rose as a tapering cone, with gently concave sides, to a height about 2,000 feet greater than its present elevation. At a later date it was truncated, probably by an explosion, which removed the upper 2,000 feet and left a summit crater from 2 to 3 miles in diameter. Remnants of the rim of this immense crater now form Peak Success and Liberty Cap. Subsequently explosive eruptions partially filled the great crater and formed two smaller craters within it. The rims of the smaller craters are still clearly traceable, although at present the depressions they encircle are nearly filled with snow. A moderately prominent point between the two younger craters, known as Crater Peak, is now the actual summit of the mountain.

As Mount Rainier stands to-day it has lost much of its youthful grace and symmetry. Its rocks have yielded to frost and storms and have been deeply sculptured by glaciers. The characteristic features produced by the decay, dissection, and erosion of the rocks forming the mountain, and the future topographic changes that may be expected to take place if the present destructive agencies continue their work, will be considered after the nature of the glaciers, to which the changes in the physiography of the mountain are mainly due, are briefly discussed.

NARRATIVE.

The reconnaissance during which the notes for this essay were obtained began at Carbonado, a small coal-mining town about 20 miles southeast of Tacoma, with which it is connected by a branch of the Union Pacific Railroad. Carbonado is situated on the border of the unbroken forest. Eastward to beyond the crest of the Cascade Mountains is a primeval forest, the density and magnificence of which it is impossible adequately to describe to one who is not somewhat familiar with the Puget Sound region. From Carbonado a trail, cut through the forest under the direction of Willis in 1881, leads to Carbon River, a stream flowing from Mount Rainier, which it formerly crossed by a bridge that is now destroyed, and thence continues to the west of the mountain to Busywild. A branch of this trail leads eastward to the north side of the mountain, making accessible a beautiful region near the timber line, known as Spray Park. A portion of the main trail and the branch leading to Spray Park is shown on the accompanying map, Pl. LXVI.

Our party consisted of Bailey Willis, geologist in charge, George Otis Smith and myself, assistants, and F. H. Ainsworth, Fred Koch, William B. Williams, and Michael Autier, camp hands.

IN THE FOREST.

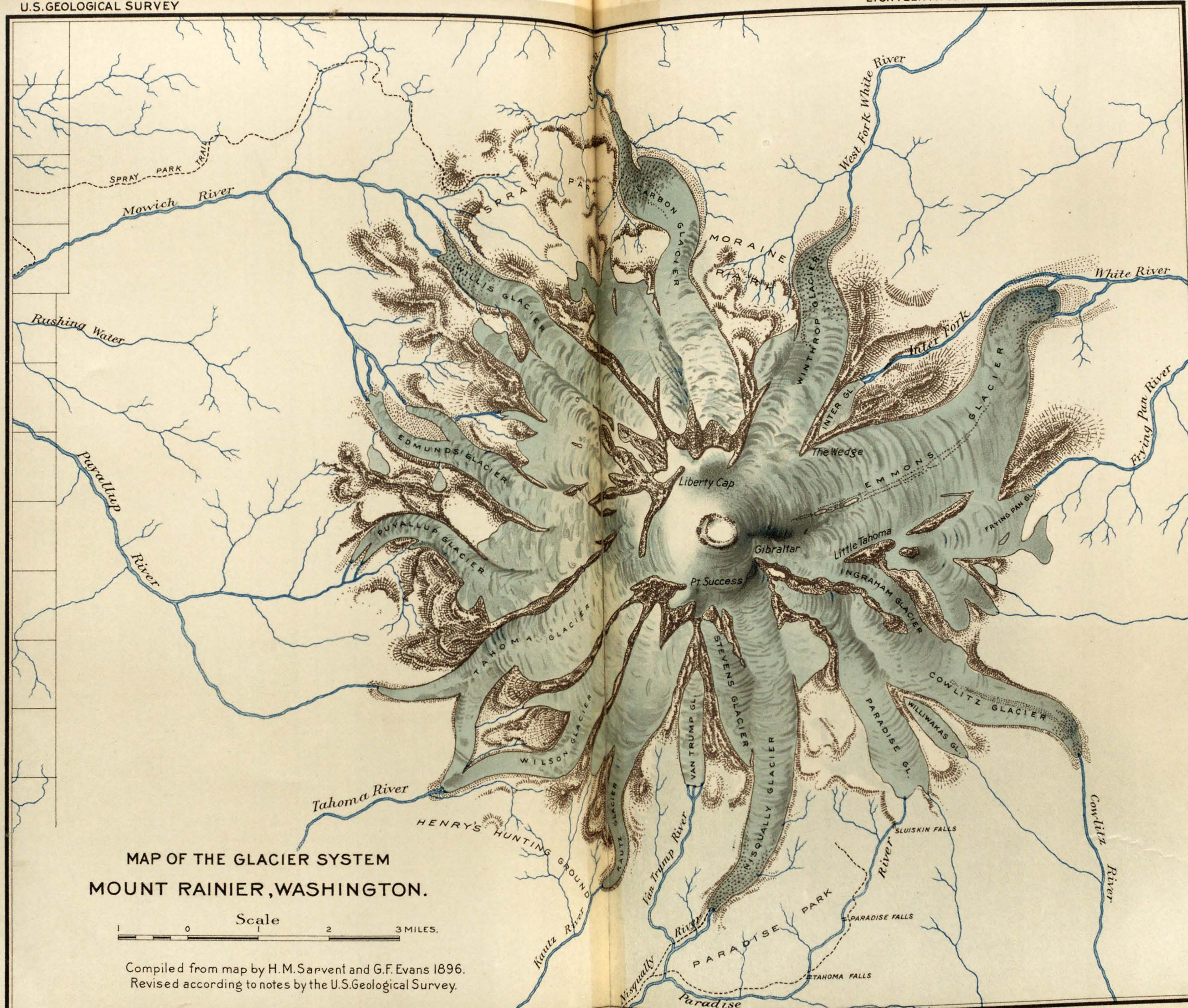
From Carbonado we proceeded with pack animals along the Willis trail, already mentioned, to the crossing of Carbon River. We then left the main trail and went up the right bank of the river by a trail recently cut as far as the mouth of Chenuis Creek. At that locality our party was divided. Willis and myself, taking blankets, rations, etc., and crossing the river, proceeded up its bowlder-strewn left bank to the foot of Carbon Glacier. The remainder of the party cut a trail along the right bank, and in the course of a few days succeeded in making a depot of supplies near where the river emerges from beneath the extremity of the glacier. The pack train was then taken back to near Carbonado for pasture.

The tramp from Carbonado to the foot of the Carbon Glacier was full of interest, as it revealed the characteristics of a great region, covered with a dense forest, which is a part of the deeply dissected Tertiary peneplain surrounding Mount Rainier. The rocks from Carbonado to Carbon River crossing are coal bearing. Extensive mines are worked at Carbonado, and test shafts have been opened at a few localities near the trail which we followed. At Carbonado the river flows through a steep-sided canyon about 300 feet deep. Near where the Willis trail crosses the stream the canyon broadens, is deeply filled with bowlders, and is bordered by forest-covered mountains fully 3,000 feet in elevation. On account of the dense forests, the scenery throughout the region traversed is wild and picturesque. At a few localities glimpses were obtained of the great snow-clad dome of Mount Rainier, rising far over the intervening tree covered foothills.

The forests of the Puget Sound region are the most magnificent on the continent. The moist atmosphere and genial climate have led to a wonderfully luxuriant growth, especially of evergreens. Huge fir trees and cedars stand in close-set ranks and shoot upward straight and massive to heights which frequently exceed 250 feet, and sometimes are even in excess of 300 feet. The trees are frequently 10 to 12 feet or more in diameter at the height of one's head and rise in massive columns without a blemish to the first branches, which are in many instances 150 feet from the ground. The soil beneath the mighty trees is deeply covered with mosses of many harmonious tints, and decked with rank ferns, whose gracefully bending fronds attain a length of 6 to 8 feet. Lithe, slender maples, termed vine-maples from their habit of growth, are plentiful, especially along the small water courses. In many places the broad leaves of the devil's club (*Fatsia horrida*) give an almost tropical luxuriance to the shadowy realm beneath the lofty canopies formed by the firs and cedars.

In writing of life in this forest while prospecting for coal in 1881, Willis[1] states that one of the fir trees which was measured rose like a huge obelisk to a height of 180 feet without a limb and tapered to a point 40 feet above. "The more slender trees, curiously enough, are the taller; straight, clear shafts rise 100 to 150 feet, topped with foliage whose highest needles would look down on Trinity spire. Cedars, hemlocks, spruce, and white firs mingle with these giants, and not competing with them in height, they fill the spaces in the vast colon-

[1] Bailey Willis, Cañons and glaciers, a journey to the ice fields of Mount Tacoma: The Northwest, April, 1883, Vol. I, p. 2.



MAP OF THE GLACIER SYSTEM

MOUNT RAINIER, WASHINGTON.

Scale
1 0 1 2 3 MILES.

Compiled from map by H. M. Sarvent and G. F. Evans 1896.
Revised according to notes by the U.S. Geological Survey.

nade. * * * The silence of these forests is awesome, the solitude oppressive. The deer, the bear, the panther, are seldom met; they see and hear first and silently slip away, leaving only their tracks to prove their numbers. There are very few birds. * * * The wind plays in the tree tops far overhead, but seldom stirs the branches of the smaller growth. The great tree trunks stand immovable. The more awful is it when a gale roars through the timber, when the huge columns sway in unison and groan with voices strangely human."

The mighty forest through which we traveled from Carbonado to the crossing of Carbon River extends over the country all about Mount Rainier and clothes the sides of the mountain to a height of about 6,000 feet. From distant points of view it appears as an unbroken emerald setting for the gleaming, jewel-like summit of the snow-covered peak.

In spite of the many attractions of the forest, it was with a sense of relief that we entered the canyon of Carbon River and had space to see about us. The river presents features of geographical interest, especially in the fact that it is filling in its valley. The load of stone contributed by the glaciers, from which the stream comes as a roaring turbid flood, is greater than it can sweep along, and much of its freight is dropped by the way. The bottom of the canyon is a desolate, flood-swept area of rounded bowlders, from 100 to 200 yards broad. The stream channel is continually shifting, and is frequently divided by islands of bowlders, heaped high during some period of flood. Many of the stream channels leading away from Mount Rainier are known to have the characteristics of the one we ascended, and show that the canyons were carved under different conditions from those now prevailing. The principal amount of canyon cutting must have been done before the streams were overloaded with débris contributed by glaciers—that is, the deep dissection of the lower slope of Mount Rainier and of the platform on which it stands must have preceded the Glacial epoch.

ON THE GLACIERS.

After a night's rest in the shelter of the forest, lulled to sleep by the roar of Carbon River in its tumultuous course after its escape from the ice caverns, we climbed the heavily moraine-covered extremity of Carbon Glacier. At night, weary with carrying heavy packs over the chaos of stones that cover the glaciers, we slept on a couch of moss beautified with lovely blossoms, almost within the spray of Philo Falls, a cataract of clear icy water that pours into the canyon of Carbon Glacier from snow fields high up on the western wall of the canyon.

I will ask the reader to defer the study of the glaciers until we have made a reconnaissance of the mountain and climbed to its summit, as he will then be better prepared to understand the relation of the glaciers, névés, and other features with which it will be necessary to deal. In this portion of our fireside explorations let us enjoy a summer outing, deferring until later the more serious task of questioning the glaciers.

From Philo Falls we ascended still higher, by following partially snow-filled lanes between the long lateral moraines that have been left by the shrinking of Carbon Glacier, and found three parallel, sharp-crested ridges about a mile long and from 100 to 150 feet high, made of bowlders and stones of all shapes, which record the former positions of the glacier. Along the western border of the oldest and most westerly of these ridges there is a valley, perhaps 100 yards wide, intervening between the abandoned lateral moraine and the western side of the valley, which rises in precipices to forest-covered heights at least 1,000 feet above. Between the morainal ridges there are similar narrow valleys, each of which at the time of our visit, July 15, was deeply snow-covered. The ridges are clothed with spruce and cedar trees, together with a variety of shrubs and flowering annuals. The knolls rising through the snow are gorgeous with flowers. A wealth of purple Bryanthus, resembling purple heather, and of its constant companion, if not near relative, the Cassiope, with white, waxy bells, closely simulating the white heather, make glorious the mossy banks from which the lingering snow has but just departed. Acres of meadow land, still soft with snow water and musical with rills and brooks flowing in uncertain courses over the deep, rich turf, are beautiful with lilies, which seemed woven in a cloth of gold about the borders of the lingering snow banks. We are near the upper limit of timber growth, where parklike openings, with thickets of evergreens, give a special charm to the mountain side. The morainal ridge nearest the glacier is forest-covered on its outer slope, while the descent to the glacier is a rough, desolate bank of stones and dirt. The glacier has evidently but recently shrunk away from this ridge, which was formed along its border by stones brought from a bold cliff that rises sheer from the ice a mile upstream. Standing on the morainal ridge overlooking the glacier, one has to the eastward an unobstructed view of the desolate and mostly stone and dirt covered ice. Across the glacier another embankment can be seen, similar to the one on the west, and, like it, recording a recent lowering of the surface of the glacier of about 150 feet. Beyond the glacier are extremely bold and rugged mountains, scantily clothed with forests nearly to their summits. The position of the timber line shows that the bare peaks above are between 8,000 and 9,000 feet high. Looking southward, up the glacier, we have a glimpse into the wild amphitheater in which it has its source. The walls of the great hollow in the mountain side rise in seemingly vertical precipices about 4,000 feet high. Far above is a shining, snow-covered peak, which Willis named the Liberty Cap. It is one of the culminating points of Mount Rainier, but not the actual summit. Its elevation is about 14,300 feet above the sea. Toward the west the view is limited by the forest-covered morainal ridges near at hand and by the precipitous slopes beyond, which lead to a northward-projecting spur of Mount Rainier, known as the Mother Mountains. This, our first view of Mount Rainier near at hand, has shown that the valley down which Carbon Glacier flows, as well as the vast amphitheater in which it has its source, is sunk in the flanks of the mountain. To restore the northern slope of the ancient volcano as it existed when the mountain was young we should have to fill the depression in which the glacier lies at least to the height of its bordering ridges. On looking down the glacier we see it descending into a vast gulf bordered by steep mountains, which rise at least 3,000 feet above its bottom. This is the canyon through which the water formed by the melting of the glacier escapes. To restore the mountain this great gulf would also have to be filled. Clearly the traveler in this region is surrounded by the records of mighty changes. Not only does he inquire how the volcanic mountain was formed, but how it is being destroyed. The study of the glaciers will do much toward making clear the manner in which the once smooth slopes have been trenched by radiating valleys, leaving mountain-like ridges between.

Another line of inquiry which we shall find of interest as we advance is suggested by the recent shrinkage of Carbon Glacier. Are all of the glaciers that flow from the mountain wasting away? If we find this to be the case, what climatic changes does it indicate?

TO CRATER LAKE.

From our camp among the morainal ridges by the side of Carbon Glacier we made several side trips, each of which was crowded with observations of interest. One of these excursions, made by Mr. Smith and myself, was up the snow fields near camp; past the prominent outstanding pinnacles known as the Guardian Rocks, one red and the other black; and through Spray Park, with its thousands of groves of spire-like evergreens, with flower-enameled glades between. On the bare, rocky shoulder of the mountain, where the trees now grow, we found the unmistakable grooves and striations left by former glaciers. The lines engraved in the rock lead away from the mountain, showing that even the boldest ridges were formerly ice covered. Our route took us around the head of the deep canyon through which flows Cataract Creek. In making this circuit we followed a rugged saw-tooth crest, and had some interesting rock climbing. Finally, the sharp divide between Cataract Creek and a small stream flowing westward to Crater Lake was reached, and a slide on a steep snow slope took us quickly down to where the flowers made a border of purple and gold about the margins of the snow. Soon we were in the forest, and gaining a rocky ledge among the trees, could look down on Crater Lake, deeply sunk in shaggy mountains which still preserve all of their primitive freshness and beauty. Snow lay in deep drifts beneath the shelter of the forest, and the lake was ice covered except for a few feet near the margin. This was on July 20. I have been informed that the lake is usually free of ice before this date, but the winter preceding our visit was of more than usual severity, the snowfall being heavy, and the coming of summer was therefore much delayed.

The name Crater Lake implies that its waters occupy a volcanic crater. Willis states that Nature has here placed an emerald seal on one of Pluto's sally ports; but that the great depression now water-filled is a volcanic crater is not so apparent as we might expect. The basin is in volcanic rock, but none of the characteristics of a crater due to volcanic explosions can be recognized. The rocks, so far as I saw them, are massive lavas, and not fragmental scoriæ or other products of explosive eruptions. On the bold, rounded rock ledges down which we climbed in order to reach the shore, there were deep glacial scorings, showing that the basin was once deeply filled with moving ice. My observations were not sufficiently extended to enable me to form an opinion as to the origin of the remarkable depression, but whatever may have been its earlier history, it has certainly been profoundly modified by ice erosion.

Following the lake shore southward, groping our way beneath the thick, drooping branches which dip in the lake, we reached the notch in the rim of the basin through which the waters escape and start on their journey to Mowich River and thence to the sea. We there found the branch of the Willis trail leading to Spray Park, and turned toward camp. Again we enjoyed the luxury of following a winding pathway through silent colonnades formed by the moss grown trunks of noble trees. On either side of the trail worn in the brown soil the ferns and flowering shrubs were bent over in graceful curves, and at times filled the little-used lane, first traversed fifteen years before.

The trail led us to Eagle Cliff, a bold, rocky promontory rising as does El Capitan from the Yosemite, 1,800 feet from the forest-lined canyon of Mowich River. From Eagle Cliff one beholds the most magnificent view that is to be had in all the wonderful region about Mount Rainier. The scene beheld on looking eastward toward the mighty mountain is remarkable alike for its magnificence and for the artistic grouping of the various features of the sublime picture. In the vast depths at one's feet the tree tops, through which the mists from neighboring cataracts are drifting, impart a somber tone and make the valley's bottom seem far more remote than it is. The sides of the canyon are formed by prominent serrate ridges, leading upward to the shining snow fields of the mighty dome that heads the valley. Nine thousand feet above our station rose the pure white Liberty Cap, the crowning glory of the mountain as seen from the northward. The snow descending the northwest side of the great central dome is gathered between the ridges forming the sides of the valley and forms a white névé from which flows Willis Glacier. Some idea of the grandeur of this scene may be gained from the illustration, Pl. LXVIII. In

SCENE IN THE FOREST SOUTH OF MOUNT RAINIER.

looking up the valley from Eagle Cliff the entire extent of the snow fields and of the river like stream of ice flowing from them is in full view. The ice ends in a dirt-covered and rock-strewn terminus, just above a huge rounded dome that rises in its path. In 1881 the ice reached nearly to the top of the dome and broke off in an ice cliff, the detached blocks falling into the gulf below. The appearance of this cliff in 1885 is shown by Pl. LXXXI. The glacier has now withdrawn its terminus well above the precipice where it formerly fell as an ice cascade, and its surface has shrunk away from well-defined moraines in much the same manner as has already been noted in the case of Carbon Glacier. A more detailed account of the retreat of the extremity of Willis Glacier will be given later.

From Eagle Cliff we continued our tramp eastward along the trail leading to Spray Park, climbed the zigzag pathway up the face of a cliff in front of Spray Falls, and gained the picturesque and beautiful park-like region above. An hour's tramp brought us again near the Guardian Rocks. A swift descent down the even snow fields enabled us to reach camp just as the shadows of evening were gathering in the deeper canyons, leaving the silent snow fields above all aglow with reflected sunset tints.

ACROSS CARBON GLACIER.

Taking heavy packs on our backs on the morning of July 21, we descended the steep broken surface of the most recent moraine bordering Carbon Glacier in its middle course, some idea of which is conveyed by Pl. LXXIV, and reached the solid blue ice below. Our course led us directly across the glacier, along the lower border of the rapidly melting covering of winter snow. The glacier is there about a mile across. Its central part is higher than its border, and for the most part the ice is concealed by dirt and stones. Just below the névé, however, we found a space about half a mile long in which melting had not led to the concentration of sufficient débris to make traveling difficult. Farther down the glacier, where surface melting was more advanced, the entire glacier, with the exception of a few lanes of clear ice between the ill-defined medial moraines, was completely concealed beneath a desolate sheet of angular stones. On reaching the east side of the glacier we were confronted with a wall of clay and stones, the inner slope of a moraine similar in all respects to the one we had descended to reach the west border of the glacier. A little search revealed a locality where a tongue of ice in a slight embayment projected some distance up the wall of morainal material, and a steep climb of 50 or 60 feet brought us to the summit. The glacier has recently shrunk—that is, its surface has been lowered from 80 to 100 feet by melting.

