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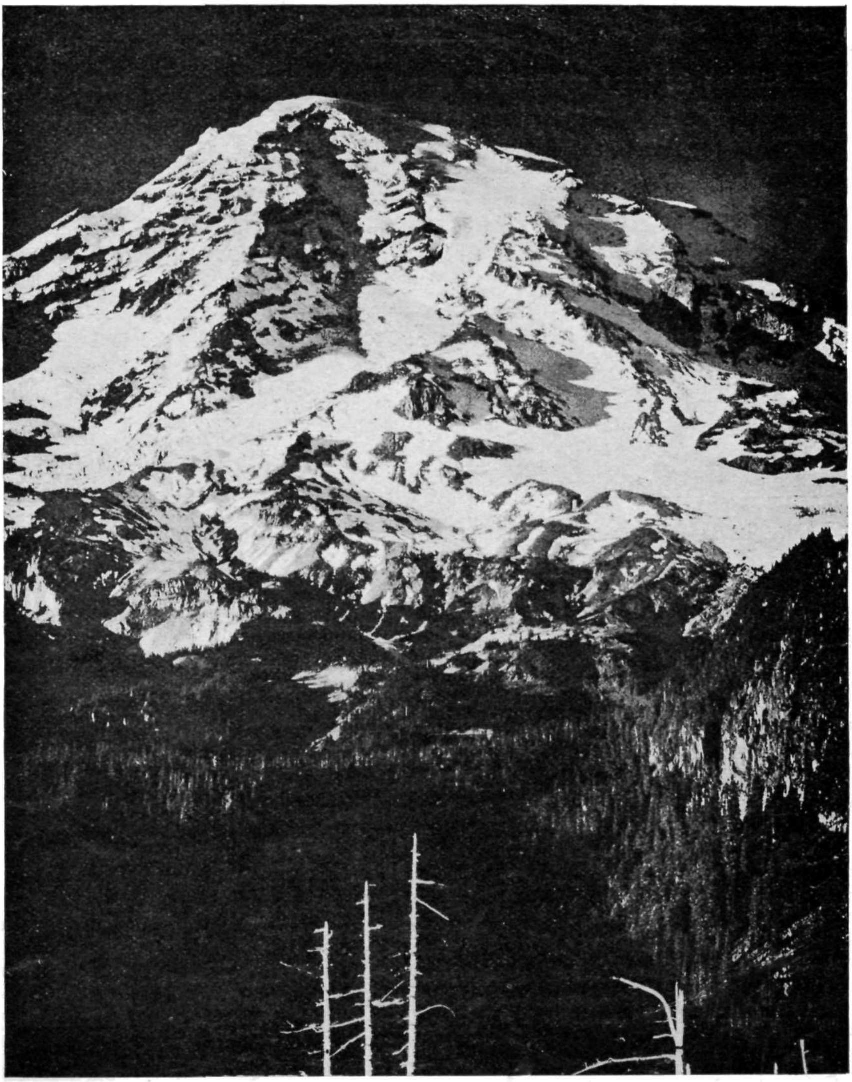
MOUNT RAINIER AND ITS GLACIERS

MOUNT RAINIER NATIONAL PARK



UNITED STATES
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MOUNT RAINIER AND ITS GLACIERS.[1]

By F. E. Matthes, *United States Geological Survey.*

INTRODUCTION.

The impression still prevails in many quarters that true glaciers, such as are found in the Swiss Alps, do not exist within the confines of the United States, and that to behold one of these rare scenic features one must go to Switzerland, or else to the less accessible Canadian Rockies or the inhospitable Alaskan coast. As a matter of fact, permanent bodies of snow and ice, large enough to deserve the name of glaciers, occur on many of our western mountain chains, notably in the Rocky Mountains, where a national reservation—Glacier National Park—is named for its ice fields; in the Sierra Nevada of California, and farther north, in the Cascade Range. It is on the last-named mountain chain that glaciers especially abound, clustering as a rule in groups about the higher summits of the crest. But this range also supports a series of huge, extinct volcanoes that tower high above its sky line in the form of isolated cones. On these the snows lie deepest and the glaciers reach their grandest development. Ice clad from head to foot the year round, these giant peaks have become known the country over as the noblest landmarks of the Pacific Northwest. Foremost among them are Mount Shasta, in California (14,162 feet); Mount Hood, in Oregon (11,225 feet); Mount St. Helens (9,697 feet), Mount Adams (12,307 feet), Mount Rainier (14,408 feet), and Mount Baker (10,730 feet), in the State of Washington.

Easily king of all is Mount Rainier. Almost 250 feet higher than Mount Shasta, its nearest rival in grandeur and in mass, it is overwhelmingly impressive, both by the vastness of its glacial mantle and by the striking sculpture of its cliffs. The total area of its glaciers amounts to no less than 45 square miles, an expanse of ice far exceeding that of any other single peak in the United States. Many of its individual ice streams are between 4 and 6 miles long and vie

[1] Many of the illustrations in this article were furnished by Messrs. Asahel Curtis, G. V. Caesar, A. H. Barnes, L. G. Linkletter, and T. H. Martin and the Seattle-Tacoma Rainier National Park Committee. The names of the photographers are given below the illustrations, but the department desires to make a general acknowledgment of the courtesy of these gentlemen in making this material available.—Editor.

in magnitude and in splendor with the most boasted glaciers of the Alps. Cascading from the summit in all directions, they radiate like the arms of a great starfish. (See map, p. 24.) All reach down to the foot of the mountain and some advance considerably beyond.

As for the plea that these glaciers lie in a scarcely opened, out-of-the-way region, a forbidding wilderness as compared with maturely civilized Switzerland, it no longer has the force it once possessed. Rainier's ice fields can now be reached from Seattle or Tacoma, the two principal cities of western Washington, in a few hours' journeying, either by rail or by automobile. The cooling sight of crevassed glaciers and the exhilarating flower-scented air of alpine meadows need no longer be exclusive pleasures, to be gained only by a trip abroad.

LOCATION OF MOUNT RAINIER.

Mount Rainier stands on the west edge of the Cascade Range, overlooking the lowlands that stretch to Puget Sound. Seen from Seattle or Tacoma, 60 and 50 miles distant, respectively, it appears to rise directly from sea level, so insignificant seem the ridges about its base. Yet these ridges themselves are of no mean height. They rise 3,000 to 4,000 feet above the valleys that cut through them, and their crests average 6,000 feet in altitude. Thus at the southwest entrance of the park, in the Nisqually Valley, the elevation above sea level, as determined by accurate spirit leveling, is 2,003 feet, while Mount Wow (Goat Mountain), immediately to the north, rises to an altitude of 6,045 feet. But so colossal are the proportions of the great volcano that they dwarf even mountains of this size and give them the appearance of mere foothills. An excellent idea of Rainier's overshadowing bulk may be gained from figure 1, which shows a vertical section through its cone and through the Tatoosh Range. This section, it should be understood, is free from vertical exaggeration, and is based upon accurate trigonometric data obtained by the United States Geological Survey in the course of its topographic surveys of the Mount Rainier National Park. The point chosen on the Tatoosh Range is Pinnacle Peak, one of the higher summits, 6,562 feet in altitude. That peak rises nearly 4,000 feet above the Nisqually River, which at Longmire has an elevation of 2,700 feet, yet it will be seen that Mount Rainier towers still 7,846 feet higher than Pinnacle Peak.

From the top of the volcano one fairly looks down upon the Tatoosh Range, to the south; upon Mount Wow, to the southwest; upon the Mother Mountains, to the northwest, indeed, upon all the ridges of the Cascade Range. Only Mount Adams, Mount St. Helens, and Mount Hood loom like solitary peaks above the even sky line (fig. 2), while the ridges below this line seem to melt together in one vast, continuous mountain platform. And such a

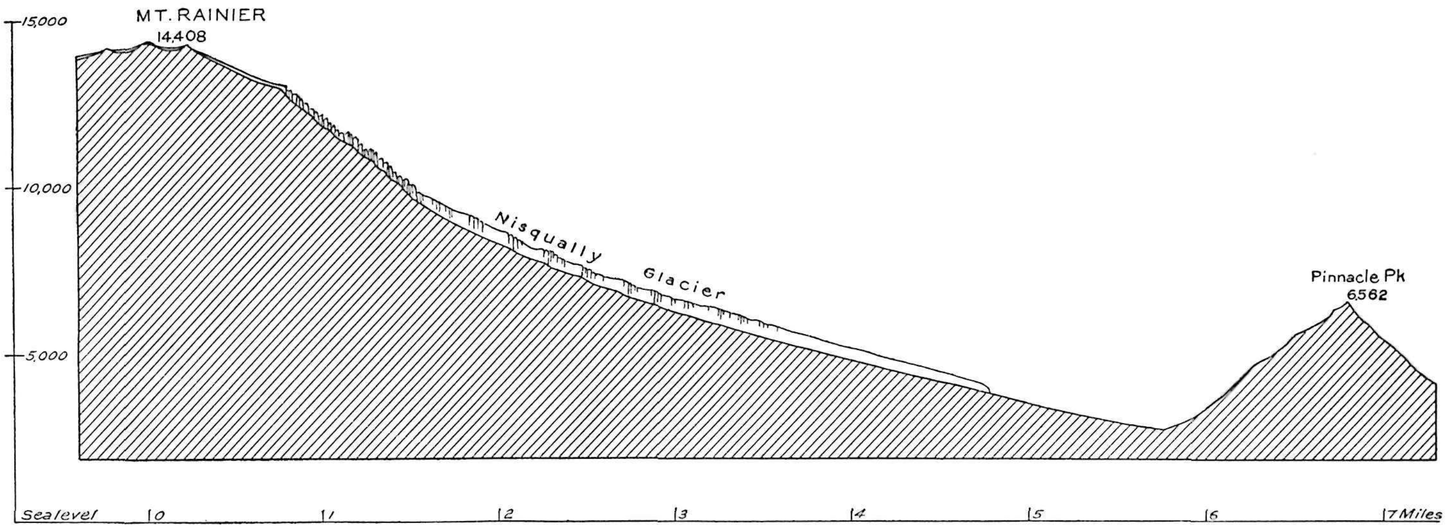


FIG. 1.—THE CONE OF MOUNT RAINIER AND THE TATOOSH RANGE, IN CROSS SECTION. THIS DRAWING IS BASED UPON ACCURATE TRIGONOMETRIC DATA AND IS FREE FROM VERTICAL EXAGGERATION.

FIG. 2.—THE EVEN SKY LINE OF THE CASCADE RANGE AND THE CONE OF MOUNT ADAMS, AS SEEN FROM THE BASE OF MOUNT RAINIER.
Photo by Linkletter.

platform, indeed, one should conceive the Cascade Range once to have been. Only it is now thoroughly dissected by profound, ramifying valleys, and has been resolved into a sea of wavelike crests and peaks.

THE CONE OF MOUNT RAINIER.

Mount Rainier stands, in round numbers, 10,000 feet high above its immediate base, and covers 100 square miles of territory, or one-third of the area of Mount Rainier National Park. In shape it is not a simple cone tapering to a slender, pointed summit like Fuji Yama, the great volcano of Japan. It is, rather, a broadly truncated mass resembling an enormous tree stump with spreading base and irregularly broken top. Its life history has been a varied one. Like all volcanoes, Rainier has built up its cone with the materials ejected by its own eruptions—with cinders and bombs (steam-shredded particles and lumps of lava), and with occasional flows of liquid lava that have solidified into layers of hard, basaltic rock. At one time it attained an altitude of not less than 16,000 feet, if one may judge by the steep inclination of the lava and cinder layers visible in its flanks. Then a great explosion followed that destroyed the top part of the mountain, and reduced its height by some 2,000 feet. The volcano was left beheaded, and with a capacious hollow crater, surrounded by a jagged rim.

Later on this great cavity, which measured nearly 2 miles across, from south to north, was filled by two small cinder cones. Successive feeble eruptions added to their height until at last they formed together a low, rounded dome—the eminence that now constitutes the mountain's summit. It rises only about 400 feet above the rim of the old crater, and is an inconspicuous feature, not readily identifiable from all sides as the highest point. (See fig. 21, p. 41.) In fact, so broad is the mountain's crown that from no point at its base can one see the top. The higher portions of the old crater rim, moreover, rise to elevations within a few hundred feet of the summit, and, especially when viewed from below, stand out boldly as separate peaks that mask and seem to overshadow the central dome. Especially prominent are Point Success (14,150 feet) on the southwest side, and Liberty Cap (14,112 feet) on the northwest side.

The altitude of the main summit was for many years in doubt. Several figures had been announced from time to time, no two of them in agreement; but all of these, it is to be observed, were obtained by more or less approximate methods. In 1913 the United States Geological Survey, in connection with its topographic surveys of the Mount Rainier National Park, was able to make a new series of measurements by triangulation methods at close range. These give the peak an elevation of 14,408 feet, thus placing it near the top of the list of high summits of the United States. This last figure, it should be added, is not likely to be in error by more than a foot or two and may with some confidence be regarded as final. Greater exactness of determination is scarcely practicable in the case of Mount Rainier, as its highest summit consists actually of a mound of snow the height of which naturally varies somewhat with the seasons and from year to year.

This crowning snow mound, which was once supposed to be the highest point in the United States, still bears the proud name of Columbia Crest. It is essentially a huge snowdrift or snow dune (fig. 4), heaped up by the westerly winds. Driving furiously up through the great breach in the west flank of the mountain, between Point Success and Liberty Cap, they eddy lightly as they shoot over the summit and there deposit their load of snow.

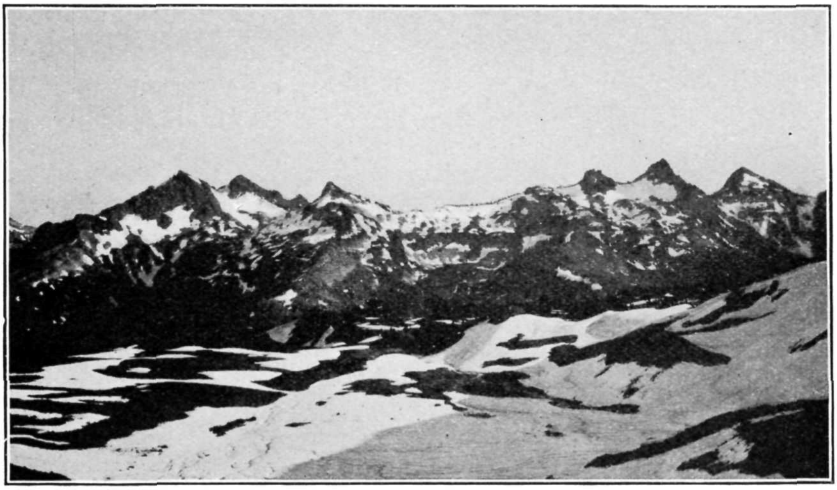


FIG. 3.—THE TATOOSH RANGE, FROM PARADISE GLACIER.

Photo by Matthes.

The drift is situated at the point where the rims of the two summit craters touch, and represents the only permanent snow mass on these rims, for some of the internal heat of the volcano still remains and suffices to keep these rock-crowned curving ridges bare of snow the better part of the year. It is intense enough, even, to produce numerous steam jets along the inner face of the rim of the east crater, which appears to be the most recently formed of the two. The center of this depression, however, is filled with snow, so that it has the appearance of a shallow, white-floored bowl some 1,200 feet in diameter. Great caverns are melted out by the steam jets under the edges of the snow mass, and these caverns afford shelters which, though uninviting, are not to be despised. They have proved a blessing to more than one party that has found itself compelled to remain overnight on the summit, saving them from death in the icy gales.

That Mount Rainier should still retain so much of its internal heat is not surprising in view of the recency of its eruptions. It is known to have been active at intervals during the last century, and actual

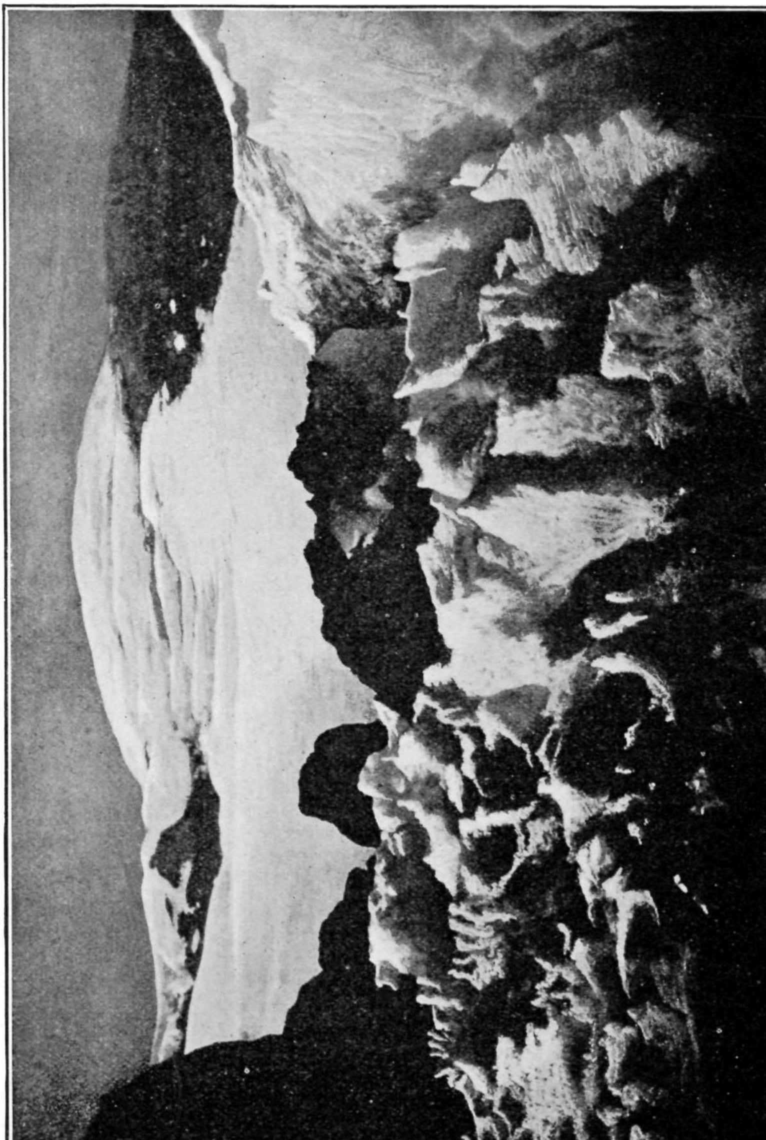


FIG. 4.—VIEW ACROSS THE EAST SUMMIT CRATER. THE SNOW MOUND ON THE FARTHER SIDE, KNOWN AS COLUMBIA CREST, IS THE HIGHEST POINT OF MOUNT RAINIER (14,408 FEET). THE INTERNAL HEAT OF THE VOLCANO KEEPS THE CRATER RIM PARTLY BARE OF SNOW.

Photo by Barnes.

record exists of feeble eruptions in 1843, 1854, 1858, and 1870. Indian legends mention a great cataclysmal outburst at an earlier period.

At present the volcano may be regarded as dormant and no apprehension need be felt as to the possibility of an early renewal of its activity. The steam jets in the summit crater, it is true, as well as the hot springs at the mountain's foot (Longmire Springs), attest the continued presence of subterranean fires, but they are only feeble evidences as compared with the geysers, the steam jets, and the hot springs of the Yellowstone National Park. Yet that region is not considered any less safe to visit because of the presence of these thermal phenomena.

In spite of Mount Rainier's continued activity until within the memory of man, its sides appear to have been snow clad for a considerable length of time. Indeed, so intense and so long-continued has been the eroding action of the ice that the cone is now deeply ice-scarred and furrowed. Most of its outer layers, in fact, appear already to have been stripped away. Here and there portions of them remain standing on the mountain's flanks in the form of sharp-crested crags and ridges, and from these one may roughly surmise the original dimensions of the cone. Mere details in the volcano's sculpture, these residual masses are, some of them, so tall that, were they standing among ordinary mountains, they would be reckoned as great peaks. Particularly noteworthy is Little Tahoma, a sharp, triangular tooth on the east flank, that rises to an elevation of 11,117 feet. (See fig. 11, p. 26.) In its steep, ice-carved walls one may trace ascending volcanic strata aggregating 2,000 feet in thickness that point upward to the place of their origin, the former summit of the mountain, which rose almost half a mile higher than the present top.

Nor is the great crater rim left by the explosion that carried off the original summit preserved in its entirety. Point Success and Liberty Cap are the only two promontories that give trustworthy indication of its former height and strength. Probably they represent the more massive portions on the southwest and northwest sides, respectively, while the weaker portions to the east and south have long since crumbled away under the heavy ice cascades that have been overriding them for ages. Only a few small rocky points remain upon which the snows split in their descent. The most prominent, as well as the most interesting, is the one on the southeast side, popularly known as Gibraltar Rock. Really a narrow, wedge-shaped mass, it appears in profile like a massive, square-cut promontory. (Fig. 6.) The trail to the summit of the mountain passes along its overhanging south face and then ascends by a precipitous chute between ice and rock. It is this part of the ascent that is reputed as the most precarious and hazardous.

From the rim points downward the ice cover of the cone divides into a number of distinct stream-like tongues or glaciers, each sunk in a great hollow pathway of its own. Between these ice-worn trenches the uneroded portions of the cone stand out in high relief, forming as a rule huge triangular "wedges," heading at the sharp rim points and spreading thence downward to the mountain's base. There they assume the aspect of more gently sloping, grassy table-lands, the charming alpine meadows of which Paradise Park and Spray Park are the most famous. Separating these upland parks are the profound ice-cut canyons which, beyond the glacier ends, widen out into densely forested valleys, each containing a swift-flowing river. No less than a dozen of these ice-fed torrents radiate from the volcano in all directions, while numerous lesser streams course from the snow fields between the glaciers.

Thus the cone of Mount Rainier is seen to be dissected from its summit to its foot. Sculptured by its own glacier mantle, its slopes have become diversified with a fretwork of ridges, peaks, and canyons.

NISQUALLY GLACIER.

THE LOWER END.