On the east side of the glacier we found several steep, sharp-crested ridges, clothed with forest trees, with narrow, grassy, and flower-strewn dells between, in which banks of snow still lingered. The ridges are composed of bowlders and angular stones of a great variety of sizes and shapes, and are plainly lateral moraines abandoned by the shrinking of the glacier. Choosing a way up one of the narrow lanes, bordered on each side by steep slopes densely covered with trees and shrubs, we found secure footing in the hard granular snow, and soon reached a more open, parklike area, covered with mossy bosses of turf, on which grew a great profusion of brilliant flowers. Before us rose the great cliffs which partially inclose the amphitheater in which Carbon Glacier has its source. These precipices, as already stated, have a height of about 4,000 feet, and are so steep that the snow does not cling to them, but descends in avalanches. Above the cliffs, where the inclination is less precipitous, the snow lies in thick layers, the edges of which are exposed in a vertical precipice rising above the avalanche-swept rock-slope below. Far above, and always the central object in the wild scenery surrounding us, rose the brilliant white Liberty Cap, one of the pinnacles on the rim of the great summit crater. Our way then turned eastward, following the side of the mountain, and led us through a region just above the timber line, which commands far reaching views to the wild and rugged mountains to the northeast. This open tract, leading down to groves of spruce trees and diversified by charming lakelets, bears abundant evidence of having formerly been ice-covered, and is known as Moraine Park.

In order to retain our elevation we crossed diagonally the steep snow slopes in the upper portion of the Moraine Park. Midway over the snow we rested at a sharp crest of rock, and found that it is composed of light-colored granite. Later we found that much of the area between the Carbon and Winthrop glaciers is composed of this same kind of rock. Granite forms a portion of the border of the valley through which flow the glaciers just named, and furnished them with much granitic débris, which is carried away as moraines and later worked over into well-rounded bowlders by the streams flowing from the ice. The presence of granite pebbles in the courses of Carbon and White rivers, far below the glaciers, is thus accounted for.

A weary tramp of about 4 miles from the camp we had left brought us to the border of Winthrop Glacier. In the highest grove of trees, which are bent down and frequently lie prone on the ground, although still living, we selected a well-sheltered camping place. Balsam boughs furnished luxuriant beds, and the trees killed by winter storms enabled us to have a roaring camp fire. Fresh trail of mountain goats and their but recently abandoned bed showed that this is a favorite resort for those hardy animals. Marmots were also abundant, and frequently awakened the echoes with their shrill, whistling cries. The elevation of our camp was about 8,000 feet.

From our camp on the cliffs above the west border of Winthrop Glacier we made excursions across that glacier and to its heavily moraine-covered extremity. The snow mantle that is spread over the region about Mount Rainier each winter melts first on the rugged plateau surrounding the base of the mountain, and, as the summer's heat increases, gradually withdraws up the mountain sides, but never so as to uncover the more elevated region. The snow line—that is, the position to which the lower border of the mantle of perennial snow withdraws late in summer—has an elevation of about 9,000 feet. The lower margin of the wintry covering is always irregular, however, extending farthest down on the glaciers and retreating highest on the rocks. At the time of our visit the snow had melted off of nearly all the region below our camp, leaving only dirt-stained snow banks in the more completely sheltered recesses and in deeply shaded dells in the adjacent forests. On the glaciers all the region at a greater elevation than our camp was white and free from dirt and stones, while the hard glacial ice was abundantly exposed at lower altitudes and ended in a completely moraine-covered terminus. Above us all was barren, white, and wintry; below lay the flowery vales and grass parks, warm and inviting, leading to the welcome shade of noble forests. Our course led upward into the frozen region.

TO THE WEDGE.

On leaving the camp on the border of Winthrop Glacier we began our alpine work. There were five in the party selected for the difficult task of scaling Mount Rainier, namely: Willis, Smith, Ainsworth, Williams, and myself. Taking our blankets, a small supply of rations, an alcohol lamp, alpenstocks, a rope 100 feet long to serve as a life line, and a few other articles necessary for traveling above timber line, we began the ascent of Winthrop Glacier early on the morning of July 23. Our route was comparatively easy at the start, but became steeper and steeper as we advanced. The snow was firm and, except for the numerous crevasses, presented no great difficulties to be overcome. In several places the névé rises in domes as if forced up from beneath, but caused in reality by bosses of rock over which the glacier flows. These domes are broken by radiating crevasses which intersect in their central portions, leaving pillars and castle-like masses of snow with vertical sides. At one locality, in attempting to pass between two of these shattered domes, we found our way blocked by an impassable crevasse. Considerable time was lost in searching for a practicable upward route, but at length, by making a detour to the right, we found a way which, although steep, allowed us to pass the much crevassed area and gain the sharp ridge of rock which divides the névé snow flowing from the central dome of the mountain, and marks the separation between Winthrop and Emmons glaciers. This prow-like promontory, rising some 500 feet above the glaciers on either hand, we named The Wedge. This is the upward pointing, acute angle of a great V-shaped portion of the lower slope of the mountain, left in bold relief by the erosion of the valleys on either side. As will be described later, there are several of these remnants about the sides of the mountain at the same general horizon, which record a somewhat definite stage in the destruction of the mountain by ice erosion.

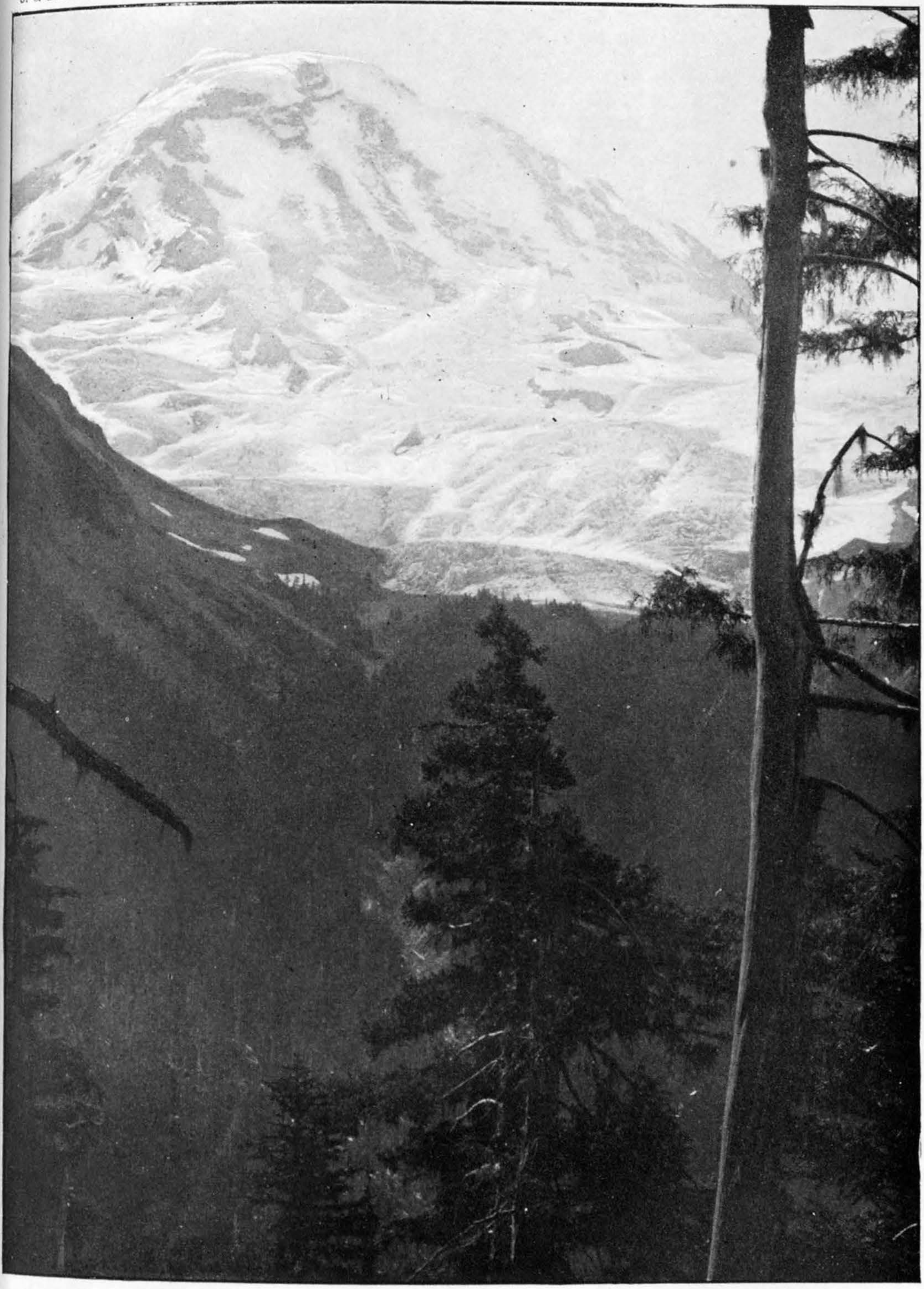
On reaching The Wedge we found it an utterly desolate rocky cape in a sea of snow. We were at an altitude of about 10,000 feet, and far above timber. Water was obtained by spreading snow on smooth rocks or on rubber sheets, and allowing it to melt by the heat of the afternoon sun. Coffee was prepared over the alcohol lamp, sheltered from the wind by a bed sheet supported by alpenstocks. After a frugal lunch, we made shelf like ledges in a steep slope of earth and stones and laid down our blankets for the night. From sheltered nooks amid the rocks, exposed to the full warmth of the declining sun, we had the icy slopes of the main central dome of the mountain in full view and chose what seemed the most favorable route for the morrow's climb.

Surrounded as we were by the desolation and solitude of barren rocks, on which not even a lichen had taken root, and pure white snow fields, we were much surprised to receive passing visits from several humming birds, which shot past us like winged jewels. They came up the valley occupied by the Emmons Glacier, turned sharply at The Wedge, and went down the way of the Winthrop Glacier. What tempts these children of the sunlight and the flowers into the frozen regions seems a mystery. That the humming birds are bold explorers was not new to me, for the reason that on several occasions in previous years, while on the snow-covered slopes of Mount St. Elias, far above all vestiges of vegetation, my heart had been gladdened by glimpses of their brilliant plumage.

When the sun declined beyond the great snow-covered dome that towered above us, and the blue shadows crept down the previously dazzling cliffs, the air became cold and a strong wind made our perch on the rocks uncomfortable. Wrapping ourselves in our blankets we slept until the eastern sky began to glow with sunrise tints.

TO THE SUMMIT.

Early on the morning of July 24 we began the climb of the steep snow slopes leading to the summit of the mountain. Roped together as we had been on the previous day, we slowly worked our way upward, in a tortuous course, in order to avoid the many yawning crevasses. The way was steep and difficult. Some members of the party felt the effects of the rarefied air, and as we lacked experience in true alpine work our progress was slow and laborious. Many of the crevasses that our course crossed were of the nature of faults. Their upper rims stood several feet above their lower margins, and thus added to the difficulty of passing them. Our aim at first was to traverse the névé of Emmons Glacier and gain the less rugged slope bordering it on the south, but the intervening region was greatly broken and, as we found



MOUNT RAINIER; THE LIBERTY CAP AND WILLIS GLACIER, FROM THE TRAIL NEAR EAGLE CLIFF; LOOKING SOUTHEAST.

after several approaches to it, utterly impassable. The climb presented no special difficulties other than the extreme fatigue incident to climbing steep snow slopes, especially while attached to a life line, and the delays necessitated by frequently turning and retracing our steps in order to get around wide crevasses.

Once while crossing a steep snow slope diagonally, and having a wide crevasse below us, Ainsworth, who was next to the rear of the line, lost his footing and slid down the slope on his back. Unfortunately, at that instant, Williams, who was at the rear of the line, removed his alpenstock from the snow, was overturned by the pull on the line, and shot head first down the slope and disappeared over the brink of the crevasse. A strong pull came on the members of the party who were in advance, but our alpenstocks held fast, and before assistance could be extended to the man dangling in midair, he climbed the taut rope and stood unhurt among us once more. The only serious result of the accident was the loss of an alpenstock.

Pressing on toward the dark rim of rock that we could now and then catch glimpses of at the head of the snow slopes and which we knew to be the outer portion of the summit crater, we crossed many frail snow bridges and climbed precipitous slopes, in some of which steps had to be cut. As we neared the summit we met a strong westerly gale that chilled us and benumbed our fingers. At length, weary and faint on account of the rarity of the air, we gained the lower portion of the rim of stones marking the position of the crater. While my companions rested for a few moments in the shelter of the rocks, I pressed on up the rugged slope and gained the top of the rim.

The stones exposed at the summit are bare of snow, possibly on account of the heat from below, and are rounded and their exposed surfaces polished. The smooth, black bowlders shine in the sunlight much the same as the sand-burnished stones in desert regions. Here on the mountain's brow, exposed to an almost continuous gale, the rocks have been polished by drifting snow crystals. The prevailing rounded form that the stones present may be the result of weathering, or possibly is due to the manner in which the fragments were ejected from the volcano. My hasty examinations suggested the former explanation.

Descending into the crater, I discovered crevices from which steam was escaping, and on placing my hands on the rocks was rejoiced to find them hot. My companions soon joined me, and we began the exploration of the crater, our aim being to find the least uncomfortable place in which to take refuge from the freezing blast rather than to make scientific discoveries.

The crater that we had entered is one of the smaller and more recent ones in the truncated summit of the peak, and is deeply filled with snow, but the rim is bare and well defined. The steam and heat from the rocks have melted out many caverns beneath the snow. In one of these we found shelter.

A NIGHT IN THE CRATER.

The cavern we chose in which to pass the night, although irregular, was about 60 feet long by 40 wide, and had an arched ceiling some 20 feet high. The snow had been melted out from beneath, leaving a roof so thin that a diffused blue light penetrated the chamber. The floor sloped steeply, and on the side toward the center of the crater there was a narrow space between the rocks and the descending roof which led to unexplored depths. As a slide into this forbidding gulf would have been exceedingly uncomfortable, if not serious, our life line was stretched from crag to crag so as to furnish a support and allow us to walk back and forth during the night without danger of slipping. Three arched openings or doorways communicated with other chambers, and through these drafts of cold air were continually blowing. The icy air chilled the vapor rising from the warm rocks and filled the chamber with steam which took on grotesque forms in the uncertain, fading light. In the central part of the icy chamber was a pinnacle of rock, from the crevices of which steam was issuing with a low hissing sound. Some of the steam jets were too hot to be comfortable to the ungloved hand. In this uninviting chamber we passed the night. The muffled roar of the gale as it swept over the mountain could be heard in our retreat and made us thankful for the shelter the cavern afforded.

The floor of our cell was too uneven and too steeply inclined to admit of lying down. Throughout the night we leaned against the hot rocks or tramped wearily up and down holding the life line. Cold blasts from the branching ice chambers swept over us. Our clothes were saturated with condensed steam. While one side of the body resting against the rocks would be hot, the strong drafts of air with a freezing temperature chilled the other side. After long hours of intense darkness the dome of snow above us became faintly illuminated, telling that the sun was again shining. After a light breakfast and a cup of tea, prepared over our alcohol lamp, we resumed our exploration, none the worse for the exposures of the night.

ON CRATER PEAK.

Following the inner rim of the crater so as to be sheltered from the gale still blowing steadily from the west, we gained its northern border and climbed to the topmost pinnacle, known as Columbia's Crest. This pinnacle rises about 50 feet above the general level of the irregular rim of the crater, and is the highest point on the mountain. Its elevation, as previously stated, is 14,526 feet.

The magnificent view described by former visitors to this commanding station, which we had hoped would reward our efforts, was concealed beneath a canopy of smoke that covered all of the region about the mountain to a depth of about 10,000 feet. The surface of the layer of smoke was sharply defined, and appeared like an undulating sea surrounding the island on which we stood. Far to the northward rose the regular conical summit of Mount Baker, like an isolated seagirt island. A few of the rugged and more elevated summits, marking the course of the Cascade Mountains, could be discerned to the eastward. The summits of Mount Adams and Mount St. Helens were in plain view and seemingly near at hand. All of the forest-covered region between these elevated summits was blotted out by the dense, heavy layer of smoke, which rose until it met the westerly gale of the upper regions.

During the ascent of Mount Rainier by Emmons and Wilson, previously referred to, more favorable atmospheric conditions prevailed than at the time of my visit, and the region about the base of the mountain was clearly revealed. In describing the view from the summit Emmons says:

From the northeastern rim of the crater we could look down an unbroken slope of nearly 10,000 feet to the head of the White River, the upper half or two-thirds of which was so steep that one had the feeling of looking over a perpendicular wall. [It was up this slope that the climb briefly described above was made.] The systems of glaciers and the streams which flowed from them lay spread out as on a map at our feet; radiating out in every direction from the central mass, they all with one accord curve to the westward to send their waters down toward Puget Sound or the Lower Columbia. [Attention has already been directed to the westward curvature of the streams from Mount Rainier on reaching the tilted peneplain on which the mountain stands, and the explanation has been suggested that they are consequent streams the direction of which was determined by the original slope of the now deeply dissected plateau.]

Looking to the more distant country, the whole stretch of Puget Sound, seeming like a pretty little lake embowered in green, could be seen in the northwest, beyond which the Olympic Mountains extend out into the Pacific Ocean. The Cascade Mountains, lying dwarfed at our feet, could be traced northward into British Columbia, and southward into Oregon, while above them, at comparatively regular intervals, rose the ghost-like forms of our companion volcanoes. To the eastward the eye ranged for hundreds of miles over chain on chain of mountain ridges, which gradually disappeared in the dim, blue distance.

THE MOUNTAIN'S SUMMIT.

In the truncated summit of Mount Rainier there are three craters. The largest one, partially filled by the building of the two others, is the oldest, and has suffered so greatly from subsequent volcanic explosions and erosion that no more than its general outline can be traced. Peak Success and Liberty Cap are prominent points on the rim of what remains of this huge crater. Its diameter, as nearly as can be judged, is about 2½ miles. Within the great crater, in the formation of which the mountain was truncated and, as previously stated, lost fully 2,000 feet of its summit, there are two much smaller and much more recent craters. The larger of these, the one in which we took refuge, is about 300 yards in diameter, and the second, which is an incomplete circle, its rim having been broken by the formation of its more recent companion, is perhaps 200 yards across. The rim of each now partially snow-filled bowl is well defined, and rises steeply from within to a sharp crest. The character of the inner slopes shows that much rocky material has been detached and has fallen into the cavities from which it was ejected. The rock in the crater walls is in fragments and masses, some of them well rounded and probably of the nature of volcanic bombs. In each of the smaller craters there are numerous steam jets. These show that the rock below is still hot, and that water percolating downward is changed to steam. These steam jets evidently indicate the presence of residual heat and not an actual connection with a volcanic center deep below the surface. All the evidence available tends to show that Rainier is an extinct volcano. It belongs, however, to the explosive type of volcanoes, of which Vesuvius is the best-known example, and there is no assurance that its energies may not be reawakened.

THE DESCENT.

In descending we chose the south side of the mountain, knowing from the reports of many excursionists who had ascended the peak from that direction that a practicable route could probably be found. Threading our way between numerous crevasses we soon came in sight of a bold, outstanding rock mass, which we judged to be Gibraltar, and succeeded in reaching it with but little difficulty. On gaining the junction of the rock with the snow fields rising above it, we found evidences of a trail, which was soon lost, however, and only served to show that our general course was the right one. A deep, narrow space between the border of Nisqually Glacier and the precipitous side of Gibraltar, from which the snow and ice had been melted by the heat reflected from the cliffs on our left, led us down to a shelf on the lower side of the promontory, which proved a safe and easy way to the crest of a rocky rib on the mountain side which extended far down toward the dark forests in view below.