The first ice one meets on approaching the mountain from Longmire Springs lies in the upper end of the Nisqually Valley. The automobile road, which up to this point follows the west side of the valley, winding in loops and curves along the heavily wooded mountain flank, here ventures out upon the rough boulder bed of the Nisqually River and crosses the foaming torrent on a picturesque wooden bridge. Some fifteen hundred feet above this structure, blocking the valley to a height of some 400 feet, looms a huge shapeless pile of what seems at first sight only rock débris, gray and chocolate in color. (Fig. 5.) It is the dirt-stained end of one of the largest glaciers—the Nisqually. From a yawning cave in its front issues the Nisqually stream, a river full fledged from the start.

The altitude here, it should be noted, is a trifle under 4,000 feet (elevation of bridge is 3,908 feet); hence the ice in view lies more than 10,000 feet below the summit of the mountain, the place of its origin. And in this statement is strikingly summed up the whole nature and economy of a glacier such as the Nisqually.

A glacier is not a mere stationary blanket of snow and ice clinging inert to the mountain flank. It is a slowly moving streamlike body that descends by virtue of its own weight. The upper parts are continually being replenished by fresh snowfalls, which at those high altitudes do not entirely melt away in summer; while the lower end, projecting as it does below the snow line, loses annually more by melting than it receives by precipitation, and is maintained only by the continued accession of masses from above. The rate at which the ice advances has been determined by Prof. J. N. Le Conte, of the University of California. In 1903 he placed a row of stakes across the glacier, and with the aid of surveying instruments obtained accurate measurements of the distances through which they moved

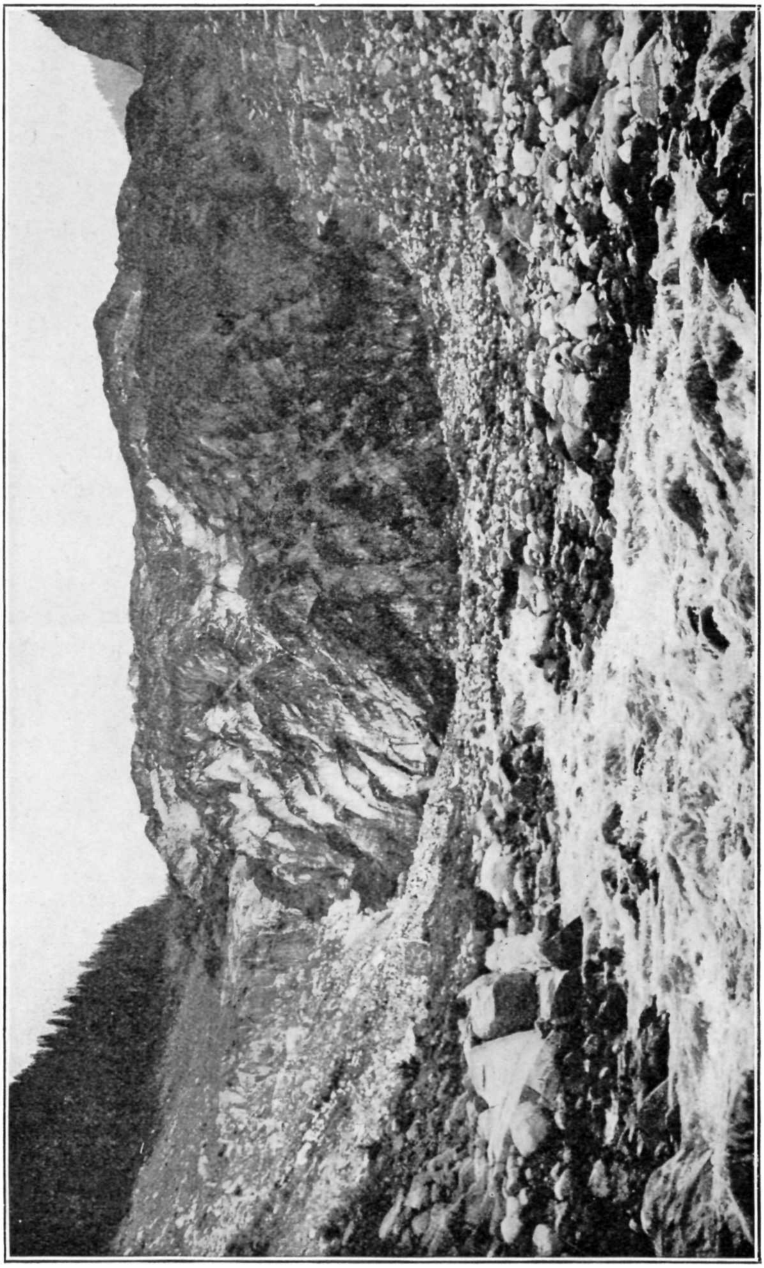


FIG. 5.—THE DYING LOWER END OF THE NISQUALLY GLACIER, SEEN FROM THE BRIDGE ON THE AUTOMOBILE ROAD TO PARADISE PARK. THE COLOR OF THE ICE IS OBSCURED BY ROCK DÉBRIS.

Photo by Barnes.

from day to day. He found that in summer, when the movement is greatest, it averages 16 inches per day. This figure, however, applies only to the central portion of the glacier—the main current, so to speak—for the margins necessarily move more slowly, being retarded by friction against the channel sides.

The foot of the Nisqually Glacier, accordingly, is really composed of slowly advancing ice, but so rapid is the melting at this low altitude that it effectually counterbalances the advance, and thus the ice front remains essentially stationary and apparently fixed in place. Actually, it is subject to slight back and forward movements, amounting to a foot or more per day; for, as one may readily imagine, fluctuations in snowfall and in temperature, above or below the normal, are ever likely to throw the balance one way or another.

A glacier may also make periodic advances or retreats on a larger scale in obedience to climatic changes extending over many years. Thus all the glaciers on Mount Rainier, as well as many in other parts of the world, are at present, and have been for some time, steadily retreating as the result of milder climate or of a lessening in snow supply. Only so recently as 1885 the Nisqually Glacier reached down to the place now occupied by the bridge, and it is safe to say that at that time no engineer would have had the daring to plan the road as it is now laid. In the last 35 years, however, the Nisqually Glacier has retreated fully 1,500 feet.

Evidences of similar wholesale recession are to be observed at the ends of the other glaciers of Mount Rainier, but the measure of their retreat is not recorded with the precision that was possible in the case of the Nisqually Glacier.

THE LOWER COURSE.

As one continues the ascent by the automobile road a part of the glacier's lower course comes into view, and one gains some idea of its stream-like character. More satisfying are the views from Paradise Park. (Fig. 6.) Here several miles of the ice stream (its total length is nearly 5 miles) lie stretched out at one's feet, while looking up toward the mountain one beholds the tributary ice fields and ice streams, pouring, as it were, from above, from right and left, rent by innumerable crevasses and resembling foaming cascades suddenly crystallized in place. The turmoil of these upper branches may be too confusing to be studied with profit, but the more placid lower course presents a favorable field for observation, and a readily accessible one at that.

A veritable frozen river it seems, flowing between smooth, parallel banks, half a mile apart. Its surface, in contrast to the glistening ice cascades above, has the prevailingly somber tint of old ice, relieved here and there by bright patches of last winter's snow. These lie for the most part in gaping fissures or crevasses that run athwart the glacier at short intervals and divide its body into narrow slices. In the upper course, where the glacier overrides obstacles in its bed, the crevasses are particularly numerous and irregularly spaced, some-

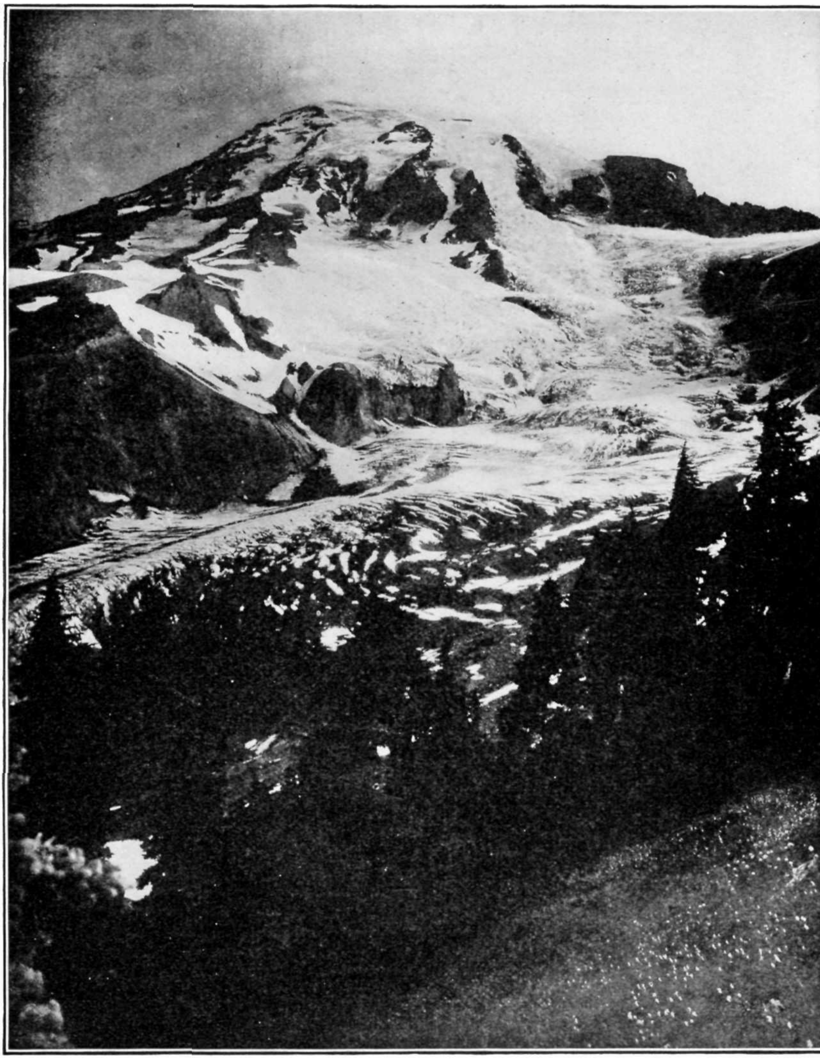


FIG. 6.—GENERAL VIEW OF NISQUALLY GLACIER FROM THE HEIGHTS OF PARADISE PARK. THE SQUARE-CUT ROCK MASS TO THE RIGHT OF THE SUMMIT IS GIBRALTAR ROCK, THE CHIEF OBSTACLE IN THE ASCENT OF THE PEAK.

Photo by Curtis.

times occurring in two sets intersecting at right angles, and cutting the ice into huge square prisms. Farther down the ice stream's current is more sluggish and the crevasses heal up by degrees, producing a united surface, over which one may travel freely.

Gradually, also, the glacier covers itself with débris. Angular rock fragments, large and small, and quantities of dust, derived from the rock walls bordering the ice stream higher up, litter its surface and hide the color of the ice. At first only a narrow ridge of such material—a moraine, as it is called—accompanies the ice river on each side, resembling a sharp-crested embankment built by human hands to restrain its floods; but toward the lower end of the glacier, as the ice wastes away, the débris contained in it is released in masses, and forms brown marginal bands, fringing the moraines. In fact, from here on down it becomes difficult to tell where the ice of the glacier ends at the sides and where the moraines begin.

The lower part of the glacier also possesses a peculiar feature in the form of a débris ridge about midway on its back—a medial moraine. Most of the way it stretches like a slender, dark ribbon, gradually narrowing upstream. One may trace it with the eye up to its point of origin, the junction of the two main branches of the glacier, at the foot of a sharp rock spur on the mountain's flank.

In the last mile of the Nisqually's course, this medial moraine develops from a mere dirt band to a conspicuous embankment, projecting 40 feet above the ice. Not the entire body of the ridge, however, is made up of rock débris. The feature owes its elevation chiefly to the protective influence of the débris layer on its surface, which is thick enough to shield the ice beneath from the hot rays of the sun, and greatly retards melting, while the adjoining unprotected ice surfaces are rapidly reduced.

A short distance above the glacier's terminus the medial moraine and the ever-broadening marginal bands come together. No more clear ice remains exposed, irregular mounds and ridges of débris cover the entire surface of the glacier, and the moraine-smothered mass assumes the peculiar inchoate appearance that is so striking upon first view.

THE UPPER NÉVÉS.

In utter contrast with the glacier's dying lower end are the bright snow fields on the summit in which it commences its career. Hard by the rock rim of the east summit crater the snows begin, enwrapping in an even, immaculate layer the smooth sides of the cinder cone. Only a few feet deep at first, they thicken downward by degrees, until, a thousand feet below the crater, they possess sufficient depth and weight to acquire movement. Occasional angular crevasses here interrupt the slope and force the summit-bound traveler to make wearying detours.

Looking down into a gash of this sort one beholds nothing but clean snow, piled in many layers. Only a faint blue tinges the crevasse walls, darkening but slowly with the depth, in contrast to the intense indigo hue characteristic of the partings in the lower course of the glacier. There the material is a dense ice, more or less crystalline in texture; here it is scarcely more than snow, but slightly compacted and loosely granular—what is generally designated by the Swiss term "névé."

For several thousand feet down, as far as the 10,000-foot level, in fact, does the snow retain this granular consistency. One reason for the slowness with which it compacts is found in the low temperatures that prevail at high altitudes and preclude any considerable melting. The air itself seldom rises above the freezing point, even in the middle of the day, and as a consequence the snow never becomes soft and mushy, as it does at lower levels.

When snow assumes the mushy, "wet-sugar" state, it is melting internally as well as at its outer surface, owing both to the water that soaks into it and to the warming of the air inclosed within its innumerable tiny pores (which tiny air spaces, by the way, give the snow its brilliant whiteness). Snow, in this condition has, paradoxical though it may sound, a temperature a few tenths of a degree higher than the melting point—a fact recently established by delicate temperature measurements made on European glaciers. It is this singular fact, no doubt, that explains how so many minute organisms are able to flourish and propagate in summer on the lower portions of many glaciers. It may be of interest to digress here briefly in order to speak of these little known though common forms of life.

FAUNA AND FLORA OF GLACIERS.

Several species of insects are among the regular inhabitants of glaciers. Most of them belong to a very low order—the Springtails, or *Thysanura*—and are so minute that in spite of their dark color they escape the attention of most passers-by. If one looks closely, however, they may readily be observed hopping about like miniature fleas or wriggling deftly into the cavities of the snow. It seems to incommode them but little if in their acrobatic jumps they occasionally alight in a puddle or in a rill, for they are thickly clad with furry scales that prevent them from getting wet—just as a duck is kept dry by its greasy feathers.

Especially plentiful on the lower parts of the Rainier glaciers, and more readily recognized, are slender dark-brown worms of the genus *Mesenchytraeus*, about 1 inch in length. Millions and millions of them may be seen on favorable days in July and August writhing on the surface of the ice, evidently breeding there and feeding on organic matter blown upon the glacier in the form of dust. So essential to their existence is the chill of the ice that they enter several inches, and sometimes many feet below the surface on days when the sun is particularly hot, reappearing late in the afternoon.

Mention also deserves to be made of that microscopic plant *Protococcus nivalis*, which is responsible for the mysterious pink or light, rose-colored patches so often met with on glaciers—the "red snow" of a former superstition. Each patch represents a colony or culture comprising billions of individuals. It is probable that they represent but a small fraction of the total microflora thriving on the snow, the other species remaining invisible for lack of a conspicuous color.

SNOW CUPS AND HONEYCOMBS.

To return to the frigid upper névés, it is not to be supposed that they suffer no loss whatever by melting. The heat radiated directly to them by the sun is capable of doing considerable damage, even while the air remains below the freezing point. At these high altitudes the sun heat is astonishingly intense, as more than one uninitiated mountain climber has learned to his sorrow by neglecting to take the customary precaution of "painting" his face before making the ascent. In a few hours the skin is literally scorched and begins to blister painfully.

At the foot of the mountain the sun heat is relatively feeble, for much of it is absorbed by the dust and vapor in the lower layers of the atmosphere, but on the summit, which projects 2 miles higher, the air is thin and pure, and lets the rays pass through but little diminished in strength.

The manner in which the sun affects the snow is peculiar and distinctive. Instead of reducing the surface evenly, it melts out many close-set cups and hollows, a foot or more in diameter and separated by sharp spires and crests. No water is visible anywhere, either in rills or in pools, evaporation keeping pace with the reduction. If the sun's action is permitted to continue uninterrupted for many days, as may happen in a hot, dry summer, these snow cups deepen by degrees, until at length they assume the aspect of gigantic bee cells, several feet in depth. (Fig. 7.) Snow fields thus honeycombed are often met with on the slopes above Gibraltar Rock. They are wearisome to traverse, for the ridges and spines are fairly resistant, so that one must laboriously clamber over them. Most exasperating, however, is the going after a snowstorm has filled the honeycombs. Then the traveler, waist deep in mealy snow, is left to flounder haphazard through a hidden labyrinth.

Of interest in this connection is the great snow cliff immediately west of Gibraltar Rock. (Fig. 8.) Viewed from the foot of that promontory, the sky line of the snow castle fairly bristles with honeycomb spines; while below, in the face of the snow cliff, dark, wavy lines, roughly parallel to the upper surface, repeat its pattern in subdued form. They represent the honeycombs of previous seasons, now buried under many feet of snow, but still traceable by the dust that was imprisoned with them.

FIG. 7.—SNOW CUPS AND "HONEYCOMBS" PRODUCED IN A HIGH NÉVÉ FIELD BY THE HOT RAYS OF THE SUN. THE AIR AT THESE HEIGHTS REMAINS ALMOST CONSTANTLY BELOW THE FREEZING POINT.

Photo by G. K. Gilbert.

ICE CASCADES.

The snow cliff west of Gibraltar Rock is of interest also for other reasons. It is the end of a great snow cascade that descends from the rim of the old crater. Several such cascades may be seen on the south side of the mountain, separated by craggy remnants of the crater rim. Above them the summit névés stretch in continu-

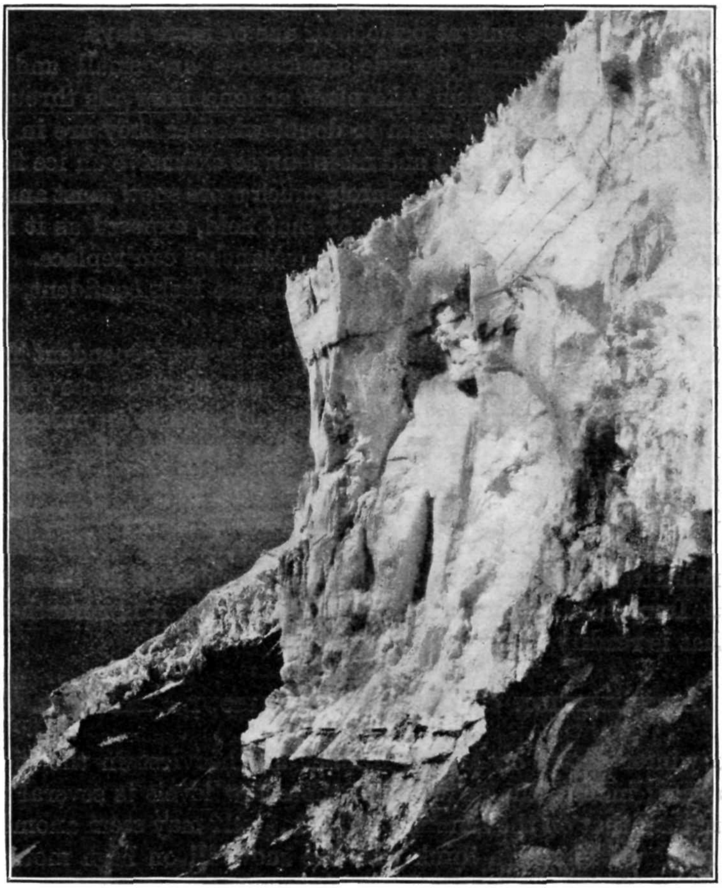


FIG. 8.—THE SNOW CLIFF WEST OF GIBRALTAR ROCK. THE SPINES ON THE SKY LINE PROJECT FROM BETWEEN DEEP "HONEYCOMBS." THE WAVY LINES IN THE FACE OF THE CLIFF INDICATE HONEYCOMBED SURFACES OF FORMER SEASONS, BURIED UNDER THE SNOWS OF SUCCESSIVE WINTERS.

Photo copyrighted by Barnes.

ous fields, but from the rim on down, the volcano's slopes are too precipitous to permit a gradual descent, and the névés break into wild cascades and falls. Fully two to three thousand feet they tumble, assembling again in compact, sluggish ice fields on the gentler slopes below.

Of the three cascades that feed the Nisqually Glacier only the central one, it is to be observed, forms a continuous connection between the summit névés and the lower ice fields. (Fig. 6.) The two others, *viz*, the one next to Gibraltar and the westernmost of the three, terminate in vertical cliffs, over great precipices of rock. From them snow masses detach at intervals and produce thundering avalanches that bound far out over the inclined ice fields below. Especially frequent are the falls from the cliff near Gibraltar. They occur hourly at certain times but as a rule at periods of one or more days.

From the westernmost cascade avalanches are small and rare. Indeed, as one watches them take place at long intervals throughout a summer one can not but begin to doubt whether they are in themselves really sufficient to feed and maintain so extensive an ice field as lies stretched out under them. Surely much more snow must annually melt away from the broad surface of that field, exposed as it lies to the midday sun, than the insignificant avalanches can replace. Were they its only source of supply, the ice field, one feels confident, would soon cease to exist.

The fact is that the ice field in question is not dependent for its support on the avalanches from above. It may receive some contributions to its volume through them, but in reality it is an independent ice body, nourished chiefly by direct snow precipitation from the clouds. And this is true, in large measure, of all the ice fields lying under the ice cascades. The Nisqually Glacier, accordingly, is not to be regarded as composed merely of the cascading névés, reunited and cemented together, but as taking a fresh start at these lower levels. Improbable though this may seem at first, it is nevertheless a fact that is readily explained.

DISTRIBUTION OF SNOWFALL ON MOUNT RAINIER.

The winter snows on Mount Rainier are heaviest in the vicinity of its base; indeed, the snowfall at those low levels is several times greater than that on the summit. This in itself may seem anomalous. So accustomed is one to think that the snowfall on high mountains increases with the altitude that it seems strange to find a case in which the opposite is true. Yet Mount Rainier stands by no means alone in this regard. The Sierra Nevada and the Andes, the Himalayas and the Alps, all show closely analogous conditions.