Gibraltar is a portion of the cone of Rainier built before the explosion which truncated the mountain. It is an outstanding and very prominent rock mass, as may be seen in Pls. LXXIV and LXXVII, left in bold relief by the ice excavation which has carved deep valleys on each side. The rock divides the descending névé in the same manner as does The Wedge, and causes a part of the snow drainage to flow to the Cowlitz and the other part to be tributary to the Nisqually Glacier. The rocks forming Gibraltar consist largely of fragments ejected from the crater above, but present a rude stratification due to the presence of lava flows. When seen from the side and at a convenient distance, it is evident that the planes of bedding, if continued upward at the same angle, would reach above the present summit of the mountain. Gibraltar, like The Wedge and several other secondary peaks on the sides of Mount Rainier, are, as previously explained, the sharp, upward-pointing angles of large V-shaped masses of the original volcanic cone, left in bold relief by the excavation of deep valleys radiating from the

NÉVÉ ON THE EAST SIDE OF MOUNT RAINIER.

central peak. On the backs, so to speak, of these great V-shaped portions of the mountain which now seem to rest against the central dome, secondary glaciers, or interglaciers as they may be termed, have excavated valleys and amphitheaters. In the V-shaped mass of which Gibraltar is the apex, a broad amphitheater-like depression has been cut out, leaving a bold cliff above it. The excavation of the amphitheater did not progress far enough up the mountain to cut away the apex of the V-shaped mass, but left it with a precipice on its lower side. This remnant is Gibraltar. An attempt will be made later to describe more fully the process of glacial erosion of a conical mountain, and to show that the secondary topographic features of Mount Rainier are not without system, as they appear at first view, but really result from a process which may be said to have a definite end in view.

Below Gibraltar the descent was easy. Our life line was no longer needed. Tramping in single file over the hard surfaces of the snow field, remnants of the previous winter's snow, we made rapid progress, and about noon gained the scattered groves of spruce trees which form such an attractive feature of Paradise Park.

Fortunately, we found Prof. E. S. Ingraham, of Seattle, and a party of friends, including several ladies, encamped in Paradise Park, and the hospitality of the camp was extended to us. During the afternoon we basked in the warm sunshine, and in the evening gathered about a roaring campfire and enjoyed the society of our companions, who were enthusiastic in their praise of the wonderful scenes about their camp.

PARADISE PARK.

The southern side of Mount Rainier is much less precipitous than its northern face, and the open park-like region near timber line is broader, more diversified, and much more easy of access. The general elevation of the park is between 5,000 and 7,000 feet, and it is several thousand acres in extent. Its boundaries are indefinite. It merges into the heavily forested region to the south, and into more alpine regions on the side toward the mountain, which towers above it on the north. To the east it is bordered by Cowlitz Glacier, and on the west by Nisqually Glacier. Each of these fine ice rivers descends far below timber line. The small interglacier, known as the Paradise Glacier, may be considered as lying within the limits of the park.

Paradise Park presents many and varied charms. It is a somewhat rugged land, with a deep picturesque valley winding through it. The trees grow in isolated groves. Each bunch of dark-green firs and balsams is a cluster of gracefully tapering spires. The undulating meadows between the shady groves are brilliant in summer with a veritable carpet of gorgeous blossoms. In contrast to the exquisite charms of the groves and flower-decked rolling meadows are desolate ice fields and rugged glaciers which vary, through many tints and shades, from silvery whiteness to intense blue. Added to these minor charms, and

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Something of the magnificence of Mount Rainier as seen by visitors to Paradise Park is revealed in the accompanying photograph (Pl. LXXI), here reproduced through the kindness of Mr. E. Curtis, of Seattle. The view was taken near sunset, when the chill of evening was just beginning to dissipate the vapors that enshrouded the summit of the great peak.

While the central attraction to the lover of mountain scenery in Paradise Park is the vast snow-covered dome of Mount Rainier, there are other mountains in view that merit attention. To the east rises the serrate and rugged Tattoosh range, shown on Pl. LXXII, which is remarkable for the boldness with which its bordering slopes rise from the forested region about it and the angularity of its many serrate summits. This range has never been explored except by miners and hunters, who have made no record of their discoveries. It is virgin ground to the geologist and geographer. Distant views suggest that the Tattoosh Mountains have been sculptured from a plateau, probably an upraised peneplain in which there existed a great mass of igneous rock surrounded by less resistant Tertiary sediments. The softer rocks have been removed, leaving the harder and more resistant ones in bold relief, to become sculptured by rain and frost into a multitude of angular peaks. This attractive, and as yet unstudied, group of peaks is in plain view from Paradise Park, and may be easily reached from them by a single day's tramp. Many other delightful excursions are open to one who pitches his tent in the alpine meadows on the south side of Mount Rainier.

TO LITTLE TAHOMA.

Bidding our friends in Paradise Park good-by, we resumed our journey early on the morning of July 26. Ascending toward Gibraltar until an elevation of about 10,000 feet was reached, we turned eastward for the purpose of traversing the eastern slope of the mountain and regaining our camp at Winthrop Glacier. After crossing the upper portion of Paradise Glacier, we traversed broad and but little broken snow fields to the brink of the valley down which Cowlitz Glacier flows. Beyond Cowlitz Glacier, at about the same level that we had reached, we could see the bold, cathedral-like crags of Little Tahoma, the upward-pointing angle of a secondary mountain mass which divides Cowlitz and Emmons glaciers. Not wishing to descend into the deep valley before us and climb out again on the farther side, we chose to cross the névé fields to our left and endeavor to pass over a rugged and much broken region where the main current of Cowlitz Glacier descends a rocky slope about a thousand feet high. In following the route chosen we became involved in a succession of crevasses and ice precipices, which caused much delay. Slowly working our way upward, we reached the base of the highest ice wall, but a vertical cliff of ice about 50 feet high barred all further progress in that direction. Reluctantly we turned back and, losing all the advantage we had gained by three or four hours of excessively hard climbing, went down the central portion of the Cowlitz Glacier until we reached the level of the highest grove of trees on its left bank, and crossing to the land chose a delightful and well-sheltered spot beneath low pine trees at which to rest for the night.

Our camp was perhaps half a mile below where the ice stream flowing southward from Little Tahoma, and named Ingraham Glacier on the map forming Pl. LXVI, joins the main Cowlitz Glacier. Our bivouac was in a delightful locality, and would have furnished a pleasant camping place if we had been provided with the necessary blankets and rations with which to make life comfortable. As it was, we had to sleep on the moss without covering, our feet to a blazing fire. For food each man had one hard-tack and a cup of tea, without sugar or milk, for each meal. Near at hand was a cascade of clear water, furnished by the melting snow fields on the back of the spur of which Little Tahoma is the culminating summit. A larger cascade a mile below tumbled over the rugged cliffs and awakened the echoes on the precipices across the glacier. The music of the falling waters filled the intervals of our broken sleep. The full moon shed a soft light over the white glacier and rugged rocks, and added a charm to a wild scene that under more comfortable conditions would have been considered one of the most fascinating we met during our excursion.

All of the Cowlitz Glacier in view was heavily snow-covered, and broken in a systematic manner by marginal crevasses which left the shore at angles of about 45° and trended upstream. The appearance of this glacier at a later stage in the melting of its covering of snow is shown on Pl. LXXVI. The glacier is deeply sunk in a well-defined valley, and is, perhaps, the most characteristic example of a glacier of the alpine type to be found on the slopes of Mount Rainier.

Rising with the sun and partaking of our allotted single hard-tack and a cup of tea, we climbed the rugged cliff at the base of which we had passed the night, taking a route explored the previous afternoon by Smith and Ainsworth, and gained the summit of the cliff overlooking Ingraham Glacier.

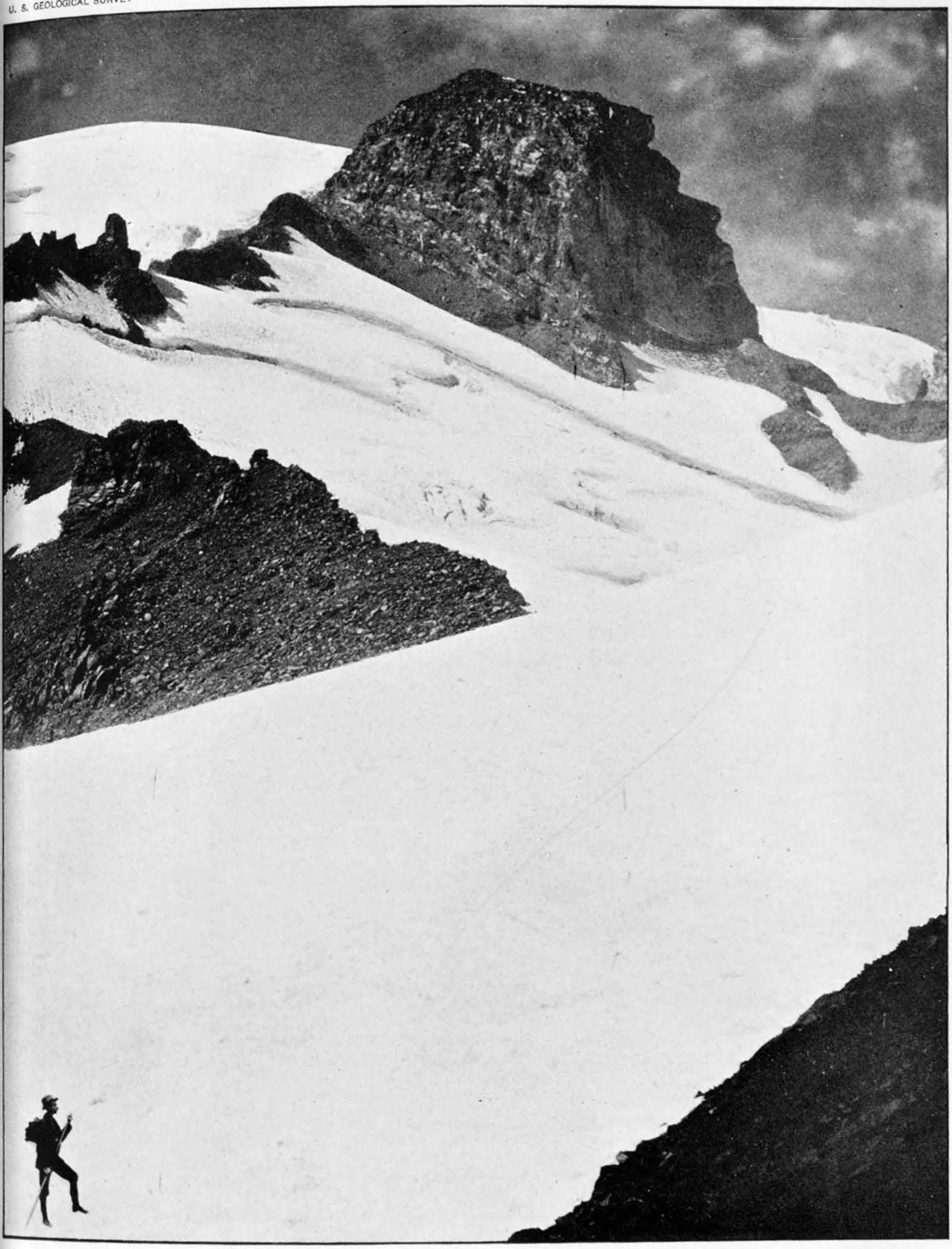
A deep descent of 500 feet over ledges of crumbling lava brought us to the hard ice below. An hour's tramp up the glacier and along the base of magnificent cliffs of volcanic agglomerate and lava in rude, irregular layers brought us to the sharp angle of rock at the base of Little Tahoma, against which the névé snows from the central dome divide. The descending snow meets the wedge of rock and is parted by it as the current is divided by the prow of a ship at anchor. The ice and snow, much shattered and standing in pinnacles, rises a hundred feet more against the obstruction in its downward course. The cliffs are or being cut away by the strong ice current, and rise above it in vertical precipices that culminate in sharp spires a thousand feet above the glacier. This proved a splendid locality for studying the manner in which the névé divides on reaching the medial portion of the main mountain side, and for seeing the modifications in the topography due to the erosion of glaciers flowing from the central dome.

To the north of Little Tahoma and flowing eastward is Emmons Glacier, the largest ice stream of Mount Rainier. This glacier is greatly broken, especially in its upper course, and has a peculiar feature not seen in connection with any other glacier. In its central portion there are two nearly parallel ridges of rock, which begin far up toward the summit of the main dome and descend for a mile or more below the level of the prow-like point of Little Tahoma. These parallel ridges appear from a distance to be medial moraines, and in part this is their true character. All along the dark belts in the center of the glacier, however, there are narrow and angular crests of rock in place, which project above the surface of the snow and ice. These crests of rock cause great crevasses to form in the ice flowing on either side of them and between them. For this reason Emmons Glacier is more difficult to cross than any other met with during our reconnaissance. The origin of the parallel rocky crests, the nature of which is shown to some extent on Pl. LXXIII, and their place in the topographic development of the mountain was not fully made out.

ACROSS EMMONS GLACIER.

The névé of Emmons Glacier abreast of the prow of Little Tahoma was so greatly shattered that, looking down on it from the cliffs against which the névé divides, no practicable way for crossing could be chosen. Going down onto the glacier and following its side under the shadow of Little Tahoma for about a mile, we found the slope more gentle, with fewer crevasses, and then turned our faces toward The Wedge, where we had left our blankets four days previously. A way across the glacier was finally discovered, however, by patiently making trial after trial and going about the ends of the widest breaks. Many narrow crevasses were jumped, others were crossed by frail snow bridges. By persistent effort we at length gained the narrow crest of rock in the center of the glacier, and although our goal was in plain view, many difficulties had still to be overcome before we reached our former camping ground.

A hasty lunch and a cup of coffee renewed our strength. Taking



GIBRALTAR, A REMNANT OF THE CONE OF MOUNT RAINIER.

our blankets on our backs once more, we started on the homeward tramp down the Winthrop Glacier. The footprints made five days previously were clearly visible at first, but each impression stood in high relief, owing to the more rapid melting of the uncompacted snow about it. The descent was easy and rapid. By 5 in the afternoon we again joined the members of our party who had remained in the timber-line camp on the west border of Winthrop Glacier.

THE RETURN.

Our plan was to carry our reconnaissance about the west slope of Mount Rainier, so as to gain at least a general idea of all of the glaciers flowing from the mountain, and of other features in the geography and geology of the region, but learning that the forest along the trail leading to Carbonado was on fire, a change became necessary.

Returning to our former camp on the west side of Carbon Glacier, plans were quickly made for dividing the party. Willis, with the camp hands, returned to the lower extremity of Carbon Glacier and thence to Carbonado, while Smith and myself, taking a small supply of rations, but without tents or blankets, turned our faces westward and visited Willis Glacier, Eagle Cliff, Crater Lake, and thence by way of the Spray Park trail and the main Willis trail also reached Carbonado.

Our reconnaissance extended from July 15 to 31, inclusive. Our route may be traced on the accompanying sketch map, Pl. LXVI, on which the glaciers and main topographic features of the mountain are indicated. The glaciers on the southwest side of the mountain between Willis and Nisqually glaciers were not visited, but some of their principal features were seen from distant points of observation.

ICE EROSION OF AN ISOLATED, CONICAL MOUNTAIN.

The study of the manner in which the topography of Mount Rainier has been modified by ice erosion has suggested certain general principles which control the sculpturing of an isolated mountain peak sufficiently lofty to be crowned with perennial snow and to give origin to glaciers. Although these conclusions were reached after detailed studies of individual glaciers and of the topographic changes resulting from long-continued ice erosion, it is convenient in describing the glaciers of Mount Rainier to have in mind at least the general laws governing their distribution and behavior.

The geology of Mount Rainier and its present general form show that when in its greatest perfection it was a conical mountain, with gracefully concave sides. The upper portion of the mountain is formed to a large extent of fragments thrown out during explosive eruptions. Lava flows are also abundant, but did not greatly modify the character of the slope as determined by the falling of projectiles shot out of the summit crater. The primitive form was that of a typical scoria and lapilli cone of the character of Fusiyama, Japan, and other conical volcanic piles which still retain their youthful perfection of form.

Whether or not Rainier was truncated before the glaciers had greatly modified its lower slopes is unknown, but the truncation was not sufficient to have much influence on the character of the glacial mantle formed about it. In either case the height of the mountain—between 15,000 and 16,000 feet before the explosion that truncated its summit, and about 14,500 feet after that event—insured the gathering of perennial snows and the formation of névé fields and glaciers on its more elevated portions without an intervening period of weathering and stream erosion. The main topographic changes that have resulted must therefore be due to glacial action and to the eroding power of streams fed by the melting of the ice.

The weathering of rock masses unprotected by snow and ice has also assisted in the work of deforming the once symmetrical peak. Climatic conditions similar to those to which Mount Rainier is now exposed would lead to the covering of the mountain above an elevation of about 10,000 feet with a sheet of perennial snow. The snow would change to the condition of a névé, which would give origin to glaciers. Assuming that the peak was originally a perfectly symmetrical cone with smooth, even sides, and that the névé formed a uniform covering over the upper third of its surface, the downward flow of the névé would be equal in all directions. The spreading of the ice as it flowed down the cone, a progressively greater area being covered by it as it descended, would insure equal melting, except so far as that might be influenced by the unequal amount of heat reaching the southern and northern sides of the peak, and would either thin away uniformly in all directions or be gathered into local streams.

Many disturbing conditions come in, however, in the case of a peak like Mount Rainier, composed of loose agglomerate and lava sheets. Irregularities in the surface of the cone, erosion by streams flowing from the ice, unequal drifting of the snow as well as unequal melting owing to variations in exposure on the northern and southern sides, etc., would lead to the gathering of the descending ice into more or less well-defined streams. Individualized ice streams once established would hold their position and by their erosion would sink deeper and deeper into the rocks. From the extremity of each glacier a stream fed by the melting ice would carve a gorge or canyon leading to rivers on the plain below. As the ice gathered in well-defined streams melting would be retarded and the glaciers consequently extended farther and farther down the water-cut gorges. In this manner what may be termed *primary* glaciers would originate from the dividing of the descending névé.

Below the horizon where the primary glaciers divide the ice erosion would be confined to comparatively narrow channels, and would cut radiating trenches in the sides of the mountain. Excavation would be continued below the extremities of the glacier by the streams flowing from them, and the valleys would there be narrower than in their ice-filled depressions higher up. As the glaciers deepen their beds they sink into the mountain and are more completely sheltered from the sun, thus tending to perpetuate their own existence. Between the primary glaciers there would be portions of the lower slopes of the mountain left in relief by the excavation of the valleys between them. These V-shaped masses pointing up the mountain would form wedges against which the descending névé would divide to form primary glaciers. The Wedge and Little Tahoma are typical examples of such wedges.

The surfaces left as V-shaped masses between the primary glaciers when the division occurs above the snow line, or when a climatic change causes the perennial snow to descend lower on the mountain's sides, would become covered with snow fields, which would give origin to secondary glaciers. Interglacier, below The Wedge, and the small glaciers on the back of the V-shaped mass of which Little Tahoma is the culminating point, are examples of these secondary glaciers, or *interglaciers*, as they may be termed, after the typical example just mentioned.

The interglaciers excavate valleys and cut back amphitheaters, so that the surface of the original V-shaped mass between any two primary glaciers becomes hollowed out, leaving rocky crests along their sides. The ridges bordering the primary glaciers converge upward, and, uniting, form wedges, which, crumbling under the attacks of the destructive agencies of the air, become broken into pinnacle or other forms, the details in their sculpturing depending on the nature of the rock. The original V-shaped masses left by the intrenching of primary glaciers thus become skeleton forms, their borders and high, wedge-like, upward-pointing extremities alone projecting above the snow, except when the summer melting is far advanced.

As is well known, the erosive action of a glacier, other conditions being the same, depends on the gradient of its bottom. The abrasion of the bed of a normal alpine glacier increases from its terminus with increase of gradient up to a certain point, and then, if the gradient still increases and approaches the vertical, becomes less and less. The gradient that insures greatest erosion is not definitely known. It varies with the amount of débris with which the ice is charged, as well as with other conditons, but is apparently in the neighborhood of 30°. This law has an important bearing on the topographic changes that an isolated glacier-covered mountain passes through. Judging from the present condition of Mount Rainier and other similar isolated peaks on the Pacific coast, it appears that the most intense erosion occurs in a zone about half a mile broad, where the primary glaciers become distinct ice streams. In this zone the glaciers excavate canyons and thus increases the slope of the central mass of the mountain above the extremities of the V-shaped residual masses on its lower slopes. The heads of these valleys tend to become amphitheaters.