In each of these lofty mountain regions the precipitation is known to be heaviest at moderate altitudes, while higher up it decreases markedly. The reason is that the storm clouds—the clouds that carry most of the rain and snow—hang in a zone of only moderate elevation, while higher up the atmosphere contains but little moisture and seldom forms clouds of any great density.

In the Rainier region the height of the storm clouds is in large measure regulated by the height of the Cascade Range; for it is really this cooling mountain barrier that compels the moisture-laden winds from the Pacific Ocean to condense and to discharge. It follows that the storm clouds are seldom much elevated above the sky line of the Cascade Mountains; they cling, so to speak, to its crests and ridges, while the cone of Mount Rainier towers high above them into serener skies. Many a day one may look down from the summit, or even from a halfway point, such as Camp Muir (10,062 feet), upon the upper surface of the clouds. Like a layer of fleecy cotton they appear, smothering the lower mountains and enveloping the volcano's base.

Clouds, it is true, are frequently seen gathering about the mountain's crown, usually in the form of a circular cap or hood, precursor of a general storm, but such clouds yield but very little snow.

No accurate measurements have been made of the snowfall at the mountain's foot, but in the Nisqually Valley, at Longmire Springs, the snow often reaches a depth of 7 feet, and the total snowfall in winter may exceed 20 feet in depth. The summer heat at this low level (2,762 feet) is, of course, abundantly able to remove all of it, at least by the end of May. But higher up every thousand feet of elevation suffices to prolong appreciably the life of the snowy cover. In Paradise Park, for instance, at altitudes between 5,000 and 6,000 feet, huge snowdrifts encumber the flowering meadows until far into July. Above an altitude of 6,000 feet permanent drifts and snow fields survive in certain favored spots, while at the 7,000-foot level the snow line, properly speaking, is reached. Above this line considerable snow remains regularly from one winter to the next, and extensive ice fields and glaciers exist without any protection from the sun.

It is between the 8,000 and 10,000 foot levels, however, that one meets with the conditions most favorable for the development of glaciers. Below this zone the summer heat largely offsets the heavy precipitation, while above it the snowfall itself is relatively scant. Within the belt the annual addition of snow to the ice fields is greater than anywhere else on Mount Rainier. The result is manifest in the arrangement and distribution of the glaciers on the cone. By far the greater number originate in the vicinity of the 10,000-foot level, while those ice streams which cascade from the summit, such as the Nisqually, are in a sense reborn some 4,000 feet lower down.

PARADISE GLACIER.

A striking example of an ice body nourished wholly by the snows falling on the lower slope of Mount Rainier is the Paradise Glacier. In nowise connected with the summit névés, it makes its start at an elevation of less than 9,000 feet. Situated on the spreading slope between the diverging canyons of the Nisqually on the west and of the Cowlitz on the northeast, it constitutes a typical "interglacier," as intermediate ice bodies of this kind are termed.

Its appearance is that of a gently undulating ice field, crevassed only toward its lower edge (fig. 9) and remarkably clean throughout. No débris-shedding cliffs rise anywhere along its borders, and

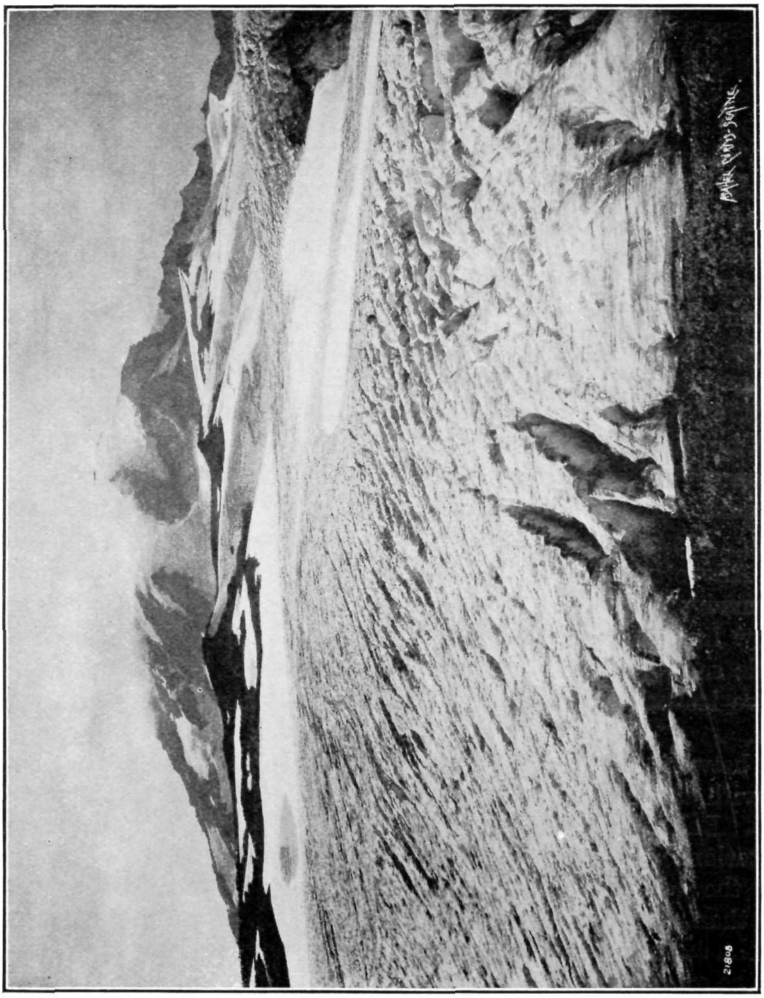


FIG. 9.—GENERAL VIEW OF PARADISE GLACIER. THE ICE BODY ORIGINATES ENTIRELY BELOW THE 9,000-FOOT LINE. MORE SNOW FALLS AT THESE RELATIVELY LOW LEVELS THAN ON THE SUMMIT OF THE PEAK.

Photo by Curtis.

this fact, no doubt, largely explains its freedom from morainal accumulations.

The absence of cliffs also implies a lack of protecting shade. Practically the entire expanse of the glacier lies exposed to the full glare of the sun. As a consequence its losses by melting are very heavy, and a single hot summer may visibly diminish the glacier's bulk. Nevertheless it seems to hold its own as well as any other glacier on Mount Rainier, and this ability to recuperate finds its explanation in the exceeding abundance of fresh snows that replenish it every winter.

The Paradise Glacier, however, is not the product wholly of direct precipitation from the clouds. Much of its mass is supplied by the wind, and accumulates in the lee of the high ridge to the west, over which the route to Camp Muir and Gibraltar Rock is laid. The westerly gales keep this ridge almost bare of snow, permitting only a few drifts to lodge in sheltered depressions, as will be clear from figure 9. But east of the ridge there are great eddies in which the snow forms long, smooth slopes that descend several hundred feet to the main body of the glacier. These slopes are particularly inviting to tourists for the delightful "glissades" which they afford. Sitting down on the hard snow at the head of such a slope, one may indulge in an exhilarating glide of amazing swiftness, landing at last safely on the level snows beneath.

The generally smooth and united surface of the Paradise Glacier, it may be added, contributes not a little to its attractiveness as a field for alpine sports. On part of it one may roam at will without apprehension of lurking peril; indeed one can sometimes journey across its entire width, from Paradise Park to the Cowlitz Rocks, without encountering a single dangerous fissure. This general absence of crevasses is accounted for largely by the evenness of the glacier's bed and by its hollow shape, owing to which the snows on all sides press inward and compact the mass in the center. Only toward its frontal margin, where the glacier plunges over an abrupt rock step, as well as in the hump of that part known as Stevens Glacier, is the ice rent by long crevasses and broken into narrow blades. Here it may be wise for the inexperienced not to venture without a competent guide, for the footing is apt to be treacherous, and jumping over crevasses or crossing them by frail snow bridges are feats never accomplished without risk.

In the early part of summer the Paradise Glacier has the appearance of a vast, unbroken snow field, blazing, immaculate, in the sun. But later, as the fresh snows melt away from its surface, grayish patches of old crystalline ice develop in places, more especially toward the glacier's lower margin. Day by day these patches expand until, by the end of August, most of the lower ice field has been stripped of its brilliant mantle. Its countenance, once bright and serene, now assumes a grim expression and becomes crisscrossed by a thousand seams, like the visage of an aged man.

Over this roughened surface trickle countless tiny rills which, uniting, form swift rivulets and torrents, indeed veritable river systems on a minature scale that testify with eloquence to the rapidity with which the sun consumes the snow. Strangely capricious in course are these streamlets, for, while in the main gravitating with the glacier's slope, they are ever likely to be caught and deflected by the numerous seams in the ice. These seams, it should be explained, are lines of former crevasses that have healed again under pressure in the course of the glacier's slow descent. As a rule they inclose a small amount of dirt, and owing to its presence are particularly vulnerable to erosion. Along them the streamlets rapidly intrench themselves—perhaps by virtue of their warmth, what little there is of

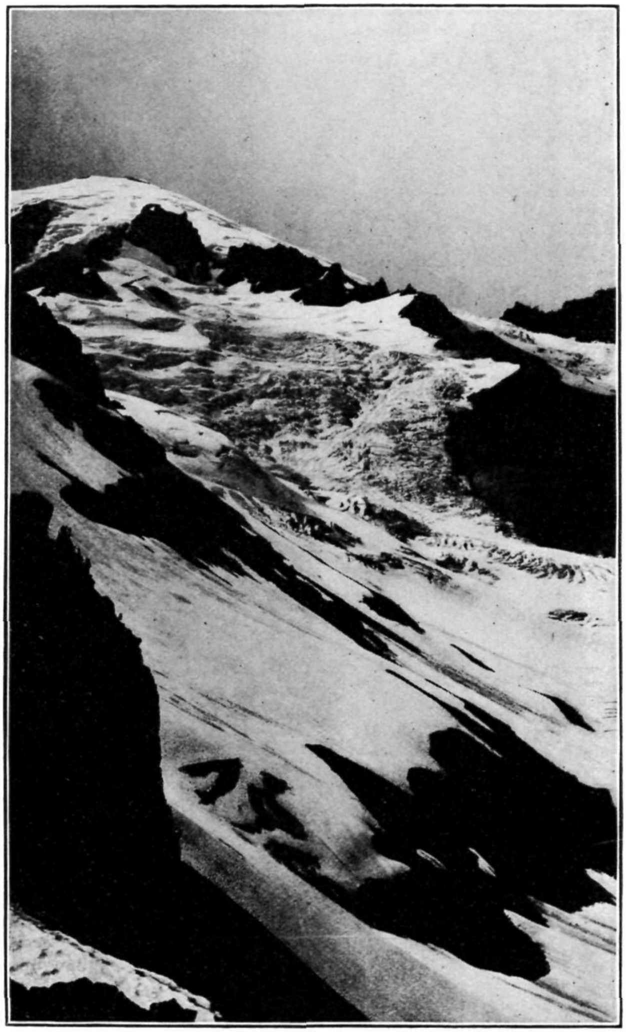
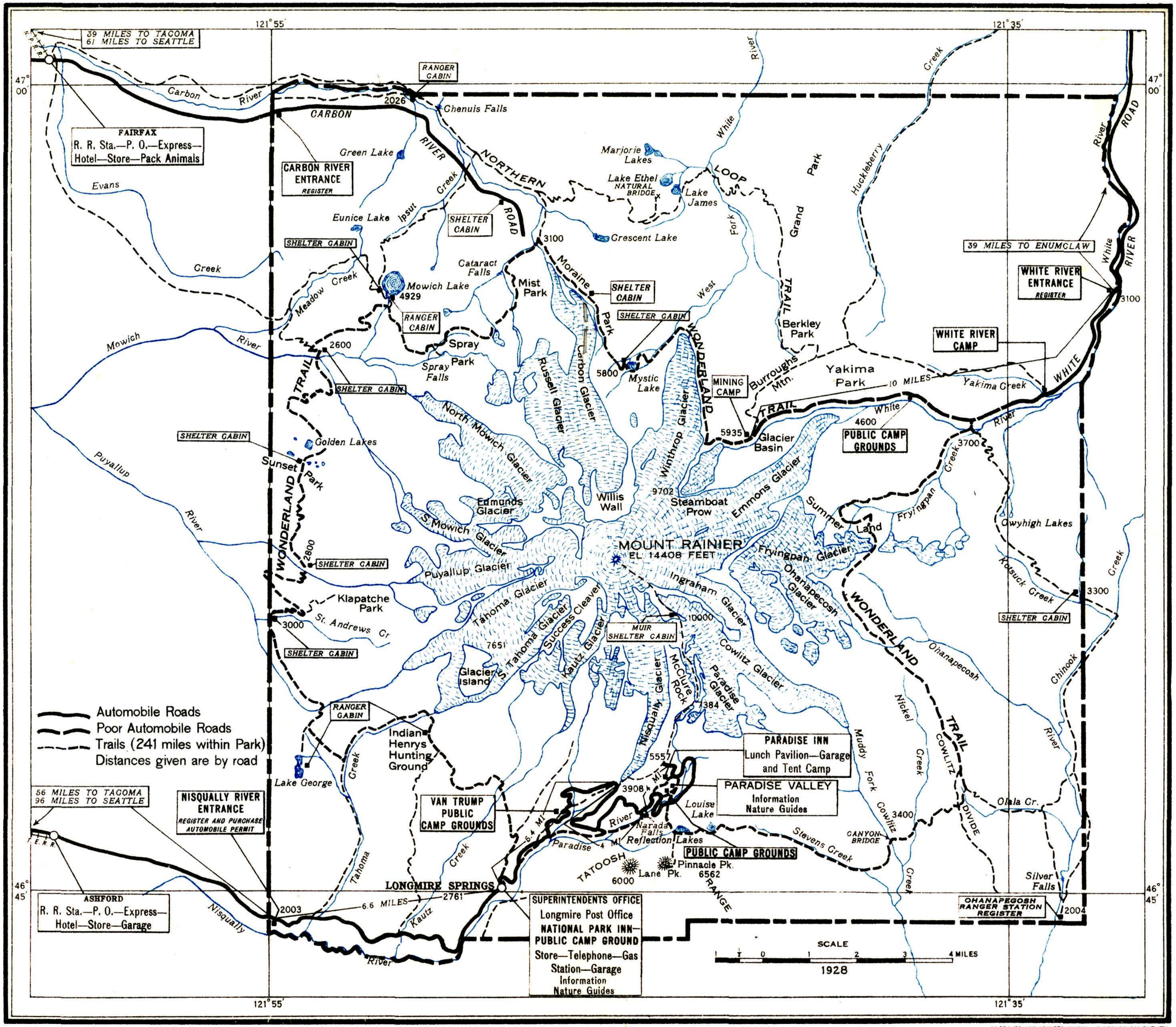


FIG. 10.—HEAD OF COWLITZ GLACIER. GIBRALTAR ROCK IS SEEN ENDWISE, AT THE APEX OF THE TWO ROCK "CLEAVERS."

Photo by Matthes.

it, as much as by actual abrasion—and hollow out channels of a freakish sort, here straight and canal-like, there making sharp zigzag turns; again broadening into profound, canoe-shaped pools, or emptying into deeper trenches by little sparkling cataracts, or passing under tiny bridges and tunnels—a veritable toy land carved in ice.



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MAP OF MOUNT RAINIER NATIONAL PARK

But unfortunately these pretty features are ephemeral, many of them changing from day to day; for, evenings, as the lowering sun withdraws its heat, the melting gradually comes to a halt, and the little streams cease to flow. The soft babbling and gurgling and the often exquisitely melodious tinkle of dripping water in hidden glacial wells are hushed, and the silent frost proceeds to choke up passages and channels, so that next day's waters have to seek new avenues.

In the region where the new crevasses open the surface drainage comes abruptly to an end. Here gaping chutes of deepest azure entrap the torrents and the waters rush with musical thunder to the interior of the glacier and finally down to its bed.

At its lower border the Paradise Glacier splits into several lobes. The westernmost sends forth the Paradise River, which, turning southwestward, plunges over the Sluiskin Falls (named for the Klickitat Indian who guided Van Trump and Hazard Stevens to the mountain in 1870, when they made the first successful ascent) and runs the length of Paradise Valley. The middle lobe has become known as Stevens Glacier (named for Hazard Stevens) and ends in Stevens Creek, a stream which almost immediately drops over a precipice of some 600 feet—the Fairy Falls—and winds southeastward through rugged Stevens Canyon. The easternmost lobes, known collectively as Williwakas Glacier, send forth two little cascades, which, uniting, form Williwakas Creek. This stream is a tributary of the Cowlitz River, as is Stevens Creek.

COWLITZ GLACIER.

Immediately adjoining the Paradise Glacier on the northeast, and not separated from it by any definite barrier, lies the Cowlitz Glacier, one of the stateliest ice streams of Mount Rainier. It flows in a southeasterly direction, and burrows its nose deeply into the forest-covered hills at the mountain's foot. Its upper course consists of two parallel-flowing ice streams, intrenched in profound troughs, which they have enlarged laterally until now only a narrow, ragged crest of rock remains between them, resembling a partition a thousand feet in height. (Fig. 10.) At the upper end of this crest stands Gibraltar Rock.

At the point of confluence of the two branches there begins a long medial moraine that stretches like a black tape the whole length of the lower course. To judge by its position midway on the glacier's back, the two tributaries must be very nearly equal in strength, yet, when traced to their sources, they are found to originate in widely different ways. The north branch, named Ingraham Glacier (after Maj. E. S. Ingraham, one of Rainier's foremost pioneers), comes from the névés on the summit; while the south branch heads in a pocket immediately under Gibraltar. No snow comes to it from the summit;

hence we can not escape the conclusion that it receives through direct precipitation and through wind drifting about as much snow as its sister branch receives from the summit regions. Like the glacier troughs below, the pocket appears to have widened laterally under

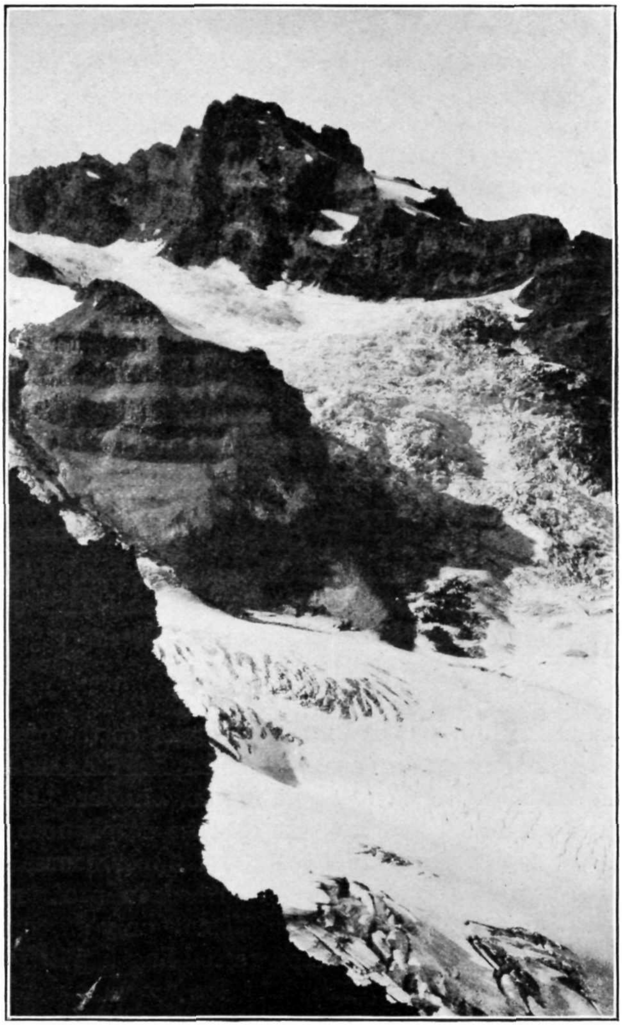

FIG. 11.—CASCADES OF INGRAHAM GLACIER. IN THE BACKGROUND LITTLE TAHOMA (11,117 FEET), A REMNANT OF THE OUTER LAYERS OF THE VOLCANO, NOW MOSTLY STRIPPED AWAY BY THE ICE.

Photo by Matthes.

the influence of the ice, and is now separated from the Nisqually ice fields to the west by only a narrow rock partition, the Cowlitz Cleaver, as it is locally called. Up this narrow crest the route to Gibraltar Rock ascends. The name "cleaver," it may be said in passing, is most apt for the designation of a narrow rock crest of this sort, and well deserves to be more generally used in the place of awkward foreign terms, such as arrete and grat.

Both branches of the Cowlitz Glacier cascade steeply immediately above their confluence (fig. 11), but the lower glacier has a gentle gradient and a fairly uneventful course. Like the lower Nisqually, it is bordered by long morainal ridges, and toward its end acquires broad marginal dirt bands. For nearly a mile these continue, leaving a gradually narrowing lane of clear ice between them. Then they coalesce and the whole ice body becomes strewn with rock débris.

The Cowlitz Glacier, including its north branch, the Ingraham Glacier, measures slightly over 6 miles in length. Throughout that distance the ice stream lies sunk in a steep-walled canyon of its own carving. Imposing cliffs of columnar basalt, ribbed as if draped in corduroy, overlook its lower course. Slender waterfalls glide down their precipitous fronts, like silver threads, guided by the basalt flutings.

From the end of the glacier issues the Muddy Fork of the Cowlitz River, which, joining the Ohanapecosh, forms the Cowlitz River proper, one of the largest streams of the Cascade Range. For nearly a hundred miles the Cowlitz River follows a southwesterly course, finally emptying in the Columbia River a short distance below Portland, Oregon.

The name Muddy Fork is a most apt one, for the stream leaves the glacier heavily charged with débris and mud, and while it gradually clears itself as it proceeds over its gravelly bed, it is still turbid when it reaches the Ohanapecosh. That stream is relatively clear, for it heads in a glacier of small extent and little eroding power, and consequently begins its career with but a moderate load; furthermore it receives on its long circuitous course a number of tributaries from the Cascade Range, all of them containing clear water.

The name Muddy, however, might with equal appropriateness be given to every one of the streams flowing from the ice fields of Mount Rainier. So easily disintegrated are the volcanic materials of which that peak is composed, that the glaciers are enabled to erode with great rapidity, even in their present shrunken state. They consequently deliver to the streams vast quantities of débris, much of it in the form of cobbles and boulders, but much of it also in the form of "rock flour."