As has been shown, especially by Willard D. Johnson, of the United States Geological Survey—the results of whose studies, however, are not yet fully published—the cliffs encircling an amphitheater in which a glacier has its source gradually recede, owing to the disintegration of the rocks in the great crevasse, termed a *bergschrund*, which is formed near where the upward-sloping névé meets the rock walls inclosing it. The rocks in the bergschrund are shattered by changes in temperature and by the freezing of water in their crevices and interstices, and the loosened fragments are plucked out by the outward flow of the névé snow. The bergschrunds are filled with snow each winter and reopened the following spring. This process leads to an energetic sapping of the bases of the cliffs and a consequent recession of their walls. The faces of the cliffs encircling an amphitheater or cirque are commonly too steep to admit of the accumulation of snow upon them, but allow it to fall in avalanches and to be blown away. The cliffs, being bare of snow, are exposed to changes of temperature and are wind-swept. These various destructive agencies assist in the extension of the amphitheater toward the summit of the mountain, and also in its general enlargement.

The primary glaciers excavate deep, steep-sided valleys, but accomplish little toward altering the profile of an isolated peak as it appears when beheld from a distance. The even slopes of the mountain become broken by the intense erosion and the deepening of amphitheaters above the extremities of the buttressing wedges. When seen in profile the mountain slopes become broken at the horizon referred to, as may be seen in Pls. LXX and LXXI. There is then a long, sweeping ascent from the base of the mountain to the horizon where the wedges terminate, and then a downward slope toward the vertical axis of the pile, leading to a belt of moderate inclination which terminates above in the steeper slopes forming the sides of the central dome.

At the summit of a lofty, snow-covered mountain there is but little erosion. The snows are mostly blown away or heaped in pyramids on the crowning summits. On mountains of sufficient height—such height varying with climatic conditions—the snow does not melt so as to be changed to a névé, but is always dry and powdery. Under such conditions relief from indefinite accumulation is secured by the blowing action of the wind, by evaporation of the snow, and by its descent in avalanches. When bare rocks are exposed on a lofty mountain, as in the case of Mount Rainier, they may become polished by drifting snow, but this action is too slight to lead to noticeable topographic changes.

By the process outlined above a regular, smooth volcanic cone which reaches well above the snow line becomes sculptured by glaciers, so as to present a precipitous central mass, with a conical or dome-shaped summit, according to the shape of the original peak, bounded by the steep walls of amphitheaters and surrounded by secondary peaks and crags forming the apices of V-shaped residual masses between primary

MOUNT RAINIER, FROM PARADISE PARK; LOOKING NORTH.

Elevation of the foreground, about 6,500 feet; elevation of the summits, 14,000 to 14,526 feet.

glaciers. From these *tahomas*—using the name of the best example on the sides of Mount Rainier as a generic term—descending lines of crags forming rocky ribs lead down to the platform on which the mountain stands.

The extension of the amphitheaters at the heads of the primary glaciers renders the sides of the central dome more and more precipitous as glacial erosion progresses. Certain of the primary glaciers may advance with their task of excavating the slopes which they descend more rapidly than others and cut back their amphitheaters faster than do their neighbors, thus making the central dome unsymmetrical. This is the case in the present stage of the erosion of Mount Rainier. Carbon Glacier, flowing northward and having its amphitheater sheltered from the noonday sun, has excavated a great recess or cirque in the side of the mountain, while the glaciers on the south side of the peak have scarcely more than begun to form similar recesses.

The process outlined above, by which an isolated snow-covered cone is sculptured by glaciers and by the streams flowing from them, is not an ideal picture of what may occur, but is rather a statement of what has taken place on Mount Rainier. The regularity in the development of topographic forms that would result from the sculpturing of a conical mountain of homogeneous rock has been modified in the example before us by irregularities in the primitive form, due in part to the truncation of the summit, but to a much greater extent by variation in rock texture. Mount Rainier, as already stated, is a composite cone built of projectiles and lava streams. The portions formed of agglomerate are open in texture and yield readily to mechanical erosion. The lava flows are frequently dense and compact and stand in relief when the adjacent agglomerate is worn away. Inequalities in snowfall also occur, owing to the prevalence of westerly winds, and, as previously mentioned, snow melting is greatest on the southern, or possibly the southwestern, side of the mountain. At an early stage in the history of the mountain after it had ceased to be an active volcano the heat of the rocks must have influenced the rate at which the snow falling on it was melted. This influence was greatest and longest continued at the summit, as some effects of the residual heat of the rocks are still to be seen there. From this cause the summit may have been bare for a long time after glaciers originated on the sides of the mountain and had begun their task of eroding the rocks.

The varied conditions just enumerated, and possibly still others, would lead to modifications in the orderly sequence of topographic changes that a lofty isolated peak of homogeneous rock would pass through.

Changes in the topography of Mount Rainier have also been influenced by great variations in climatic conditions. The mountain is supposed to be of Tertiary age, probably Pliocene (as to the definite time at which it was built I can offer no direct proof), and was exposed to the climatic changes which were such a marked feature of the Glacial period. The extent of the glaciers that flowed away from the peak during the Glacial period and the variations they experienced have not been made out. Such facts as are in hand bearing on this question indicate that the primary glaciers were well established before the coming of the Glacial period and that the ice drainage during its maximum followed valleys previously outlined, which were greatly deepened.

In spite of the modifying conditions enumerated above, and possibly still others that may have influenced the manner in which Mount Rainier has been sculptured, the changes in topography that the mountain has undergone make a near approach to what should be expected from the erosion by ice on the upper portion and by water on the lower slopes of a symmetrical peak of homogeneous rock of the height of the example before us and under the climatic conditions to which it has been exposed.

COMING TOPOGRAPHIC CHANGES.

With the postulate that existing climatic conditions will remain practically unchanged for a great length of time—the tendency of the glaciers to recede, discussed later, being checked—it is not difficult to sketch in outline the main topographical changes that Mount Rainier will pass through during the ages to come.

The primary glaciers are cutting back the cliffs encircling the amphitheaters from which they flow, and in their middle courses are slowly sinking into the sides of the mountain. This entrenching of the glaciers, by affording greater shelter for the ice, tends toward their preservation. The greatest changes in topography now in progress about Mount Rainier are at the heads of the glaciers that have made a marked advance in excavating their amphitheaters.

As an amphitheater recedes farther and farther into the side of an isolated peak the region favorable for the accumulation of snow and the growth of a névé becomes less and less extensive. For this reason the enlargement of an amphitheater leads to a decrease in the size of the glacier flowing from it. This is illustrated at the present time on Mount Rainier by Carbon Glacier, which has formed a large amphitheater on the north side of the peak. The snow on the less steep slope above the cliff leading to Liberty Cap creeps down to the verge of the precipice and there breaks off and forms avalanches, which descend to the glacier below. Carbon Glacier in reality has no true névé at present, except the snow-covered area just mentioned, above the summit of the cliffs encircling its amphitheater. The gathering ground of the glacier has been decreased by the extension of the amphitheater until it is but a fifth or a tenth of its original extent. Some compensation for the decrease in the size of the névé, as a glacier enlarges its amphitheater, is found in the fact that as the enlargement takes place the divides between the amphitheater and adjacent névé fields crumble away, and the glacier whose amphitheater recedes most rapidly diverts some of the snow drainage that was previously contributed to the neighboring glacier. This process is illustrated by Carbon Glacier, which has enlarged the western side of its amphitheater so as to divert some of the névé which formerly supplied Willis Glacier.

Carbon Glacier is still enlarging its amphitheater, and, if the process does not check itself by decreasing the area on which snow for the supply of the glacier accumulates, will cause such a recession of the cliffs at its head that the central dome of the mountain will become broken. The present symmetrical form of the mountain's summit will then be modified and replaced by a crest having a steep descent to the north and a much gentler southern slope.

If other glaciers about Mount Rainier also cut back their amphitheater so as to break the summit curve of the mountain, pinnacles and crests will replace the present rounded dome. In this stage there would be a central core, or a *matterhorn*, as it may be termed, with precipitous ribs and angular summit, surrounded by deep amphitheaters. When this stage is reached the gathering ground for névé fields will probably be so reduced that the glacier will shrink and have but little influence on the succeeding topographic changes which the mountain will pass through.

After the glaciers have ceased their work, weathering and stream erosion will continue. The mountain will become more and more angular, owing to the sculpturing of deep radial valleys down its sides, and the peaks and crests left between them. The history in store for the mountain when it is so altered in shape and reduced in elevation—with the exception of the central core—that glaciers can no longer be supplied by its snow, is illustrated by many ancient volcanic piles and need not be discussed at this time. Briefly stated, the topographic diversity of the mountain will increase for a time, and gradually the central core of hardened lava, filling the pipe through which eruptions formerly reached the surface, will be brought out in relief by the removal of the less compact agglomerates and lava sheets about it and stand as a tower above the ruins surrounding it. This "volcanic neck" will slowly crumble and sink to the condition of a rounded hill with rock fragments on its summit. The ultimate fate of the once glorious mountain is reduction to baselevel. When this topographic phase is reached, a plain, but little elevated above the sea, will occupy the place where now stands Mount Rainier.

PRESENT CONDITION OF THE GLACIERS.

As stated on a previous page, the ice bodies on Mount Rainier may be classified, in reference to their position on the mountain, as primary and secondary glaciers. The secondary glaciers have also been termed interglaciers, the type being Interglacier, situated on the broad V-shaped remnant of the middle mountain slope between Winthrop and Emmons glaciers.

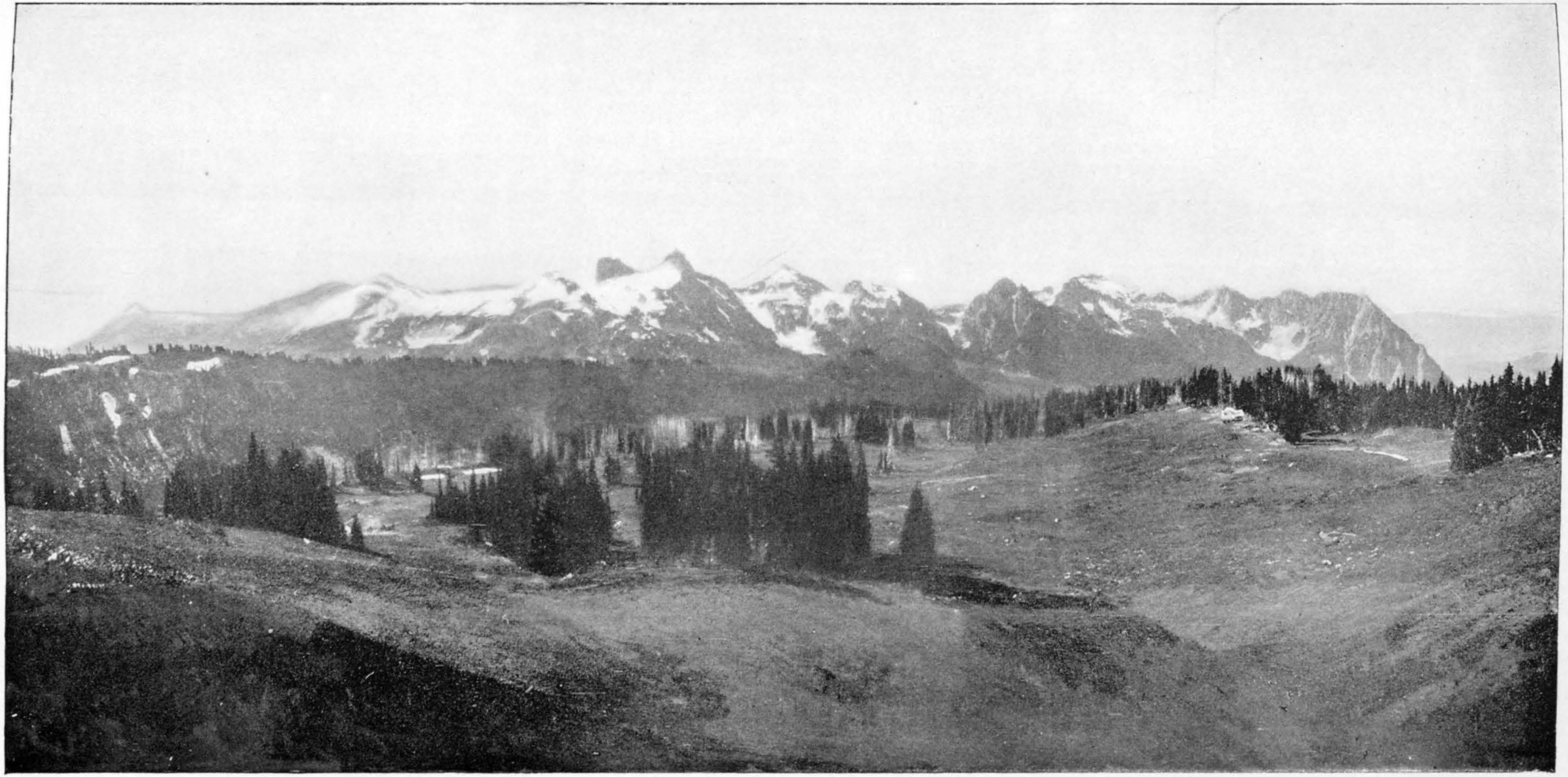
The primary ice streams in the order of their occurrence, beginning on the north side of the mountain and going about it toward the east, south, etc., are, as indicated on the accompanying map, the Carbon, Winthrop, Emmons, Ingraham, Cowlitz, Nisqually, Kautz, Wilson, Tahoma, Puyallup, Edmunds, and Willis glaciers.

The secondary streams, or interglaciers, as it is convenient to term them, in the order just stated, are Interglacier, Frying-pan, Little Tahoma, Williwakas, Paradise, Van Trump, and others not named. All the glaciers of this type are not represented on the accompanying map (Pl. LXVI), partly for the reason that they merge with indefinite snow fields, and some of them have not been recognized by those to whom we are indebted for the map. It is only in late summer or early autumn that the existence of glacial ice beneath the general snowy covering of the higher portions of the mountain can be distinguished. The interglaciers, as a rule, do not form well-defined ice streams, but are rather broad névés, from which a protrusion of glacial ice can be seen when the summer melting is far advanced. In some instances, as about the Guardian rocks, the glaciers of this type scarcely merit the name here applied to them, as they are little more than névés. These small ice bodies grade into snow accumulations which endure perhaps for several years, but are occasionally completely melted. A former extension of the interglaciers, and the previous existence of true glaciers where only deep snow accumulations now occur, is shown by the polish and grooves on the rocks below the positions they occupy. In common with the primary glaciers, those of the secondary type were formerly much more extensive than at present, but their condition during the Glacial period has not been fully determined.

CARBON GLACIER.

The amphitheater in which Carbon Glacier has its source, as already stated, is the largest excavation that has been made in the sides of Mount Rainier. The wall of rock rising above the head of the glacier is about 4,000 feet high. On this vast precipice little snow accumulates, but on its summit there is a vertical cliff of stratified névé snow about 200 feet high. This wall of snow, conspicuous on account of its contrast in color with the dark rocks below, exposes a section of the névé which rests on the slope leading from the crest of the precipice to Liberty Cap. The slow downward creep of the névé causes portions of it to break off from time to time and descend in avalanches to the bottom of the amphitheater.

In the amphitheater is a névé, it is true, but not of the ordinary type. A deep accumulation of snow is formed there each winter by the avalanches and by snow blown from neighboring heights, in addition to that which falls directly, but the surface of the deposit thus formed is uneven, and, as may be seen in the numerous crevasses, lacks the well-marked stratification which is such a characteristic feature of normal névés.



TATTOOSH RANGE, FROM PARADISE PARK; LOOKING SOUTH.

The avalanches from the cliffs encircling the head of Carbon Glacier bring down considerable rock débris, and in summer rock-falls are common, owing to the action of the wind, the loosening of blocks by changes of temperature, etc. The snow in the amphitheater thus becomes heavily charged with débris, which is carried down by the outward flow of the névé, and becomes concentrated on its surface as melting progresses. On account of the strong winds that prevail much dust is also scattered over the snow flooring the amphitheater, which serves to darken its surface.

With the recession of the walls at the head of the amphitheater there has been an increase in its breadth. Some of the snow drainage previously contributed to Willis Glacier on the west, and to a former interglacier on the east, has been diverted and now feeds Carbon Glacier. As previously stated, the recession of the cliffs at the head of the amphitheater has decreased the area of snow accumulation leading to it, and thus has led to a diminution in the size of the glacier originating in it. The loss due to the recession of the cliffs, and the consequent decrease in the extent of the elevated region of snow accumulation, has apparently been much greater than the gain due to a broadening of the amphitheater and the consequent robbing of adjacent glaciers of their snow supply. Carbon Glacier, by enlarging its amphitheater, is slowly destroying the conditions on which its existence depends. On the central portion of the great wall at the head of the amphitheater there is a buttress-like ridge, which indicates the position of a former dividing wall. At an early stage in the sculpturing of the mountain there were evidently two amphitheaters which contributed their snow to Carbon Glacier. With the enlargement of these recesses in the mountain side the ridge that divided them has nearly disappeared.

The sides of the amphitheater are rocky crests, as may be seen especially on the east, where a dark ridge of rock, marked by pinnacles and crags, separates the snow drainage of Carbon Glacier from that of Winthrop Glacier. This line of crags and pinnacles is the crest of the wall of bare rock sinking westward to Carbon Glacier, but its eastern slope is much less precipitous and is heavily covered with névé snow. A small enlargement of the amphitheater will cause a break in the divide on the summit of the cliffs, and some of the snow now flowing to Winthrop Glacier will be diverted to feed its more energetic neighbor on the west.

The outstretching ridges forming the side walls of the amphitheater extend northward and merge at their lower or northern extremities into broad, interglacier spaces at an elevation of about 9,000 feet. The amphitheater is about 8,000 feet across from east to west, and in the neighborhood of 5,000 feet in length from the base of the great cliffs at its head to the break through which the glacier outflows.

At the outlet of the amphitheater the snow, still having the characteristics of a névé, is much crevassed, especially where it passes over bosses of rock on the floor beneath. Dome-like elevations are thus caused in the glacier, which are broken by radiating fissures into castle-like blocks with precipitous walls. Domes of this nature are a characteristic feature of many of the glaciers on Mount Rainier, and the fact that they are due to the ice passing over prominent rock masses is clearly shown near the extremities of several of the primary glaciers where the rocks have been exposed by the melting and recession of the ice. The nature of these domes will be noted more in detail in connection with the descriptions which follow of Winthrop and Willis glaciers.

Just below the outlet of its amphitheater Carbon Glacier passes down a somewhat steep descent, and is much broken. Opposite Andesite Cliff the surface gradient becomes much more gentle, and for about a mile and a half downstream the glacier descends a very gentle grade. To one walking up the glacier the rise in this portion is scarcely noticeable. At the lower end of the nearly level reach just referred to the ice again descends a steep slope—which, however, scarcely merits the name of an ice fall—leading to the terminus. This last steep descent is about 1,000 feet in a mile.

In brief, the glacier descends a moderately steep slope on leaving the amphitheater, flows for a mile and a half with a very gentle grade, and then goes over the edge of a precipice and descends a steep slope to its end. The alternate breaks and level reaches of the glacier, resembling a great stairway, are not a novel feature, as is well known, but a characteristic of many alpine glaciers. The level reaches separating breaks in a glacier indicate similar topographic features of the rock surface beneath. In studying existing glaciers it is instructive to examine valleys formerly glaciated. The best reported illustrations of the alternate step and terrace features in high-grade glaciated valleys occur in the Sierra Nevada, and have been described by me in a previous article.[1] In ascending Tuolumne Valley, near its source on Mount Lyell, for example, one encounters a series of steep escarpments separated one from another by almost level reaches, in some of which there are shallow rock-basin lakes. When the great valley referred to was occupied by a glacier each of the steep descents caused an ice fall. These conditions are reproduced on a small scale by Carbon Glacier.

As is explained in part in the report just referred to, and as has been still more clearly stated by Willard D. Johnson, a glacier cuts back its beds from one ice fall to another in much the same way that a cascade in a stream recedes. The formation of scarps and shelves, as the level reaches may be termed, is due to a process similar to that by which amphitheaters are enlarged.

Opposite Andesite Cliff Carbon Glacier is about half a mile broad, but it soon increases to nearly a mile in width, and maintains this increase all the way to the brink of the steep descent a mile and a half

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[1] I. C. Russell, Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, 1889, pp. 348, 354–355.

THE SOURCE OF EMMONS GLACIER, SHOWING THE SUMMIT AND EASTERN SLOPE OF MOUNT RAINIER.

below. Indeed, but little diminution in breadth occurs until the final descent toward the terminus begins. It then contracts in width somewhat abruptly to about 1,000 feet, and ends in a precipitous slope.

Opposite Andesite Cliff the hard blue ice of the glacier is exposed. In this region there is a reach of the glacier about half a mile long, intervening between the lower edge of the névé and the heavily moraine-covered ice farther downstream, which is comparatively free from dirt and stones. The extent and character of this surface vary from day to day during the summer, the névé receding and the dirt-stained and stone-covered area at the same time increasing upstream, owing to the concentration of débris at the surface as melting progresses.

Downstream from the belt of clear ice just referred to the glacier is progressively more and more deeply covered with stones and dirt. In this region many of the minor features characteristic of moraine-covered ice, such as glacier tables, sand cones, surface streams, moulins, etc., may be recognized. About 1,000 feet downstream from Andesite Cliff four somewhat prominent medial moraines make their appearance, and may be traced to the brink of the steep descent a mile below. Two of these moraines are near the west side of the glacier, the nearest being about 700 feet from its western border, and separated from its companion by a lane of less completely débris-covered ice about 150 feet broad. The other pair of medial moraines occupy a similar position adjacent to the east side of the glacier. These medial moraines are not conspicuous features, but are marked by irregular débris pyramids, rising from 10 to 30 feet above the adjacent surface.

The débris along the west side of the glacier, derived largely from Andesite Cliff, is gray, corresponding with the color of the cliffs from which it comes; but on all other portions of the surface the prevailing color of the moraines is dark brown. Practically all of the morainal material is angular. Rounded or smooth and striated stones are seldom seen.

Below the beginning of the steep descent leading to the terminus of the glacier no ice can be seen in a general view. The entire surface is buried beneath a sheet of brown, angular débris. The larger stones range in size from a few inches to several feet, and mingled with them are large quantities of fine, earth-like material. This portion of the glacier is rugged, on account of numerous crevasses and unequal melting, due to variations in the thickness of the débris. Something of the manner in which surface morainal material is concentrated in depressions and then raised in relief by the melting of the adjacent surface so as to form débris pyramids may there be seen. This process, however, goes on most actively when a glacier has but little motion or is stagnant, and about Mount Rainier may be best studied near the terminus of Winthrop Glacier. At the end of Carbon Glacier the ice descends precipitously 300 or 400 feet, and presents a dirt-stained face too steep for one to climb without cutting steps. At the foot of this steep descent Carbon River emerges from a cavern in the ice, as a brown, roaring torrent, heavily encumbered with bowlders. The river is overloaded with coarse débris, and is filling, or aggrading, its valley all the way to the narrow canyon 3 miles above Carbonado. The condition of the valley bottom below that locality is not known to me.

Where the river leaves the icy cavern from which it emerges many of the stones in its bed are angular; these have come directly from the steep ice slope above. Other stones, many of them 2 feet or more in diameter and composed of hard rock, are well rounded; these have been brought out of the subglacial tunnel, and show that much erosion is performed by the stream before it comes to the light. Less than half a mile below the terminus of the glacier nearly all the stones that form its banks are well rounded.

The end of Carbon Glacier was seen by Willis in 1881. At the time of our visit the glacier had retreated about 100 yards, as nearly as could be estimated, above the position it occupied fifteen years previous, and the precipice at its terminus had become much less steep.

Accompanying the recession of the terminus during recent years, there has been a general lowering of the surface of the glacier all the way up to the névé, but no measure of the amount that the ice had shrunk could be made. The lowering of the surface is of the nature of a general shrinking, which is greatest near the crest of the lower ice fall, and progressively decreases upstream. One conspicuous result of this surface melting is a marked increase in the amount of superglacial débris, as noted by Willis.[1]

A recent lowering of the surface of the glacier is recorded by abandoned lateral moraines. These are conspicuous along each side of the glacier, from the brink of the lower icefall up to Andesite Cliff on the west bank and to the entrance to the amphitheater on the east side. These moraines, composed largely of sandy clay heavily charged with stones and angular rock masses, rise from the ice in precipitous escarpments from 100 to 140 feet high, and are too steep in many places to be climbed. The angle of slope toward the glacier is from 40° to 50°. These slopes are broken faces, from which stones frequently fall, and are entirely bare of vegetation. The slope referred to rises to a sharp crest, from which the slope away from the ice is more gentle, averaging between 30° and 40°. On these outer slopes spruce trees, some of them 20 to 30 feet high, are growing.

On leaving the glacier on either side and climbing the fresh slopes of morainal material bordering it, one finds other similar, parallel ridges, each of which is clothed with forest trees. These older moraines are in several instances higher than the most modern one, and show in general a progressive lowering of the surface of the ice as the width decreased.

[1] Seventeenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, p. 53.

The narrow valleys between the abandoned moraines are without forest trees, but are carpeted with moss, grasses, and a profusion of brilliant flowers. The snow lingers until late in summer in these shaded dells, and the black, humus soil, after the snowdrifts disappear, is water-soaked and in many places swampy. Thus in several ways the ridges favor the growth of forest trees, while the marshy dells between furnish conditions suitable for the growth of more lowly plants.

The abandoned lateral moraines below Andesite Cliff are in an embayment on the side of the valley. Their formation illustrates the manner in which a glacier builds moraines where the valley widens, and thus tends to make its channel even sided. The most recent moraine—the one overlooking the ice—starts from Andesite Cliff, but not at its most exposed portion. The next lateral moraine to be formed if the glacier continues to shrink will, it is to be expected, start from the extreme end of the cliffs where they now project into the glacier.

The older lateral moraines, of which there are sometimes three, and again four, abreast, terminate at their upper or proximal ends abruptly, without uniting with the cliffs from which they derived much of the material composing them. The reason for their abrupt ending is that a lateral stream following the side of the glacier cut a channel across them at their junction with the side of the valley. This process is plainly illustrated on the west border of Winthrop Glacier near its terminus.

The moraines on the east side of Carbon Glacier are in general like those just mentioned, and again all but the last formed are without connection at their proximal ends with the more elevated region above.

All of the moraines just described pertain to the present topography and were formed when the glacier had its present characteristics, except that below Andesite Cliff, when the earliest pair was formed, it was about a mile broader and its surface about 250 feet higher than now. Whether the valley was ever more deeply filled with ice than is recorded by these old moraines remains to be determined.

WINTHROP GLACIER.

The névé of Winthrop Glacier extends to the summit of Mount Rainier. A part of the snow that accumulates in the great summit crater between Crater Peak and Liberty Cap flows eastward down the precipitous slope of the central dome and contributes to the growth of the extensive névés covering all that side of the mountain. The eastern slope of the mountain is more heavily snow covered than any other portion, mainly for the reason that the prevailing westerly winds cause the snow to be deposited there in greatest abundance. The great peak rising in the path of the moist winds from the Pacific produces something like an eddy in the air currents on its eastern side, and thus favors deep snow accumulation.

All of the eastern side of the mountain above an elevation of 8,000 to 10,000 feet, except the precipitous ridges and jutting crags, is névé covered. The appearance of this side of the mountain in summer is shown on Pl. LXIX. As may be seen in the illustration to some extent, the snow is much crevassed, and is broken by faults where the cliffs are steepest. This is due to the ruggedness of the rocky slopes beneath, which yield unequally to the erosion of the descending ice and snow, but no amphitheaters or cirques have been excavated.

Near its lower limit the névé is divided by two rocky promontories, as has been previously described, known as The Wedge and Little Tahoma. These prowlike rock masses divide the névé into three primary glaciers—the Winthrop, Emmons, and Cowlitz—as shown on the accompanying map.

The névé of Winthrop Glacier descends below The Wedge, and terminates above timber line at an elevation of approximately 8,000 feet. Below the lower margin of the névé the solid blue ice of the glacier proper, in places heavily covered with débris, extends far down the valley between rugged mountains, and ends at an elevation of between 4,000 and 5,000 feet.

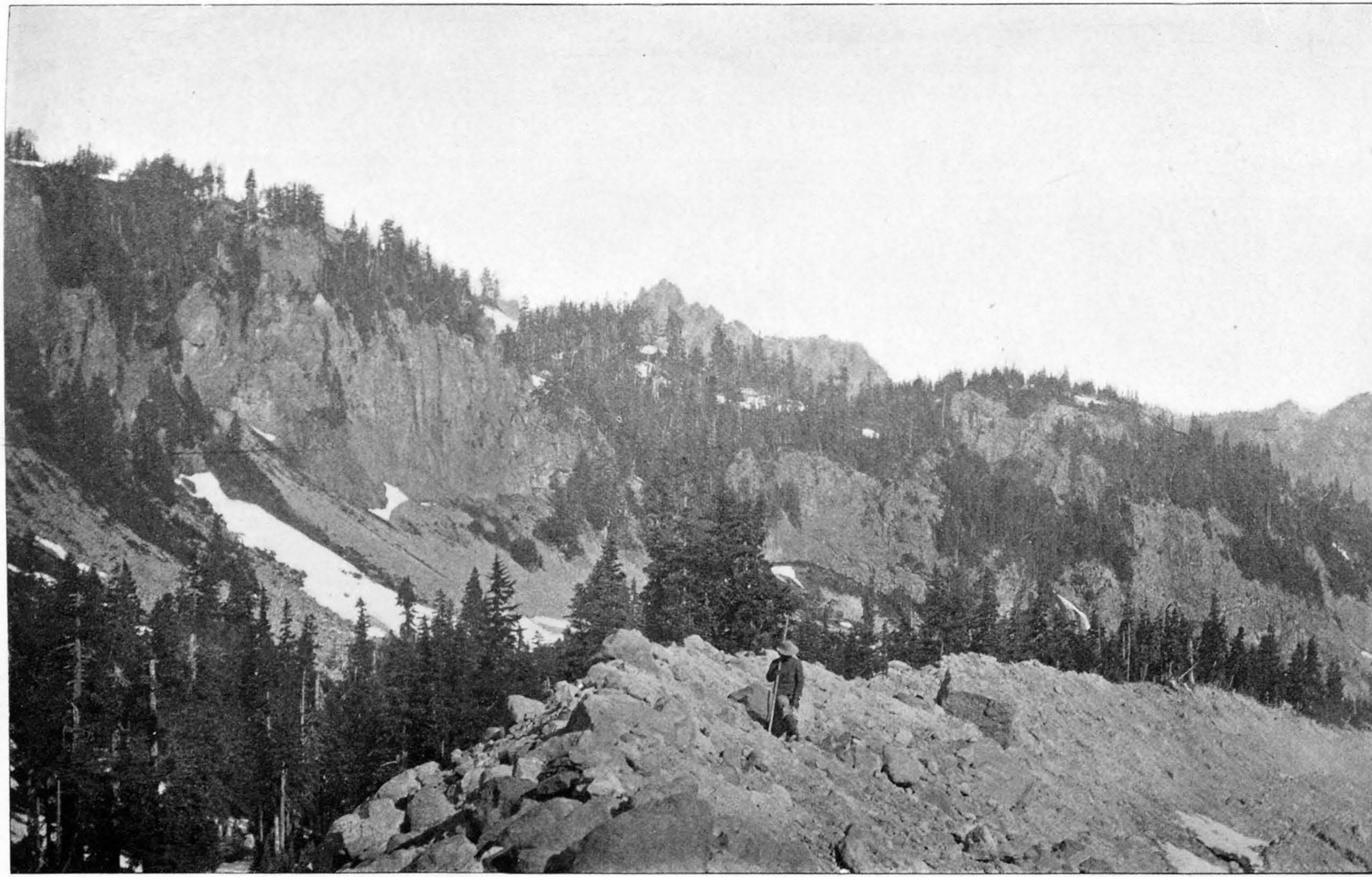
From the end of the glacier one branch of White River flows out as a swift turbid stream, heavily loaded with coarse débris.

One of the characteristic features of the glaciers about Mount Rainier, as already mentioned, is the occurrence of well-marked domes, the summits of which are commonly fractured so as to produce radiating crevasses. Several of these domes occur in Winthrop Glacier, both in the névé portion and in the glacier proper, and furnish abundant material for study.

The domes in the glaciers have the appearance that might be expected to result if a sheet of ice or of névé snow 100 to 200 feet thick could be lowered down vertically onto a surface on which there were haystack-like domes of rock 100 to 300 feet high. In such a case the ice over the domes would become fractured, while on the generally even surface between it would settle down with less breaking and conform to the general contour of the rocks beneath.

We know, however, that the snow and ice supplying the glaciers flow from higher regions, and that it must advance over the domes. This means that the ice has in fact an upward motion, for the glaciers rise in passing over the elevations in their beds. From the summits of the domes the snow, or ice, as the case may be, descends in all directions, but usually the slope is steepest on the downstream side.

A series of ice domes on the glaciers about Mount Rainier might easily be selected ranging from regular domes with practically equal slopes on all sides, through other similar forms with precipitous lower face, to precipices down which the ice descends, forming what are termed ice cascades. From analogy with the ice cascades I shall designate the elevations on the surfaces of the glaciers here described *ice domes*. Like the cascades, the domes vary in their characteristics according as they occur in a névé region or in a glacier proper.



RECENTLY ABANDONED MORAINE ON WEST SIDE OF CARBON GLACIER, JUST BELOW ANDESITE CLIFF.

The domes in the névé region, as on the upper portion of Winthrop Glacier below The Wedge, differ in appearance from those in the glacier proper, owing to differences in the physical properties of névé snow and ice. The domes in the névé have more or less of a network of wide fissures about their summits, with radiating fissures extending down the sides, which gradually contract and die out in the course of 100 or 200 yards. The radiating fissures on the upstream sides of the domes are commonly less extensive and much less conspicuous than those extending in other directions. The fissures in the summits of the domes in the névé at the time of our visit were widely expanded, and when the temperature was below freezing one could safely walk over the rough cavernous snow partially filling them and penetrate to the very center of the system of breaks. In some instances a nearly rectangular column of snow 30 feet on a side and rising 50 or 60 feet above the partially filled crevasses bordering it rose in the center like a huge obelisk.

Farther down Winthrop Glacier, in the glacier proper, the domes are equally conspicuous, but the crevasses in them are less regular and not nearly so wide as in the instances just cited. Just below the skirt of the névé as it existed at the time of our visit there are four domes inclosing a basin in which there was a shallow pond about an acre in area, which was conspicuous on account of its blue color. These domes rose, by estimate, about 50 or 60 feet above the ice on the upstream side, but the ones farthest downstream, when seen from below, had nearly twice this height. Their slopes on the upstream side descended at an angle of about 4° to 6°, but on the downstream side they were considerably steeper, probably 10° to 12°, and in one instance at least 20° or 25°. Just above each dome there is an absence of crevasses, and the ice seems to be compressed, but small breaks appear soon after the ascent begins. These crevasses are curved and tend to surround the dome as contours, but near their ends trend away from it in curves concave toward the center and die away. The crevasses become broader on the summit of the dome, especially on the brink of the steep downstream side, and as the ice descends are closed. The lower side of one of the larger domes was visited, and a hollow in the surface of the glacier was found below it. Standing in this hollow and facing the dome, one sees a steep descent, much like an icefall, with pinnacles of blue ice along the crest. On each side of the dome there is a curved ridge of ice, making the east and west walls of the depression in which the observer stands. These curved ridges become lower and lower as they leave the dome, and, uniting, completely inclose the depression, the lowest point on the rim being opposite the dome. A stream fed by surface-melting coursed along in the bottom of the depression, flowing in the direction of glacial motion for 5 or 6 rods, and then plunged into a crevasse. In the depression below other similar domes there were shallow ponds.

The barriers below the domes are evidently due to a strong flow of ice about their sides, which formed the lateral curved ridges that unite a short distance below.

That the domes are due to bosses of rock rising in the bed of the glacier is shown, as previously stated, by the appearances of such domes at the extremities of some of the glaciers which have been uncovered by the melting of the ice. One such dome stands near the extremity of Winthrop Glacier, and now forms a portion of its west wall, but was formerly completely surrounded and overridden by the glacier. The exposed rock domes are rounded, strongly glaciated, and more or less covered with morainal material. Perched bowlders, which a strong push would dislodge, are frequently seen on them. The rock domes are, in all observed instances, composed of dense, hard rock. One in Carbon Glacier, on the brink of the lower fall, is of granite. The others observed are of dense igneous rock, probably andesite. The rock about the bases of these domes is perhaps softer and more easily eroded, but that this is really the case has not been proved by observation, owing to the débris that occupies the depression and conceals the rock beneath. The impression that one gains on examining the rock domes exposed by the retreat of the glaciers is that they result from ice erosion and have been left in bold relief by the wearing away of softer rocks about them.

The manner in which a glacier rises over a dome is of interest in connection with the much-discussed problem of the cause of glacial motion. A detailed study of ice domes would apparently furnish evidence for deciding whether a glacier behaves as a rigid body that is thrust forward by a force acting from above, or as a plastic body moving under the influence of gravity. The manner in which the ice, in the case of a dome in the glacier proper, flows about the obstruction so as to form lateral ridges which gradually approach and inclose a depression below certainly favors the idea of plasticity. The ice appears to be forced over the summit of a rock dome and to rise higher than the adjacent surface upstream, both by the pressure of ice above and by the drag of the deeper ice current on either side.

It is difficult to conceive of the manner in which a rigid body would behave under the conditions here referred to, but there appears to be no reason for assuming that it would close in below the domes; we should expect, rather, to find an open channel below each obstruction, with precipitous and much-broken walls.

On the east side of Winthrop Glacier, below The Wedge, the rocks rise precipitously and form cliffs, from which much débris falls. The glacier is evidently sapping the cliffs that border it from The Wedge to near its termination. On the west side the limit of the névé fields is indefinite, there being many crags that rise through the snow above the timber line.

Below that horizon, however, the glacier's margin is sharply defined by bordering precipices. The ice has there melted back from rugged

UPPER ICE CASCADES OF THE COWLITZ GLACIER.

cliffs so as to leave a marginal valley some 200 feet deep, in which a stream flows. The margin of the glacier is heavily moraine-covered and much broken by crevasses. In places it is impassable. The extremity of the glacier, as already stated, flows past a bold rock dome, which was formerly covered by the ice, and at a later stage, as the glacier receded, divided into two branches, the eastern one being the broader. As the glacier continued to retreat, the tongue of ice to the west of the rock dome melted back, and a heavy lateral moraine was deposited as a free ridge, having a curved course, which extends out from the shore and joins the rock dome. The end of the moraine near the shore has been cut away by the stream following the side of the glacier, and when traced toward the border of the valley is found to end in a precipitous slope. Standing on the crest of the moraine, on which a few small spruce trees are growing, one can look down into a deep valley to the west of the rock dome, across which the moraine has been built. The slope of the moraine on that side is steep and the descent is about 400 feet. On the side overlooking the glacier the descent is still more precipitous. The ice has shrunk away from the moraine and is now fully 100 feet below its crest.

Above the rock-dome and bordered by the sharp-crested moraine just mentioned there is an embayment in the side of the glacier, occupied by heavily débris-covered ice that is fast melting away. This stagnant ice has a markedly different aspect from that on other portions of the glacier where motion is still in progress.

The topography of stagnant moraine-covered ice is difficult to describe, but easily recognized. A prominent feature is the great number of short, steep ridges or crests, rising to a broad, gable-like angle in the center and bounded on one side by a steep crescent-shaped slope of dirty ice and on the other by a much more gentle slope, which is heavily moraine-covered. The steep slopes usually face southward, but this is not an invariable rule. Below the steep slopes, and filling the spaces between adjacent crests, there is usually a deep accumulation of stones and dirt. As melting progresses these concentrated masses of morainal material are left as débris pyramids. The moraines on stagnant ice are usually darker than on other portions of a glacier, probably on account of the greater abundance of fine, earth-like débris, which retains moisture and is always wet. The steep slopes of the ice crests in the case of the Mount Rainier Glacier are dark-brown and frequently appear nearly black, as is also true of the stagnant border of Malaspina Glacier, Alaska. These dark, wet slopes are not common on moving ice.

The eastern branch of Winthrop Glacier ends in a low slope to the east of the rock-dome referred to, and has but little morainal material in it. Above the low terminus the ice rises steeply, and has been washed clean by surface streams. Above this steep rise the ice is profoundly crevassed and can be crossed only by patiently choosing a way from one narrow ice blade to another between deep gashes in the solid blue ice.

There are many other features of Winthrop Glacier that demand attention, but in the absence of a detailed map and other illustrations an attempt to describe them is probably not advisable.

One interesting feature near the end of Winthrop Glacier, reported by E. S. Ingraham, but not seen by me, is a deep, narrow cleft in the rock, on the border of the valley and parallel to its longer axis, about a mile below where the glacier now terminates. This gorge is probably the result of stream erosion along the side of the glacier when it was much more extended than now. That this is the true explanation of its origin, however, remains for future travelers to determine.

EMMONS GLACIER.