A considerable proportion of a glacier's erosional work is performed by abrasion or grinding, its bed being scoured and grooved by the rock blocks and smaller débris held by the passing ice. As a result glacier streams ordinarily carry much finely comminuted rock, or rock flour, and this, because of its fineness, remains long in suspension and imparts to the water a distinctive color. In regions of light-colored rocks the glacier streams have a characteristic milky hue, which, as it fades out, passes over into a delicate turquoise tint.

But the lavas of Mount Rainier produce for the most part dark-hued flour, and as a consequence the rivers coming from that peak are dyed a somber chocolate brown.

A word may not be out of place here about the sharp daily fluctuations of the ice-fed rivers of the Mount Rainier National Park, especially in view of the difficulties these streams present to crossing. There are fully a score of turbulent rivers radiating from the peak, and as a consequence one can not journey far through the park without being obliged to cross one of them. On all the permanent trails substantial bridges obviate the difficulty, but in the less developed portions of the park, fording is still the only method available. It is well to bear in mind that these rivers, being nourished by melting snow, differ greatly in habit from streams in countries where glaciers are absent. Generally speaking, they are highest in summer and lowest in winter; also, since their flow is intimately dependent upon the quantity of snow being melted at a given time, it follows that in summer when the sun reaches its greatest power they swell daily to a prodigious volume, reaching a maximum in the afternoon, while during the night and early morning hours they again ebb to a relatively moderate size. In the forenoon of a warm summer day one may watch them grow hourly in volume and in violence, until toward the middle of the day they become raging torrents of liquid mud in which heavy cobbles and even boulders may be heard booming as they roll before the current. It would be nothing short of folly to attempt to ford under these conditions, whether on horseback or on foot. In the evening, however, and still better, in the early morning, one may cross with safety; the streams then have the appearance of mere mountain brooks wandering harmlessly over broad boulder beds.

OHANAPECOSH AND FRYINGPAN GLACIERS.

High above the Ingraham Glacier towers that sharp, residual mass of lava strata known as Little Tahoma (11,117 feet), the highest outstanding eminence on the flank of Mount Rainier. (Figs. 11 and 12.) It forms a gigantic "wedge" that divides the Ingraham from the Emmons Glacier to the north. So extensive is this wedge that it carries on its back several large ice fields and interglaciers, some of which, lying far from the beaten path of the tourist, are as yet unnamed. Separating them from each other are various attenuated, pinnacled crests, all of them subordinate to the main backbone which runs eastward some 6 miles and terminates in the Cowlitz Chimneys (7,607 feet), a group of tall rock towers that dominate the landscape on the east side of Mount Rainier.

Most of the ice fields, naturally, lie on the shady north slope of the main backbone; in fact, a series of them extends as far east as the Cowlitz Chimneys. One of the lesser crests, however, that running southeastward to the upland region known as Cowlitz Park, also gives protection to an ice body of some magnitude, the Ohanapecosh Glacier. Considerably broader than it is long in the direction of its flow, this glacier lies on a high shelf a mile and a half across, whence it cascades down into the head of a walled-in canyon. Formerly, no doubt, it more than filled this canyon, but now it sends down only a shrunken lobe. The stream that issues from it, the Ohanapecosh River, is really the main prong and head of the Cowlitz River.

The largest and most elevated of the ice fields east of Little Tahoma is known for its peculiar shape as Fryingpan Glacier. It covers fully 3 square miles of ground and constitutes the most extensive and most beautiful interglacier on Mount Rainier. It originates in the hollow east side of Little Tahoma itself and descends rapidly northward, overlooking the great Emmons Glacier and finally reaching down almost to its level (fig. 12). It is not a long time since the two ice bodies were confluent.

The eastern portion of the Fryingpan Glacier drains northeastward and sends forth several cascading torrents which, uniting with others coming from the lesser ice fields to the east, form the Fryingpan River, a brisk stream that joins White River several miles farther north.

Below the Fryingpan Glacier there lies a region of charming flower-dotted meadows named Summer Land, a most attractive spot for camping.

EMMONS GLACIER.[1]

Cloaking almost the entire east side of Mount Rainier is the Emmons Glacier, the most extensive ice stream on the peak (named after Samuel F. Emmons, the geologist and mountaineer who was the second to conquer the peak in 1870). About 5½ miles long and 1¾ miles wide in its upper half, it covers almost 8 square miles of territory. It makes a continuous descent from the summit to the base, the rim of the old crater having almost completely broken down under its heavy névé cascades. But two small remnants of the rim still protrude through the ice and divide it into three cascades. (Fig. 12.) From each of these dark rock islands trails a long medial moraine that extends in an ever-broadening band down to the foot of the glacier.

Conspicuous lateral moraines accompany the ice stream on each side. There are several parallel ridges of this sort, disposed in successive tiers above each other on the valley sides. Most impressively do they attest the extent of the Emmons Glacier's recent shrinking. The youngest moraine, fresh looking as if deposited only yesterday, lies but 50 feet above the glacier's surface and a scant 100 feet distant from its edge; the older ridges, subdued in outline, and already tinged with verdure, lie several hundred feet higher on the slope.

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[1] This glacier is also known locally as White Glacier.

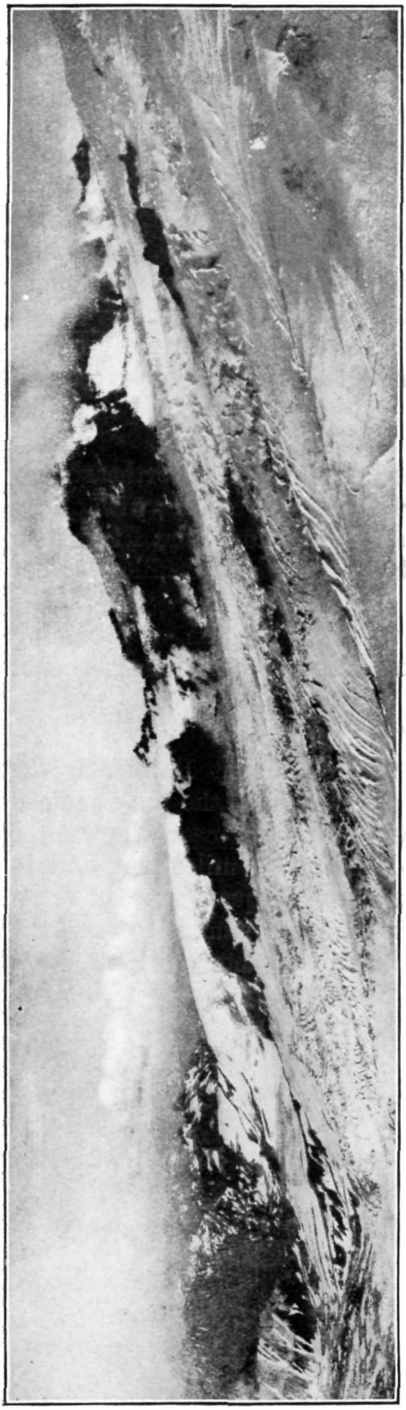

Fig. 12.—Looking south from the "Wedge" across the entire width of Emmons Glacier. In the distance are Little Tahoma, shrouded in mists, and the Fryingpan Glacier.

Photo by Curtis.

The Emmons Glacier, like the Nisqually and the Cowlitz, becomes densely littered with morainal débris at its lower end, maintaining, however, for a considerable distance a central lane of clear ice. The stream which it sends forth, White River, is the largest of all the ice-fed streams radiating from the peak. It flows northward and then turns in a northwesterly direction, emptying finally in Puget Sound.

WINTHROP GLACIER.

On the northeast side of the mountain, descending from the same high névés as the Emmons Glacier, is the Winthrop Glacier. Not until halfway down, at an elevation of about 10,000 feet, does it detach itself as a separate ice stream. The division takes place at the apex of that great triangular interspace so aptly named "the Wedge." Upon its sharp cliff edge, Steamboat Prow (fig. 13), the descending névés part, it has been said, like swift-flowing waters upon the dividing bow of a ship at anchor. The simile is an excellent one; even the long foam crest, rising along the ship's side, is represented by a wave of ice.

Undoubtedly the Wedge formerly headed much higher up on the mountain's flank. Perhaps it extended upward in the form of a long, attenuated "cleaver." It is easy to see how the ice masses impinging upon it have reduced it to successively lower levels. They are still unrelentingly at work. It is on the back of the Wedge, it may be added here, that is situated that small ice body which Maj. Ingraham named the Inter Glacier. That name has since been applied in a generic sense to all similar ice bodies lying on the backs of "wedges."

Of greatest interest on the Winthrop Glacier are the ice cascades and domes. (Figs. 13 and 14.) Evidently the glacier's bed is a very uneven one, giving rise to falls and pools, such as one observes in a turbulent trout stream. The cascades explain themselves readily enough, but the domes require a word of interpretation. They are underlain by rounded bosses of especially resistant rock. Over these the ice is lifted, much as is the water of a swift mountain torrent over submerged boulders. Immediately above

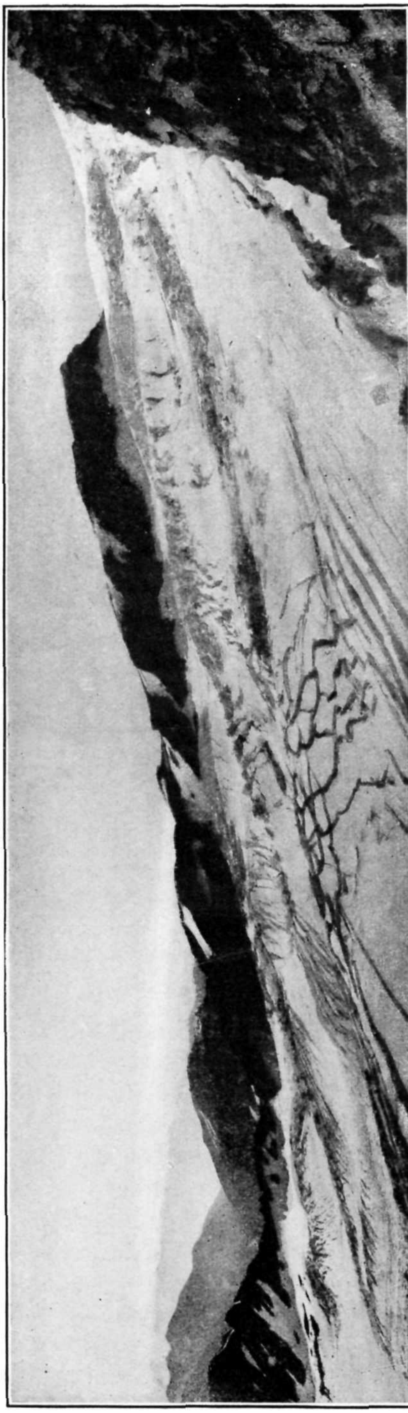

Fig. 13.—The cascades and domes of Winthrop Glacier. In the distance is the "Wedge," with "Steamboat Prow" parting the descending névés.

Photo by Curtis.

each obstruction the ice appears compact and free from crevasses, but as it reaches the top and begins to pour over it breaks, and a network of intersecting cracks divides it into erect, angular blocks and fantastic obelisks. Below each dome there is, as a rule, a deep hollow partly inclosed by trailing ice ridges, analogous to the whirling eddy that occurs normally below a bowlder in a brook. Thus does a glacier simulate a stream of water even in its minor details.