The best example of the manner in which the general névé field descending the slopes of the central dome of Mount Rainier is divided by wedges of rock into primary glaciers is furnished by Emmons Glacier and its neighboring ice streams. The origin of the wedges now dividing the névé, by the erosion of the outward-flowing ice, has already been explained.

Below The Wedge and Little Tahoma, Emmons Glacier is a well-defined ice stream, about 5 miles in length, with bold, rocky cliffs on each side. The glacier becomes heavily charged with débris along its borders from the adjacent cliffs, and in the lower portion of its course is completely covered with stones and dirt on each side. These lateral moraines become broader and broader toward the terminus of the glacier, leaving a tapering, lane-like tongue of clear ice between, but before the actual terminus is reached the ice over the entire surface is concealed by a continuous sheet of brown and barren débris. On the right-hand side of the glacier, for one or two miles above the terminus, abandoned lateral moraines occur in parallel ridges, marking a gradual shrinking of the ice. A similar record occurs also on the left side, but the moraines are there broader, and show by their color and by the relief of the surface that they rest on stagnant ice. On the side of the valley, above the stagnant moraine-covered ice just referred to, there are abandoned moraines which are banked against the steep cliffs forming the valley side.

The tongue of clear ice near the extremity of the glacier is some 2 or 3 miles long and, although gradually tapering downstream, is much of the way about one-third of the width of the valley. The grade is there low and the ice not much broken by crevasses. Down the central portion of this tongue there are two light medial morainal-bands, derived from rocky crests in the central part of the névé mostly above the horizon of Little Tahoma. These narrow rocky ledges may be seen in Pl. LXXIII.

SURFACE OF COWLITZ GLACIER.

The manner in which débris causes a decrease in the flow of the ice containing it, and final stagnation if the rock material reaches a large percentage,[1] leads to interesting suggestions in the case of the glacier here described.

The excessive load of stones and earth on the sides of the glacier, the central portion being notably free from such accumulations, causes the marginal portions to become heavily charged with englacial débris as melting progresses. The flow of the ice is thus checked, and the marginal portions of the glacier become stagnant. This is equivalent to a narrowing of the valley through which the ice flows, and the clear portion is enabled to progress farther before melting than it would if the border had not become stagnant. Emmons Glacier, like all the other primary glaciers on Mount Rainier, is evidently wasting away and its terminus receding. The process just referred to, by which the channel available for the flow of the clear ice becomes contracted, might lead to an advance of the terminus in spite of the fact that a general wasting away is in progress. The stagnant ice along the sides of the valley not only causes a decrease in the width of the channel, but shields the clear ice from melting more effectually than cliffs of rock would do. The clear ice under the present conditions is also able to advance farther than it would in a broad valley where its sides would be exposed to melting; or than it would between cliffs and rocks which, by reflecting heat, would cause even greater marginal melting than would occur in a broad valley.

Emmons Glacier is deeply intrenched. Near its terminus it is bordered on each side by bold, rugged mountain ranges, left in relief by the excavation of the valley in the which glacier lies. The valley becomes narrower and its sides still more rugged below the terminus of the glacier. The stream flowing down it, a branch of White River, like other similar rivers already mentioned, is overloaded with coarse débris and is aggrading its channel.

INGRAHAM GLACIER.

The portion of the névé descending the east side of the central dome of Mount Rainier, to the right or south of Little Tahoma, and divided by that promontory from the portion of the névé tributary to Emmons Glacier, forms a primary glacier of an abnormal type. This well-defined ice stream does not descend the mountain slope in direct course, but is deflected southward or becomes tributary to Cowlitz Glacier. Its course is oblique to what may be considered the normal flow of a primary glacier originating on an isolated peak.

Where the descending névé is split by the sharp edge of the great wedge-shaped remnant of the side of the mountain, of which Little Tahoma is the culminating peak, the ice rises against the rocks and is

[1] I. C. Russell, The influence of débris on the flow of glaciers: Jour. Geol., Vol. III, 1895, pp. 823–832.

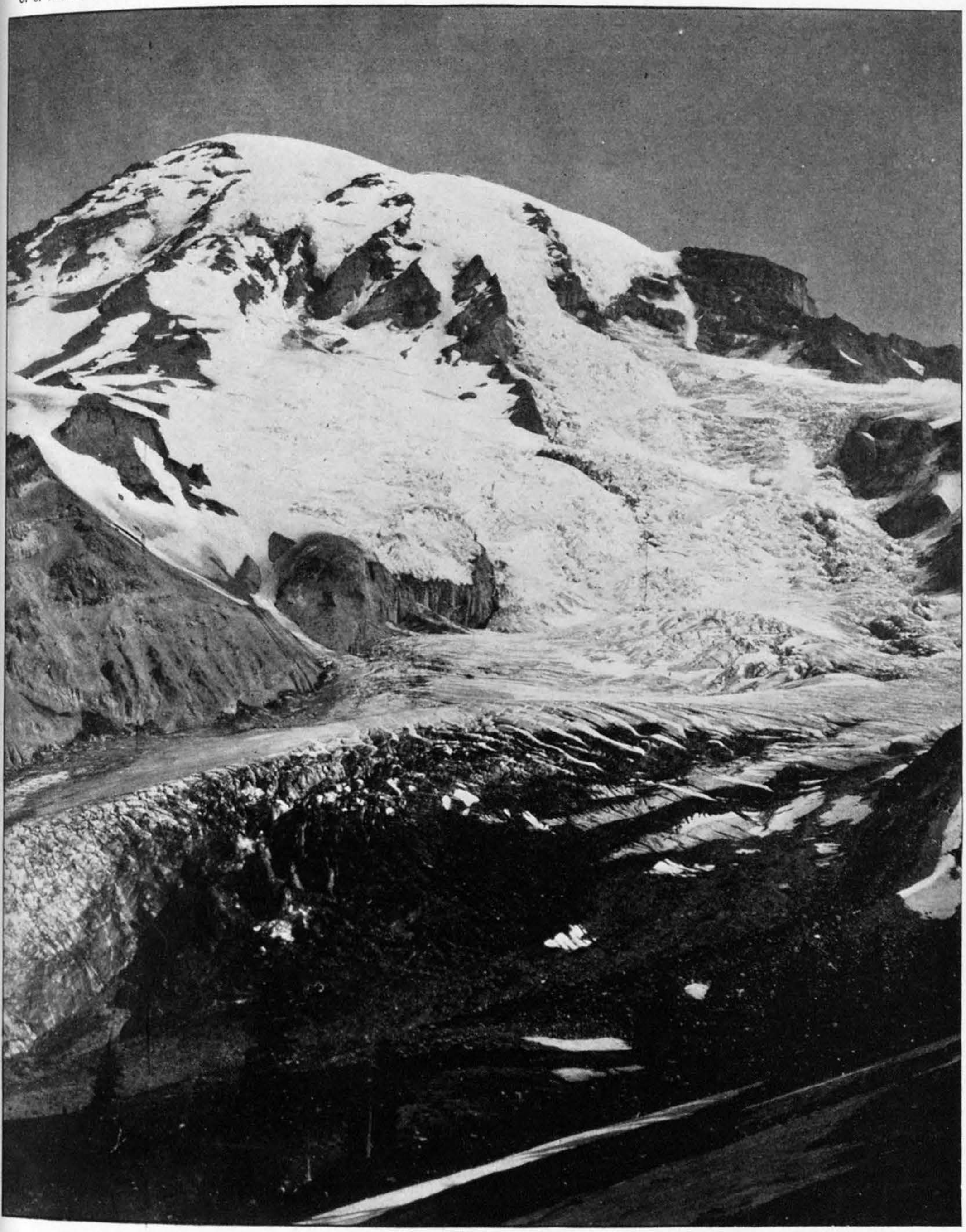
greatly shattered. The portion of the névé turned southward by the obstruction now descends a steep slope and is much crevassed; below the slope the descent is more gentle, and the hard, blue ice, but little encumbered with débris, flows on as a well-defined glacier. All along the left side of the glacier the cliffs of Little Tahoma rise in rugged precipices, from which débris is continually falling. On approaching its junction with Cowlitz Glacier, Ingraham Glacier descends a precipice about 800 feet high and forms a fine ice cascade. Something of the appearance of this steep ice-covered descent is shown in the accompanying illustration (Pl. LXXV), in which the head of Cowlitz Glacier and the bold cliffs of bedded lava and agglomerate between the two glaciers are also shown. In this illustration, also, the bedded character of the rocks forming Little Tahoma, and the manner in which the irregular strata end in the air on the left—that is, toward the summit of Mount Rainier—may be recognized. Before erosion altered the topography of the mountain, and previous to the blowing away of its summit, the strata in Little Tahoma were continued upward to the summit of the perfect volcanic cone.

The illustration to which attention has been directed is unsatisfactory on account of its "flatness." The distance from the rocks in the foreground, across Cowlitz Glacier, to the cliff of inclined beds between the two ice falls is fully a mile. The peak of Little Tahoma is about 3 miles distant. With these measures in mind the photograph reproduced in Pl. LXXV becomes more intelligible.

COWLITZ GLACIER.

The Cowlitz Glacier, above where Ingraham Glacier joins it, expands somewhat and occupies an irregular depression, having some of the features of an amphitheater. The slopes at the head of the depression are so sharp that the snow descends in avalanches. The main portion of the névé is comparatively low on the mountain side, but some of the snow drainage comes from near the summit. The valley occupied by the névé contracts just above where Ingraham Glacier comes in, and it is there that the lower limit of the névé probably occurs, but at the time of our visit the glacier was snow-covered and white as far down its course as we were able to see. The snowfall during the winter preceding our visit was unusually heavy, especially on the south side of the mountain, and the melting of the snow in spring was long delayed. Photographs taken in previous years (Pl. LXXVI) show that ordinarily in late summer the solid glacial ice is exposed and forms an extremely rugged, dirt-covered surface, where we walked with ease over hard snow.

The portion of Cowlitz Glacier below Ingraham Glacier is inclosed by bold cliffs, and is well defined. There is less evidence of shrinkage along its sides than in the case of the other glaciers examined. This is possibly due in part to the fact that Ingraham Glacier has a high grade



NISQUALLY GLACIER.

and probably conducts away much of the snow that might be considered as belonging to Emmons Glacier. A sharp-crested lateral moraine across a side expansion of the valley, a mile below Ingraham Glacier, is evidence, however, of a recent lowering of the surface of at least 75 or 100 feet.

The lower portion of Cowlitz Glacier was not seen by me, but, judging from what I observed, I should say that it furnishes the most typical example of an Alpine glacier that exists about Mount Rainier. It is readily accessible from Paradise Park, and could conveniently be made the subject of special study.

NISQUALLY GLACIER.

The Nisqually Glacier flows past Paradise Park on the west, and as this beautiful region is visited each summer by hundreds of tourists, it is, in a general way, the best known of the glaciers on Mount Rainier. My visit to the southern side of the mountain was too brief, however, to admit of my becoming acquainted with the glacier that is so familiar to many others, and instead of attempting a description of it I wish rather to suggest observations that visitors to Paradise Park may easily make.

Nisqually Glacier heads in two névé fields, which occupy what may be termed incipient amphitheaters, situated below the level of Gibraltar. Each of these depressions receives snow from avalanches that descend the steep slopes above them. The easterly névé, the one nearest Gibraltar, however, is fed by two snow streams, which endure through the summer, and from ice cascades, on which small avalanches frequently occur. These features are shown on Pl. LXXVII, which also illustrates the manner in which the glacier is crevassed and the extent of the sheet of débris covering its borders just below where the two névés unite. In this same region there are several small ice domes, one of which may be recognized in Pl. LXXIX. Visitors to Paradise Park could render assistance to students of glaciers by obtaining good photographs of this ice dome from time to time, and thus furnishing a record of the changes it passes through. By boring 2-inch auger holes to a depth of 6 or 8 feet in the ice and inserting vertical stakes, the daily rate of surface melting could be measured. A row of such stakes placed in line across the glacier would furnish a means of measuring the flow of the ice.

The Nisqually Glacier narrows to a well-defined stream to the west of Paradise Park, and at its terminus there is an archway from which Nisqually River rushes out. Photographs of the terminus taken at several dates during the summer from the same point of view—which should be so marked that it could be rediscovered year after year, for the purpose of obtaining additional pictures—would furnish data for ascertaining the advances and recessions of the glacier. To aid in these observations records should be made on the cliffs, either by chiseling into the rock or by painting an appropriate mark upon it, which would mark the position of the ice front at a definite time and admit of measurement of the fluctuations of the end of the glacier in subsequent years.[1]

Nisqually Glacier affords abundant opportunity for observing and studying the various minor features that glaciers present, such as the nature of crevasses, and their different types; the nature and origin of moraines; the manner in which lateral moraines are left stranded on the sides of a valley by the lowering of the ice; glacial tables, and the changes they pass through during the season of melting; sand cones; débris pyramids, etc. The delights of camp life in Paradise Park can be greatly enhanced by anyone who chooses to avail himself of the advantages for glacier study there afforded.

The glaciers on the southwest side of Mount Rainier have not been seen by me, and no data are available concerning them except such as are given on the accompanying map.

WILLIS GLACIER.

On the northwest side of Mount Rainier and at the head of the deep, narrow valley through which the north branch of Mowich River flows, there is a glacier, known as the Willis Glacier, which is perhaps the most interesting of any here considered. It has many of the features of the primary glaciers already described, but is of small size, and one may see all its characteristic features in a single day's excursion.

From the summit of Eagle Cliff—where may be seen the most magnificent of the views about Mount Rainier, and in fact one of the most sublime pictures of noble scenery to be had anywhere in America—the whole of Willis Glacier, from the snow fields that give brilliancy to Liberty Cap down to the dirt-stained and crevassed extremity of the ice stream, is embraced in a single view. Below the end of the glacier the river, rising in two branches from its divided extremity, rages over its bowlder-filled channels and between craggy mountains which rise in precipices on either hand. To an observer on Eagle Cliff the distant roar of the troubled waters in the wild valley at his feet is mingled with the softer music of creeks and rills that plunge down the bordering cliffs to join the torrent below.

From Eagle Cliff the manner in which Willis Glacier is divided at its extremity into two moraine-covered tongues of ice is a noticeable feature. The bold, rocky eminence that causes the division rises steeply in the center of the valley to a height of fully 1,000 feet, and is clothed on its downstream side with forest trees. For the sake of a name, I

[1] A committee of the International Congress of Geologists was appointed in 1894 for the purpose of recording observations of the nature above suggested. Prof. H. Fielding Reid, of Johns Hopkins University, Baltimore, Maryland, is a member of this committee, and will furnish instructions for making the desired observations. Photographs, or other data concerning the fluctuations of glaciers, forwarded to Professor Reid will be carefully preserved and utilized to the best advantage, full credit being given those furnishing the information. See the Journal of Geology, Vol. III, 1895, p. 284.

MARGINAL CREVASSES, NISQUALLY GLACIER.

propose to call this bold, isolated eminence Division Rock. When Eagle Cliff was first reached by Willis in 1881 the glacier since named in his honor was larger than now, and extended to near the summit of Division Rock. On gaining the brink of the cliff immediately to the north of the summit of the rock, which is conspicuous from many points of view lower down the valley, the ice broke off so as to form a precipice at the summit of the rock cliff. As will be shown below, this observation enables us to make a rough measure of the amount that the end of the glacier has receded during the past fifteen years. On reaching Division Rock the glacier divides into two tapering tongues, more fully described below, and as seen from Eagle Cliff is marked by three rather faint medial moraines, separated by lanes of clear ice. The central moraine ends at the division produced by the rock, and the ones on each side follow the central portion of the tongue of ice in the valley at its sides.

In visiting Willis Glacier I approached it from the east by way of the Guardian Rocks, and came to the brink of the canyon through which it flows midway between its terminus and the steeper portions of its névé. The crest of the cliffs of jointed andesite bordering the glacier on the northeast rise more than 1,000 feet above its surface and furnish exceedingly favorable localities for observing the glacier at their base. From such a station the entire glacier, from the clear white snow fields culminating at Liberty Cap down the steep side of the central dome, where the névé is much broken, to the blue ice below, and on to the moraine-covered terminus, is in full view. The entire distance from Liberty Cap, where the snow accumulates, to the extremity of the glaciers, where it melts away, is approximately 5 miles. The distance from the head of the slightly defined amphitheater in which the glacier heads to its terminus is about 3 miles. The breadth of the glacier where its borders are best defined, about a mile above its terminus, is approximately 3,000 feet. These measures, or rather estimates, show that the glacier is small, but the many interesting features it exhibits make it one of the most instructive of the glaciers in the system to which it belongs.

The north wall of the canyon through which the glacier flows is exposed to the sun, and the snow is melted from it early in the summer, while the south wall nearly to the end of the glacier remains heavily snow-covered throughout the year. From these snow fields broad, irregular névés descend to feed the glacier. Owing to this difference in exposure and to the manner in which the opposite sides of the canyon are affected by névé erosion and weathering, the southward facing wall is steep and rugged, with some vegetation in favored places, while the northward-facing slopes are gentle.

At the head of the canyon there is a steep ascent to the summit of the mountain, resembling the higher and more precipitous cliffs at the head of Carbon Glacier. On these cliffs irregular patches of névé snow are to be seen. The snow from these small accumulations, as well as from the less steep slopes about Liberty Cap, descends in avalanches to the head of the canyon. There is a noticeable enlargement of the canyon near its head, but it is not extensive enough to be classed as an amphitheater. The snow falling in avalanches, and also that which accumulates at the head of the canyon during the winter seasons, forms a névé, which is rugged and much broken by ice domes and crevasses. The lower limit of the névé is about 3,000 yards above Division Rock and just above a conspicuous ice fall which crosses the entire width of the glacier. In the névé region there are eight ice domes, which give to its surface an unusual topography. In these elevations the snow rises so as to form well-defined domes, which are, by estimate, from 20 to 50 feet high and from 150 to 200 feet in diameter. As the snow rises on the upstream side of a dome it becomes crevassed. The breaks at first are narrow and curve about the domes, but are highest and broadest in the central part. As the snow advances over the dome the crevasses widen and expose sections of dirt-stained snow beneath a clear, white surface layer 4 to 6 feet deep. On passing the crest the ridges between the crevasses crumble and fill the breaks with a confused mass of shattered blocks. This breaking is a characteristic feature of the downstream sides of the domes in the Willis Glacier, although not more noticeable than in many other examples seen, and gives to the lower sides of the elevation the characteristics of ice falls. In none of the crevasses about the domes could the underlying rock be distinguished.

From the behavior of the névé in passing over the domes just described we should expect the upstream sides of the rocks beneath to be rounded and otherwise glaciated, while their downstream faces would be broken and angular. This, as is well known, corresponds with what is frequently seen in glaciated regions. Division Rock, at the present terminus of Willis Glacier, illustrates the character of the bosses which cause the domes now forming such a characteristic feature of the névé region a mile or two above. This rock is worn and rounded on its upstream side, but presents a broken and angular precipice when seen from below.

The grade of the névé portion of the glacier is gentle; in fact, to one standing by its side, in its lower portion, the surface appears almost level, except that it is higher in the middle than at the margins. Below the ice fall just below the lower limit of the névé the descent to the terminus of the glacier above Division Rock is 840 feet, or about 1 foot in 10.

Above the ice fall mentioned above the névé is not only nearly flat for some 2,000 feet, but practically without crevasses. The absence of crevasses in this region is mainly due, no doubt, to the absence of inequalities on the rocky floor beneath, but is in part explained by the fact that the previous winter's snow, forming the surface, conceals the breaks that may exist in the ice beneath.

Below the névé, at the time of my visit, July 30, there was clear ice forming a belt some 500 feet broad, which extended across the glacier and was limited below by the ice fall. In this portion crevasses begin, which at first are narrow, and grow broader and broader as the ice nears the brink of the precipice over which it falls. The first crevasses to be seen are marginal, and trend upstream at angles of about 40° with the shore, but toward their distal extremities they curve downstream. Soon the crevasses from either side meet in the center of the glacier. These long breaks at first have a gentle downstream curvature in the central portion. Nearer and nearer the brink of the fall the crevasses become wider and wider, and at the same time more pronouncedly curved, until the brink of the precipice is reached. The walls of ice there become broken and fall in blocks and fragments of many shapes and sizes into the intervening crevasses. On the brink of the fall there are numerous blades and tower-like pinnacles, from 10 to 15 feet thick and 20 to 30 feet high, which are inclined forward as they pass over the precipice and fall from time to time with a crash.

The most interesting feature of the ice fall is that the surface of the glacier, as the ice approaches the steep descent, rises sharply, as it does in passing over a dome. The backward or upstream slope of the surface of the glacier in the central part, as measured with a clinometer, while on a level with it on the adjacent shore, is between 2° and 2° 30′. The total rise is about 20 feet. This rise of the surface on nearing the brink of the precipice seems to show that a ridge of hard rock there crosses the bed of the glacier. The nature of the rock in the precipice down which the ice descends is revealed at the end of the fall, but whether there is softer rock above it or not was not observed. When the ice passed over Division Rock a rise of the glacier, like that just described, must have occurred, since the surface of the rock slopes downward toward the east, forming an inclined plane, up which the glacier traveled. The inclination of the surface of the rock was not measured, but by estimate is certainly 3° to 5°. The length of the inclined plane now exposed is about 500 feet.

At the ice fall described above the glacier descends precipitously 400 feet. On the face of the fall the crevasses so conspicuous above are closed and the surface slopes sharply downstream, probably at an angle of 6° or 10°, for about 500 feet, and then becomes more gentle. The ice at the base of the fall is evidently strongly compressed. Blue bands at right angles to the flow of the glacier were observed, but a careful study of them was not made. Surface streams are common on this portion of the glacier during midday in summer, but they soon reach crevasses and disappear.

Descending the glacier, one finds that the ice near the terminus is much wasted by melting, surface débris becomes abundant, and in the central portion above Division Rock deep crevasses appear, which are parallel in a general way with the direction of flow. The crevasses indicate that the ice is split on coming in contact with the rock on which it divides.

On reaching Division Rock we found that in the middle of the V formed by the division of the glacier we could step from the ice onto the rock, although at the sides of the rock the ice had melted away so as to form deep gulfs.

Just where the ice divides, a monument of rough stones about 4 feet high was built. This monument is on the top of a small rounded rock dome somewhat detached from the main mass of Division Rock, and records the position of the terminus of the glacier at the center of the V referred to on July 30, 1896. Division Rock, as stated above, rises steeply from the monument to its summit, and is strewn with stones. On its summit there are about ten small evergreen trees, which show that the actual summit was not occupied by the glacier when it was seen by Willis in 1881.

The distance from the monument described above to the brink of the cliff at the summit of which the ice broke off, as observed by Willis, at the date just stated, is about 500 feet. The glacier has retreated this distance during the past fifteen years, but this is not an accurate measure of total recession, since at the time the position of the terminus was first recorded it formed a vertical precipice of ice on the summit of the cliff referred to. In the summer of 1881 the glacier formed an ice cascade at the lower side of Division Rock, but the fallen ice did not reunite below the cliff.

The appearance of Division Rock in the summer of 1885, when the glacier still ended in a precipice at its lower margin, is shown in Pl. LXXXI.

The glacier, after being parted by Division Rock, sends a sloping and rapidly tapering débris-covered tongue of ice down the deep valleys on each side of it. The southern tongue is the larger of the two, and now ends about abreast of the highest portion of the rock.

Upstream from Division Rock the ice rises somewhat steeply, is heavily covered with débris, and so broken by crevasses that it is with difficulty one can climb it. Just above the first sharp rise, and on the right or northern bank of the glacier, there is another bold rock, similar to Division Rock, but close to the border of the canyon. This eminence was formerly covered by the glacier, but has been abandoned sufficiently long to allow forest trees to grow on its summit and northwestern side.

The retreat of the glacier within recent years has been accompanied by a lowering of its surface, as is plainly recorded by fresh-looking ridges of débris along its border. On the northern side of the glacier, for a mile above the fall of 400 feet, there are three well-defined abandoned lateral moraines. The youngest of these, the one nearest the glacier, rises about 50 feet above the ice, and at the fall is about on a level with the pinnacles on its crest. The second moraine is about 40 feet higher

ICE DOMES, NISQUALLY GLACIER.

than the first, and, unlike the more recent one, is partially clothed with small trees; above this again is a thick moraine, the crest of which is lower than that of the second.

Below the 400-foot fall there is an abandoned lateral moraine, probably of the same age as the youngest moraine described above, which is 100 to 120 feet above the glacier. The vertical interval between this moraine and the present surface of the ice increases gradually downstream. This moraine shows a recent recession of the ice, and probably marks a stage in the lowering of its surface, which was determined in the reach between the 400-foot fall and the present terminus by the obstruction made by Division Rock.

There are many other instructive features to be seen on Willis Glacier which would well repay detailed study, but the time available did not enable me to make accurate notes concerning them. It is to be hoped that future travelers will report especially the position of the ice with reference to the monument built on the east end of Division Rock, and, if possible, secure photographs of the glacier from the point of view from which the photograph reproduced in Pl. LXXXI was obtained.

INTERGLACIERS.

I can offer but scanty information concerning the interglaciers about Mount Rainier, as the time available for making the reconnaissance on which this report is based was too short to admit of more than a casual examination of a few of them. That the small glaciers originating on the remnants of the mountain side, between the deep canyons carved by the primary glaciers, however, are of importance in the process of topographic development through which Mount Rainier is passing, is evident from even the hasty observations available.

The type of the interglaciers is furnished by the example from which the generic name is derived. Interglacier, named by E. S. Ingraham, occupies a broad, deep depression on the V-shaped remnant of the eastern slope of the mountain, between Winthrop and Emmons glaciers. The apex of this V-shaped mass is The Wedge, described on a previous page. The glacier receives no snow drainage from the main central dome of Mount Rainier, but is supplied by the snow falling on the V-shaped area referred to. The glacier has deepened its basin by excavation until something of an amphitheater has been formed, the rim of which is the divide between Interglacier and Winthrop Glacier on one side and Emmons Glacier on the other. The rocky ridge separating Interglacier from Winthrop Glacier has been broken at one locality, principally by the lateral erosion of the latter ice stream, so as to form what has been named St. Elmo Pass.

Interglacier flows eastward, but melts away before reaching the valley which Emmons Glacier occupies. The stream formed by its melting is tributary to White River.

The interglacier below Little Tahoma has a broad snow field, below which there is a protrusion of true glacial ice in summer. Instead of descending the slope of the mountain so as to excavate a symmetrical amphitheater, however, this glacier divides and is tributary to Emmons Glacier on the north and to Cowlitz Glacier on the south. The névé to the east of Little Tahoma divides into two branches, in much the same manner as the main névé field about the central dome of the mountain gives origin to primary glaciers. The two small glaciers fed by this snow field have excavated depressions for themselves, leaving a sharp, wedge-like mass of rock at the place of division. On the eastern slope of this secondary V-shaped remnant of the mountain side, left in relief by the cutting away of its borders, there is a small snow field, shown on the accompanying map, which probably has true glacial ice beneath it. Under the tentative system of classification used above for the glaciers about Mount Rainier the little glacier here referred to would belong to a tertiary series. This small nameless glacier demands attention from future travelers, as it supplements in an instructive manner the evidence furnished by the larger glaciers of the topographic development of an isolated peak under the influence of glacial erosion.

As may be seen on consulting the map just referred to, each of the branches of the interglacier to the east of Little Tahoma again subdivides, leaving in each instance at the place of bifurcation a wedge-like rock mass facing toward the névé from which the glaciers have their source. A similar division of glaciers into branches is illustrated on a much larger scale by several of the ice streams on the southwest side of Mount Rainier. In these instances, however, it is probable that rock domes similar to Division Rock at the extremity of Willis Glacier cause the ice streams to divide, and not the increase in the area of the mountain side with distance from its apex.

The information referred to above concerning the topography of the V-shaped area east of Little Tahoma and the existence of a small glacier in that region representing a tertiary series is based entirely on the excellent sketch map forming Pl. LXVI, which is here reproduced, with some slight changes, from a manuscript map prepared by Messrs. H. M. Sarvent and G. F. Evans, of Tacoma, Washington, from surveys made by themselves.

Between Cowlitz and Nisqually glaciers there is another secondary glacier or interglacier known as Paradise Glacier. Other small ice bodies on the sides of Mount Rainier, beginning at about timber line and occupying areas more or less completely inclosed by primary glaciers, may be easily recognized, but to attempt a detailed description of them at this time would be premature.

The interglaciers were formerly much more extensive than now, and much of the beauty of the park-like regions in the neighborhood of the upper limit of timber growth is due to the changes they made in the relief of the mountain side, both by rounding and smoothing the rocks over which they flowed and by heaping moraines upon them. Many of

END OF NISQUALLY GLACIER.

the crags and pinnacles which give diversity to the scenery on the steep mountain slopes, like the Guardian Rocks near Spray Park, Gibraltar and the numerous crests near it, and other similar crags in Henry's Hunting Ground, etc., are remnants spared by the glaciers which once enveloped nearly the entire surface of the mountain, but still in their deeper portions flowed in most instances in well-defined channels.

RECESSION AND SHRINKAGE OF THE GLACIERS.

Every glacier about Mount Rainier that was examined by the writer furnished evidence of a recent recession of its terminus and of a lowering of its surface. In two instances—the Carbon and Willis glaciers—rough measurements of the amount of these changes during the past fifteen years were obtained.

A recent recession of the extremities of the glaciers is shown by barren areas below them on which vegetation is advancing. All of the primary glaciers extend below timber line, and in a climate like that of the region about Mount Rainier any area where there is sufficient soil soon becomes covered with young trees. The barren area about the ends of the glacier may in part be accounted for by the fact that the streams from the glaciers shift their positions from time to time and sweep away the earth in their courses or make deposits of bowlders and stones; but about the extremity of each glacier there are areas not thus affected which are similar in soil conditions to adjacent areas on which large trees are growing. The forests are advancing on the barren areas and gradually taking possession of them. This evidence, even if actual observations of the recession of the extremities of the glaciers were not available, is sufficient to show that the ice streams have for a number of years been growing shorter and shorter.

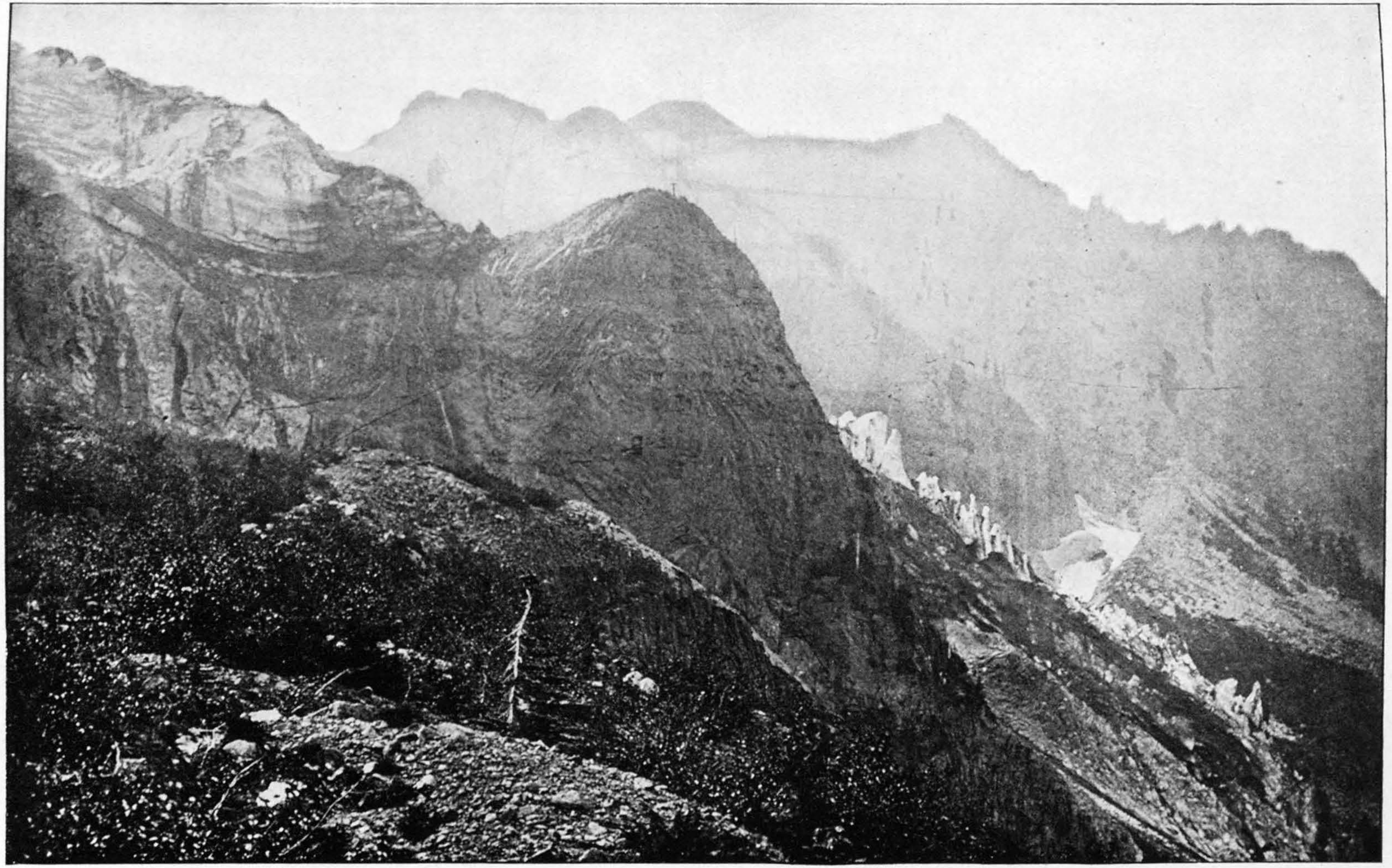
The fact that abandoned lateral moraines bordering the glaciers below their névé fields are in many instances not yet clothed with vegetation, while older moraines of a similar character are forest covered, is evidence that their surfaces have been recently lowered. The elevation of the crests of these recently abandoned lateral moraines above the surface of the glacier that they border is least, or perhaps not at all, noticeable just below the lower borders of the névés, and becomes progressively greater and greater downstream. The lowering of the surfaces of the glaciers is due largely to surface melting. This leads to a concentration of englacial débris at the surface. For this reason the lower portions of the glaciers are almost always heavily covered with stones and earth. As the superficial débris increases in thickness it affords greater and greater protection to the ice beneath, and surface melting is correspondingly retarded. The influence of climate on the melting of the glaciers is thus counteracted to a marked degree. While in the case of glaciers that are free of morainal material or but lightly loaded surface melting would be in excess of subsurface melting, it is apparent that in the case of heavily moraine-covered ice bodies the rate of melting is greatest below the surface portion. The subsurface melting is apparently due to the descent of surface streams into crevasses and moulins and to the heat furnished by streams from the adjacent land which flow through englacial or subglacial tunnels.

The marked recession and shrinkage in progress in the case of the glaciers on Mount Rainier is evidence of a climatic change which is accompanied either by a decrease in the snowfall or by an increase in the mean annual melting, or, what is more probable, of both. Whether the recession and surface lowering of the glaciers is a continuous process or is varied by minor periods of advance and rise of the surface is not known. Judging by what has been observed in the case of the glaciers of the Alps, however, it is to be expected that the glaciers about Mount Rainier will be found to pulsate, as it were—that is, their extremities, although in process of retreat when a period of ten or twenty years is considered, will be found to alternately advance and retreat when smaller periods of time are considered, the algebraic sum of the fluctuations being in the direction of recession. It is for the purpose of obtaining more detailed information in reference to the fluctuations of the glaciers that records of the positions occupied by their extremities, suggested in a preceding page, are desired.

The rapid recession and marked lowering of the surfaces of the glaciers about Mount Rainier is not peculiar to that system of ice streams, but is shared by all of the glaciers of the west coast of North America, with but one known exception. In no instance have the minor fluctuations of the glaciers referred to been observed, but the fact of a general retreat of the extremities of the glaciers, from those in the High Sierra of California to western Alaska, is well known.[1] Not only are the glaciers of the Cordilleran region of North America undergoing a gradual decrease, but all others in the northern hemisphere, with the possible exception of those of Greenland and adjacent regions, are likewise shrinking back into the higher portions of the mountains from which they flow, although in some instances exhibiting local advances.

The recession of the glaciers referred to is evidence that a climatic change has been in progress for at least a score of years, and probably for over a century, which is unfavorable to the existence of perennial ice. Evidently the mean annual snowfall is becoming less, the mean summer temperature greater, the prevalence of clouds and fogs in the summer season decreasing, or a combination of these changes in conditions throughout the entire northern hemisphere is leading, on an average, to an excess of melting over snow accumulation. Observations on the fluctuations of the extremities of the glaciers about Mount Rainier thus have increased interest because these fluctuations form a part of a series of changes which is affecting probably the entire earth. The study of the climatic changes indicated by the fluc-

[1] I. C. Russell, Glaciers of North America, Ginn & Co., Boston, 1897, pp. 146–159.



DIVISION ROCK, WILLIS GLACIER.

tuations of existing glaciers has a still wider bearing, as it may be expected to throw light on the much-discussed problem of the cause of the cold of the Glacial period.

RÉSUMÉ.

Mount Rainier is a typical example of a lofty volcanic cone built largely of projectiles, but containing also many lava streams. It belongs with the class of volcanic mountains known as composite cones.

At one time the mountain was more lofty than it now is, its reduction in height being due to an explosive eruption which blew away the upper 2,000 feet of the original cone, leaving a great crater in the truncated remnant. After the loss of its summit the mountain was not symmetrical; the rim of its great summit crater was highest on the west, and lowest and probably breached on the eastward side.

At a more recent date two smaller craters were formed by mild explosive eruptions within the great crater and nearly filled it. The building of these secondary craters partially restored the symmetrical outline of the top of the mountain, but gave to it a dome-shaped instead of a conical summit. Whether glaciers were formed on the mountain previous to its truncation, or appeared only after that event, is unknown.

There is no evidence to show that the higher portion of the mountain was exposed to stream erosion previous to the gathering of perennial snows and the formation of glaciers. Broad névé fields were formed about the sides of the mountain, and extended from the summit far down its sides. The lower limit of the snow fields fluctuated with climatic changes, which also caused many variations in the size and extent of the glaciers flowing from them. The descending névé, on spreading as the area to be covered increased with decrease of elevation, became divided and gave origin to primary glaciers which carved deep canyons in the middle slope of the mountain. The backward cutting of the heads of the canyons led to the excavation of more or less well-defined amphitheaters.

Below the extremities of the primary glaciers the rivers formed by the melting ice carved deep canyons, not only in the lower slopes of the mountain, but in the platform or plateau on which it is situated.

Secondary glaciers, originating on the interspaces between the primary glaciers, excavated depressions, the rims of which now stand as ridges and peaks about the middle slopes of the main mountain mass.

The modifications in the general history due to a great extension of the glaciers during the Glacial epoch remain to be studied. All of the glaciers about Mount Rainier are receding and shrinking within the valley walls that confine them. Evidence of a marked climatic change unfavorable to the existence of perennial ice is thus indicated, which is in harmony with similar evidence furnished by nearly all the known glaciers of the northern hemisphere.

WASHINGTON NATIONAL PARK.

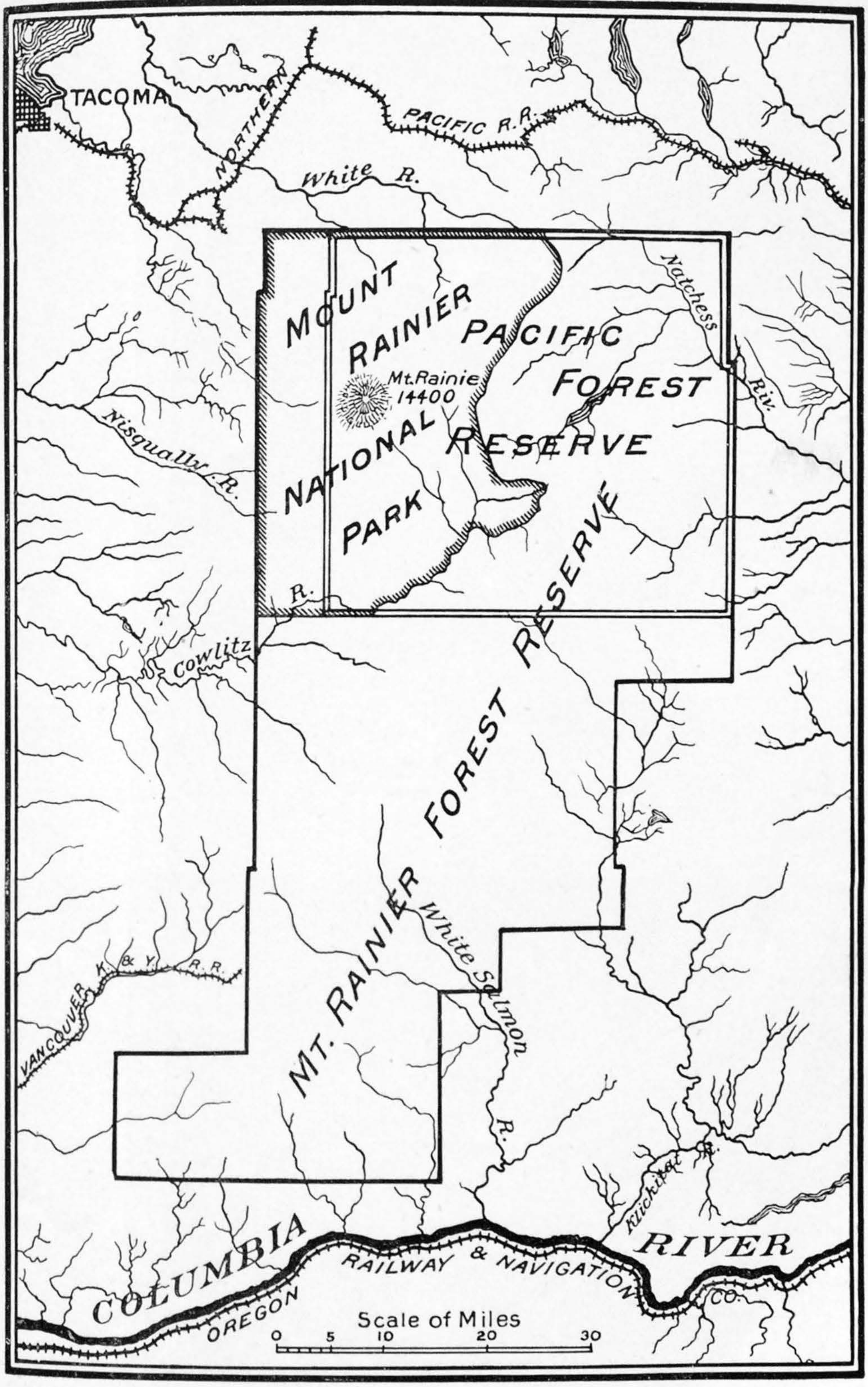
The magnificence of Mount Rainier and the wonderful beauty of the region immediately surrounding it have led to an earnest desire on the part of nearly all who are familiar with the Puget Sound country and are considerate of the future welfare of the State of Washington to have the mountain and its environs reserved in a state of nature as a national park.

Not only is the setting aside of the proposed park thought desirable on what may be considered æsthetic grounds—as the preservation of a tract of primitive forest from the inroads of lumbermen and from fires kindled through carelessness or with a ruthless desire to destroy may be termed—but students of forestry see clearly that to preserve the natural vegetation about Mount Rainier means a check on the floods in the river flowing from the mountain and a lessening of the danger from inundations in the thickly settled valleys leading to Puget Sound and Columbia River.

In 1893, by proclamation of President Cleveland, a rectangular tract of land, indicated on the map forming Pl. LXXXII, about 35 miles square, and including Mount Rainier in its western portion, was made a forest reserve. As may be seen from the map, more than half of this reserve lies east of the crest of the Cascade Mountains. Owing to a mistake due to the imperfection of the maps available, the western boundary of the reserve was made a north-south line passing only about 3½ miles west of the summit of Mount Rainier, and thus leaving much of the western slope of the mountain, including some of its snow fields and glaciers, outside of the protected area. To correct this mistake, and also in order to secure more complete protection for the region about Mount Rainier, a bill was introduced in Congress on June 11, 1896 (H. R. No. 4058), for the purpose of creating a national park, to be known as the "Washington National Park," which should include an area about 25 miles square, of which the summit of Mount Rainier would be about the central point. The boundaries of this proposed park are also shown on Pl. LXXXII.

Owing to the precedence of other business, the bill referred to did not come up for action in 1896, but before the close of the last session of the Fifty-fourth Congress it was passed—too late, however, to receive the President's signature.

The movement toward making the region about Mount Rainier a national park has attracted much attention and received the hearty support of many persons, among whom are those best qualified to judge of the desirability of preventing the region referred to from passing into the ownership of individuals or corporations. In order to indicate to the reader the widespread interest that has been awakened in this project, and to present additional information concerning the region to be included in the proposed park, I can not do better



MAP SHOWING POSITION OF PROPOSED MOUNT RAINIER FOREST RESERVE AND MOUNT RAINIER NATIONAL PARK.

than append here a memorial from committees appointed by several of the scientific societies of the United States, which was presented to the United States Senate by Senator Squire on July 16, 1894.[1] This memorial reads as follows:

To the Senate and House of Representatives of the United States of America in Congress assembled:

At a meeting of the Geological Society of America, in Madison, Wis., August 15, 1893, a committee was appointed for the purpose of memorializing the Congress in relation to the establishment of a national park in the State of Washington to include Mount Rainier, often called Mount Tacoma. The committee consists of Dr. David T. Day, Mr. S. F. Emmons, and Mr. Bailey Willis.

At a meeting of the American Association for the Advancement of Science, in Madison, Wis., August 21, 1893, a committee was appointed by that body for the same purpose as above mentioned, consisting of Maj. J. W. Powell, Prof. Joseph Le Conte, Prof. I. C. Russell, Mr. B. E. Fernow, and Dr. C. H. Merriam.

At a meeting of the National Geographic Society, held in Washington, D. C., on October 13, 1893, there was appointed a committee for the purpose above mentioned, consisting of Hon. Gardiner G. Hubbard, Hon. Watson C. Squire, Mr. John W. Thompson, Miss Mary F. Waite, and Miss Eliza R. Scidmore.

At a meeting of the Sierra Club, held in San Francisco December 30, 1893, a committee for the same purpose was appointed, composed of Mr. John Muir, President D. S. Jordon, Mr. R. M. Johnson, Mr. George B. Bayley, Mr. P. B. Van Trump.

At a meeting of the Appalachian Mountain Club, held in Boston April 11, 1894, a similar committee was appointed, consisting of Mr. John Ritchie, jr., Rev. E. C. Smith, Dr. Charles E. Fay.

The committees thus appointed were instructed by the several bodies to which they belong to cooperate in the preparation of a memorial to Congress, setting forth the substantial reasons for the establishment of such park.

Pursuant to their instructions, the committees present the following memorial to the Congress, and pray that such action may be taken by the honorable Senators and Representatives as will secure to the people of the United States the benefits of a national park which shall include the area mentioned above. In support of their prayer they beg to submit the following statement:

By proclamation of the President, in compliance with the statutes provided therefor, a Pacific Forest Reserve has been established in the State of Washington, the western portion of which is nearly coincident with the tract of land to be included in the national park for which your memorialists pray.

The western part of this reserve includes many features of unique interest and wonderful grandeur, which fit it peculiarly to be a national park, forever set aside for the pleasure and instruction of the people. The region is one of such exceptional rainfall and snowfall that the preservation of its forests is of unusual importance as a protection against floods in the lower valleys; but the scenic features, which mark it out for a national park, attract tourists, who set fire to the timber. This destruction goes on notwithstanding it is a forest reserve, and will continue until protection is afforded by adequate supervision of the area, whether as a reserve or park.

GENERAL DESCRIPTION.

The reserve is traversed through the middle from north to south by the crest of the Cascade Range, which has an elevation varying from 5,300 to 6,800 feet. This is the divide between tributaries of Puget Sound, flowing west, and those of Yakima River, flowing east. Mount Rainier, the isolated volcanic peak, 14,400 feet high, stands 12 miles west of the divide, from which it is separated by a deep valley.

[1] Senate Mis. Doc. No. 247, Fifty-third Congress, second session.

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At a meeting of the Appalachian Mountain Club, held in Boston April 11, 1894, a similar committee was appointed, consisting of Mr. John Ritchie, jr., Rev. E. C. Smith, Dr. Charles E. Fay.

The committees thus appointed were instructed by the several bodies to which they belong to cooperate in the preparation of a memorial to Congress, setting forth the substantial reasons for the establishment of such park.

Pursuant to their instructions, the committees present the following memorial to the Congress, and pray that such action may be taken by the honorable Senators and Representatives as will secure to the people of the United States the benefits of a national park which shall include the area mentioned above. In support of their prayer they beg to submit the following statement:

By proclamation of the President, in compliance with the statutes provided therefor, a Pacific Forest Reserve has been established in the State of Washington, the western portion of which is nearly coincident with the tract of land to be included in the national park for which your memorialists pray.

The western part of this reserve includes many features of unique interest and wonderful grandeur, which fit it peculiarly to be a national park, forever set aside for the pleasure and instruction of the people. The region is one of such exceptional rainfall and snowfall that the preservation of its forests is of unusual importance as a protection against floods in the lower valleys; but the scenic features, which mark it out for a national park, attract tourists, who set fire to the timber. This destruction goes on notwithstanding it is a forest reserve, and will continue until protection is afforded by adequate supervision of the area, whether as a reserve or park.

GENERAL DESCRIPTION.

The reserve is traversed through the middle from north to south by the crest cf the Cascade Range, which has an elevation varying from 5,300 to 6,800 feet. This is the divide between tributaries of Puget Sound, flowing west, and those of Yakima River, flowing east. Mount Rainier, the isolated volcanic peak, 14,400 feet high, stands 12 miles west of the divide, from which it is separated by a deep valley.

[1] Senate Mis. Doc. No. 247, Fifty-third Congress, second session.

The eastern half of the reserve differs from the western in climate, in flora, and in fauna, in geographic and geologic features, and in aspects of scenery. The eastern slope of the Cascade Range within the reserve is a mountainous region, with summits rising to a general elevation of 6,500 to 7,600 feet above the sea. It is forest covered and presents many attractions to the tourist and hunter; but it is not peculiar among the mountain regions of America either for grandeur or interest, and it is not an essential part of the area to be set apart as a national park.

The western slope of the Cascades within the reserve is short and steep as compared with the eastern. Much of it is precipitous, particularly opposite Mount Rainier, where its bare walls would appear most grand were they not in the shadow of that overpowering peak. North and south of Rainier this slope is more gradual and densely wooded.

The western half of the Pacific reserve, that portion which it is proposed shall be made a national park, is characterized by Mount Rainier, whose summit is but 4 miles from the western boundary of the reserve and whose glaciers extend beyond its limits.

Mount Tacoma is not simply a volcanic cone, peculiar for its hugeness. It was formerly a vast volcanic dome, 30 miles in radius to the north, west, and south; but rivers have cut deep canyons, glaciers have carved ample amphitheaters back into the mass, and now many serrate ridges rising from a few hundred to 10,000 feet above the sea converge at that altitude to support the central pyramid, which towers more than 4,000 feet above its base.

This grand mountain is not, like Mount Blanc, merely the dominant peak of a chain of snow mountains; it is the only snow peak in view, Mount St. Helens and Mount Adams being, like it, isolated and many miles distant. Rainier is majestic in its isolation, reaching 6,000 to 8,000 feet above its neighbors. It is superb in its boldness, rising from one canyon 11,000 feet in 7 miles. Not only is it the grandest mountain in this country, it is one of the grand mountains of the world, to be named with St. Elias, Fusiyama, and Ararat, and the most superb summits of the Alps. Eminent scientists of England and Germany, who, as members of the Alpine Club of Switzerland and travelers of wide experience, would naturally be conservative in their judgment, have borne witness to the majesty of the scenery about Rainier.

In 1883 Professor Zittel, a well-known German geologist, and Prof. James Bryce, member of Parliament and author of the American Commonwealth, made a report on the scenery about Mount Rainier. Among other things, they said:

"The scenery of Mount Rainier is of rare and varied beauty. The peak itself is as noble a mountain as we have ever seen in its lines and structure. The glaciers which descend from its snow fields present all the characteristic features of those in the Alps, and though less extensive than the ice streams of the Mount Blanc or Monta Rosa groups are in their crevasses and serracs equally striking and equally worthy of close study. We have seen nothing more beautiful in Switzerland or Tyrol, in Norway or in the Pyrenees, than the Carbon River glaciers and the great Puyallup glaciers; indeed, the ice in the latter is unusually pure, and the crevasses unusually fine. The combination of ice scenery with woodland scenery of the grandest type is to be found nowhere in the Old World, unless it be in the Himalayas, and, so far as we know, nowhere else on the American Continent."

These eminent and experienced observers further say:

"We may perhaps be permitted to express a hope that the suggestion will at no distant date be made to Congress that Mount Rainier should, like the Yosemite Valley and the geyser region of the Upper Yellowstone, be reserved by the Federal Government and treated as a national park."

But Mount Tacoma is single not merely because it is superbly majestic; it is an arctic island in a temperate zone. In a bygone age an arctic climate prevailed over the Northwest, and glaciers covered the Cascade Range. Arctic animals and arctic plants then lived throughout the region. As the climate became milder and glaciers melted, the creatures of the cold climate were limited in their geographic range to the districts of the shrinking glaciers. On the great peak the glaciers linger still. They give to it its greatest beauty. They are themselves magnificent, and with them survives a colony of arctic animals and plants which can not exist in the temperate climate of the less lofty mountains. These arctic forms are as effectually isolated as shipwrecked sailors on an island in mid-ocean. There is no refuge for them beyond their haunts on ice-bound cliffs. But even there the birds and animals are no longer safe from the keen sportsman, and the few survivors must soon be exterminated unless protected by the Government in a national park.

ECONOMIC RESOURCES.

The area of the Pacific forest reserve includes valuable timber and important water supplies. It is said to contain coal, gold, and silver.

The timber on the western slope differs from that on the eastern in size and density of growth and in kinds of trees. The forests of Puget Sound are world-renowned for the magnitude and beauty of their hemlocks, cedars, and firs. Their timber constitutes one of the most important resources of the State. Nowhere are they more luxuriant than on the foothills west and north of Mount Rainier. But their value as timber is there subordinate to their value as regulators of floods. The Puyallup River, whose lower valley is a rich hop garden, is even now subject to floods during the rapid melting of the snow on Mount Rainier in the limited area above timber line. In the broader area below timber line, but above 3,000 feet in elevation, the depth of snow in the winter of 1893 was 9 to 15 feet. Protected by the dense canopy of the fir and hemlock trees this snow melts slowly and the river is high from March to June. But let the forest be once destroyed by fire or by lumbermen and the snows of each winter, melting in early spring, will annually overwhelm the Puyallup Valley and transform it into a gravelly waste. The same is true of White River and the Nisqually.

The forests of the eastern slope, tributary to the Yakima, are of even greater importance as water preservers. They constitute a great reservoir, holding back the precipitation of the wet season and allowing it to filter down when most needed by crops. In the Yakima Valley water gives to land its value. Storage of flood waters and extensive distribution by canals is necessary. The forests being preserved to control the water, the natural storage basins should be improved and canals built. For these reasons it is most important that no part of the forest reserve should be sacrificed, even though the eastern half is not included in the national park.

The boundaries of the proposed national park have been so drawn as to exclude from its area all lands upon which coal, gold, or other valuable minerals are supposed to occur, and they conform to the purpose that the park shall include all features of peculiar scenic beauty without encroaching on the interests of miners or settlers.

ACCESSIBILITY.

None save those who can march and camp in the primeval forest can now visit Mount Rainier; but it is the wilderness, not the distance, that makes it difficult of approach. On the west the distance up the Nisqually River from the railroad at Yelm Prairie to the reserve is but 40 miles. Though heavily timbered, the valley of the Nisqually affords an easy route for a railroad. The Cowlitz Valley also offers a line of approach without difficulty by rail, it being about 50 miles from the railroad to the reserve.

On the northwest the railroad at Wilkeson is but 23 miles from the summit of Mount Rainier, and the glaciers can be reached by riding 25 miles through the great forest.

On the north the Cascade branch of the Northern Pacific Railroad crosses the range, only 13 miles in a direct line and 19 miles along the summit from the northern limit of the reserve.

On the east the city of North Yakima is but 62 miles from the summit of Mount Rainier.

The proposed park covers a mountain region which lies across the line of travel from east to west. The railroad winds northward; the travel down the Columbia River turns southward to avoid it. The great current of tourists which flows north and south through Portland, Tacoma, Seattle, Vancouver, and Alaska passes to the west within sight of Mount Rainier, and when the grand old mountain is obscured by clouds the travelers linger to see it, or, passing regretfully on their way, know that they have missed the finest view of their trip.

When a railroad is built up the Nisqually or Cowlitz Valley to the park and connection by stages is assured northward to the Cascade branch of the Northern Pacific Railroad and eastward to Yakima, the flood of travel will be diverted through the park.

ROUTES WITHIN THE RESERVE.

The point which combines accessibility with surroundings of great beauty, and which is therefore most appropriate as a hotel site, is southeast of Mount Rainier, on one of the spurs of the Tootoosh Mountains, near the Cowlitz Valley. To open this region to travel it would be sufficient to establish the hotel and its connections down the Nisqually or Cowlitz Valley, together with trails to points of interest within the park. From the hotel a principal trail would extend north to the Emmons and White River glaciers, which would thus be easily accessible, and thence the railroad at Wilkeson could readily be reached on horseback over the old Northern Pacific trail. In the future, stage roads, or possibly a railroad, would be extended over the Cowlitz Pass to the eastern slope, North Yakima would be reached via the Tieton or Tannum Valley, and Tannum Lake would become a favorite resort.

But the highway which would challenge the world for its equal in grand scenery would extend from the Cowlitz Pass northward along the crest of the range to the Cascade branch. The distance is 50 miles, 31 in the park and 19 beyond it to the railroad. Within the reserve the summit is open and park-like. On the east is a sea of mountains; on the west is a bold descent of 3,000 feet to the valleys of Cowlitz and White rivers, beyond which Tacoma rises in overpowering grandeur, 8,000 feet above the road and only 12 miles distant.

CONCLUSION.

A committee of your memorialists has carefully examined the existing maps of the State of Washington with special reference to the position of this reserve, and finds that the boundaries of the reserve are farther east, in relation to Mount Rainier, than was supposed. The western boundary traverses the slope of Mount Rainier at altitudes of 7,000 to 9,000 feet, and the glaciers extend several miles beyond it. In order to include all of the glacial area and the immediately adjacent forest on the west, your memorialists respectfully recommend that the western boundary of the park be drawn one range west of that of the reserve, viz, at the range line between ranges 6 and 7 east of the Willamette meridian. By this change no part of the Wilkeson-Carbonado coal field would be included in the park.

Your memorialists find, as already stated, that it is not necessary to include the eastern slope of the Cascades in the park, and furthermore that it is desirable to leave the Natchez Pass on the north and the Cowlitz Pass on the south open for the construction of railroads. Your memorialists therefore pray that the park be defined by the following boundaries: Beginning at the northwest corner of sec. 19, T. 18 N., R. 7 E. of the Willamette meridian; thence south 24 miles more or less to the south west corner of sec. 18, T. 14 N., R. 7 E.; thence east 27 miles more or less to the summit of the Cascade Range; thence in a northerly direction to a point east of the place of beginning, and thence west 26 miles more or less to the place of beginning.

Your memorialists respectfully represent that—

Railroad lines have been surveyed and after the establishment of a national park would soon be built to its boundaries. The concessions for a hotel, stopping places, and stage routes could be leased and the proceeds devoted to the maintenance of the park. The policing of the park could be performed from the barracks at Vancouver by details of soldiers, who would thus be given useful and healthful employment from May to October.

The establishment of a hotel would afford opportunity for a weather station, which, in view of the controlling influence exerted by Mount Rainier on the moisture-laden winds from the Pacific, would be important in relation to local weather predictions.

Your memorialists further represent that this region of marvelous beauty is even now being seriously marred by careless camping parties. Its valuable forests and rare animals are being injured and will certainly be destroyed unless the forest reserve be policed during the camping seasons. But efficient protection of the undeveloped wilderness is extraordinarily difficult and in this case practically impossible.

Therefore, for the preservation of the property of the United States, for the protection from floods of the people of Washington in the Yakima, Cowlitz, Nisqually, Puyallup, and White River valleys, and for the pleasure and education of the nation, your memorialists pray that the area above described be declared a national park forever.

For the National Geographic Society:

GARDINER G. HUBBARD,
President.

For the American Association for the Advancement of Science:

J. W. POWELL.

For the Geological Society of America:

BAILEY WILLIS.

For the Sierra Club:

JOHN MUIR.

For the Appalachian Mountain Club:

JOHN RITCHIE, Jr.

WASHINGTON, D. C., *June 27, 1894.*