The domes of the Winthrop Glacier measure 50 to 60 feet in height. A sample of the kind of obstruction that produces them appears, as if specially provided to satisfy human curiosity, near the terminus of the glacier. There one may see, close to the west wall of the troughlike bed, a projecting rock mass, rounded and smoothly polished, over which the glacier rode but a short time ago.

FIG. 14.—A CREVASSED DOME ON THE LOWER WINTHROP GLACIER.

Photo by Geo. V. Caesar.

Another feature of interest sometimes met with on the Winthrop Glacier, and for that matter also on the other ice streams of Mount Rainier, are the "glacier tables." These consist of slabs of rock mounted each on a pedestal of snow and producing the effect of huge toadstools. The slabs are always of large size, while the pedestals vary from a few inches to several feet in height.

The origin of the rocks may be traced to cliffs of incoherent volcanic materials that disintegrate under the frequent alternations of frost and thaw and send down periodic rock avalanches, the larger fragments of which bound out far upon the glacier's surface.

The snow immediately under these large fragments is effectually protected from the sun and does not melt, while the surrounding snow, being unprotected, is constantly wasting away, often at the rate of several inches per day. Thus in time each rock is left poised on a column of its own conserving. There is, however, a limit to the height which such a column can attain, for as soon as it begins to exceed a certain height the protecting shadow of the capping stone no longer reaches down to the base of the pedestal and the slanting rays of the sun soon undermine it. More commonly, however, the south side of the column becomes softened both by heat transmitted from the sun-warmed south edge of the stone, as well as by heat reflected from the surrounding glacier surface and as a consequence the table begins to tilt. On very hot days, in fact, the inclination of the table keeps pace with the progress of the sun, much after the manner of a sun-loving flower, the slant being to the southeast in the forenoon and to the southwest in the afternoon. As the snow pillar increases in height it becomes more and more exposed and the tilting is accentuated until at last the rock slides down.

In its new position the slab at once begins to generate a new pedestal, from which in due time it again slides down and so the process may be repeated several times in the course of a single summer, the rock shifting its location by successive slips an appreciable distance across the glacier in a southerly direction.

As has been stated, the slabs on glacier tables are always of large size. This is not a fortuitous circumstance; rocks under a certain size, and especially fragments of little thickness, can not produce pedestals; in fact, far from conserving the snow under them, they accelerate its melting and sink below the surface. This is especially true of dark-colored rocks. Objects of dark color, as is well known to physicists, have a faculty for absorbing heat, whereas light-colored objects, especially white ones, reflect it best. Dark-colored fragments of rock lying on a glacier, accordingly, warm rapidly at their upper surface and, if thin, forthwith transmit their heat to the snow under them, causing it to melt much faster than the surrounding clean snow, which, because of its very whiteness, reflects a large percentage of the heat it receives from the sun. As a consequence each small rock fragment and even each separate dust particle on a glacier melts out a tiny well of its own, as a rule not vertically downward but at a slight inclination in the direction of the noonday sun. And thus, in some localities, one may behold the apparently incongruous spectacle of large and heavy rocks supported on snow pillars alongside of little fragments that have sunk into the ice.

There is also a limit to the depth which the little wells may attain; as they deepen, the rock fragment at the bottom receives the sun heat each day for a progressively shorter period, until at last it receives so little that its rate of sinking becomes less than that of the melting glacier surface. Nevertheless it will be clear that the presence of scattered rock débris on a glacier must greatly augment the rate of melting, as it fairly honeycombs the ice and increases the number of melting surfaces. Wherever the débris is dense, on the other hand, and accumulates on the glacier in a heavy layer, its effect becomes a protective one and surface melting is retarded instead of accelerated. The dirt-covered lower ends of the glaciers of Mount Rainier are thus to be regarded as in a measure preserved by the débris that cloaks them; their life is greatly prolonged by the unsightly garment.

CARBON GLACIER.

In many ways the most interesting of all the ice streams on Mount Rainier is the Carbon Glacier, the great ice river on the north side, which flows between those two charming natural gardens, Moraine

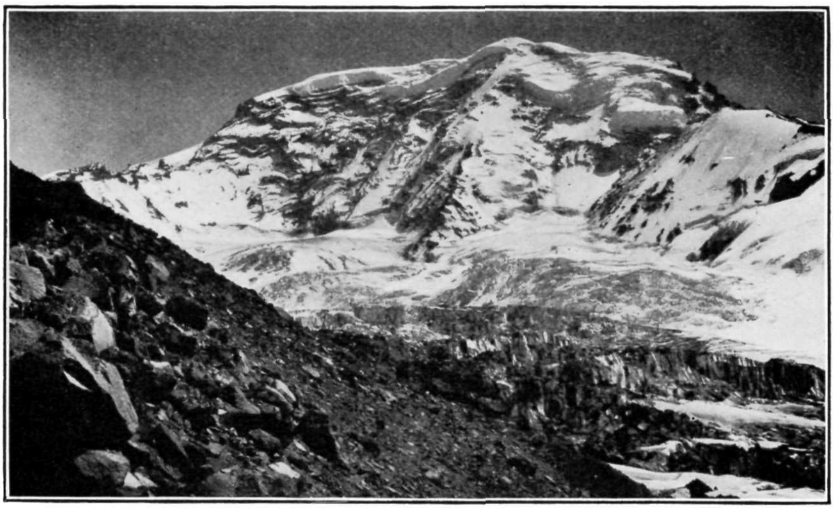

FIG. 15.—THE GREAT AMPHITHEATER OF CARBON GLACIER. THE HEADWALL MEASURES 3,600 FEET IN HEIGHT. GREAT AVALANCHES FALL PERIODICALLY FROM THE SNOW CLIFFS ABOVE, WHICH THEMSELVES ARE 200 TO 300 FEET HIGH.

Photo by Geo. V. Caesar.

Park and Spray Park. (Fig. 19.) The third glacier in point of length, it heads, curiously, not on the summit, but in a profound, walled-in amphitheater, inset low into the mountain's flank. (Fig. 15.) This amphitheater is what is technically known as a glacial cirque, a horseshoe-shaped basin elaborated by the ice from a deep gash that existed originally in the volcano's side. It has the distinction of being the largest of all the ice-sculptured cirques on Mount Rainier, and one of the grandest in the world. It measures more than a mile and a half in diameter, while its head wall towers a sheer 3,600 feet. So well proportioned is the great hollow, however, and so simple are its outlines that the eye finds difficulty in correctly estimating the dimensions. Not until an avalanche breaks from the 300-foot névé cliff above and hurls itself over the precipice with crashing thunder, does one begin to realize the depth of the colossal recess. The falling snow mass is several seconds in descending, and though weighing hundreds of tons, seemingly floats down with the leisureliness of a feather.

These avalanches were once believed to be the authors of the cirque. They were thought to have worn back the head wall little by little, even as a waterfall causes the cliff under it to recede. But the real manner in which glacial cirques evolve is better understood to-day. It is now known that cirques are produced primarily by the eroding action of the ice masses embedded in them. Slowly creeping forward, these ice masses, shod as they are with débris derived from the encircling cliffs, scour and scoop out their hollow sites, and enlarge and deepen them by degrees. Seconding this work is the rock-splitting action of water freezing in the interstices of the rock walls. This process is particularly effective in the great cleft at the glacier's head, between ice and cliff. This abyss is periodically filled with fresh snows, which freeze to the rock; then, as the glacier moves away, it tears or plucks out the frost-split fragments from the wall. Thus the latter is continually being undercut. The overhanging portions fall down, as decomposition lessens their cohesion, and so the entire cliff recedes.

A glacier, accordingly, may be said, literally, to gnaw headward into the mountain. But, as it does so, it also attacks the cliffs that flank it, and as a consequence, the depression in which it lies tends to widen and to become semicircular in plan. In its greatest perfection a glacial cirque is horseshoe shaped in outline. The Carbon Glacier's amphitheater, it will be noticed, consists really of two twin cirques, separated by an angular buttress. (Fig. 15.) But this projection, which is the remnant of a formerly long spur dividing the original cavity, is fast being eliminated by the undermining process, so that in time the head wall will describe a smooth, uninterrupted horseshoe curve.

In its headward growth the Carbon Glacier, as one may readily observe on the map, has encroached considerably upon the summit platform of the mountain, the massive northwest portion of the crater rim of which Liberty Cap is the highest point. In so doing it has made great inroads upon the névé fields that send down the avalanches, and has reduced this source of supply. On the other hand, by deploying laterally, the glacier has succeeded in capturing part of the névés formerly tributary to the ice fields to the west, and has made good some of the losses due to its headward cutting. But, after all, these are events of relatively slight importance in the glacier's career; for like the lower ice fields of the Nisqually, and like most glaciers on the lower slopes of the mountain, the Carbon Glacier is not wholly dependent upon the summit névés for its supply of ice. The avalanches, imposing though they are, contribute but a minor portion of its total bulk. Most of its mass is derived directly from the low hanging snow clouds, or is blown into the cirque by eddying winds. How abundantly capable these agents are to create large ice bodies at low altitudes is convincingly demonstrated by the extensive névé fields immediately west of the Carbon Glacier, to which the name Russell Glacier has been applied. It is to be noted, however, that these ice fields lie spread out on shelves fairly exposed to sun and wind. How much better adapted for the accumulation of snow is the Carbon Glacier's amphitheater. Not only does it constitute an admirably designed catchment basin for wind-blown snow, but an effective conserver of the névés collecting in it. Opening to the north only, its encircling cliffs thoroughly

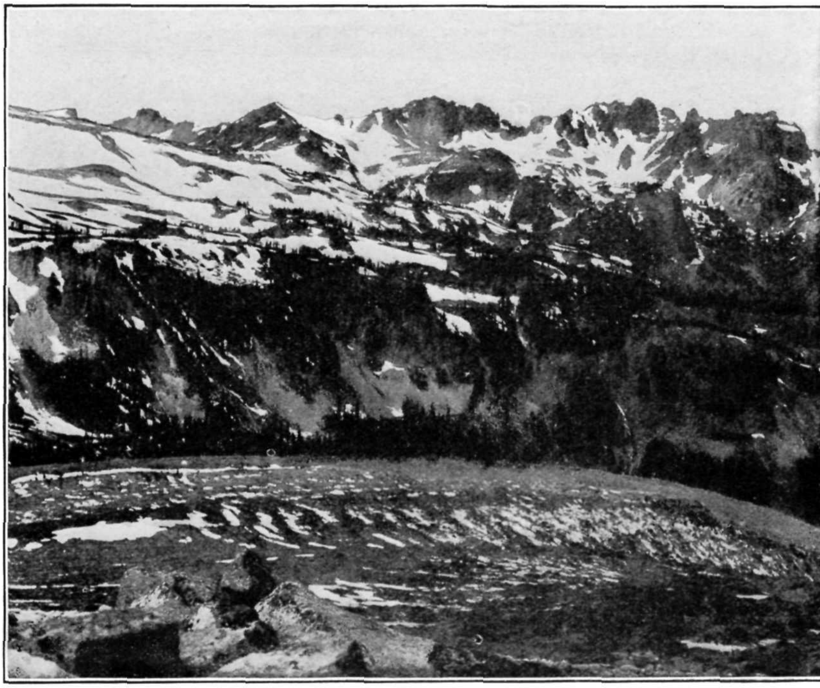

FIG. 16.—LOWER COURSE OF CARBON GLACIER, SHOWING MEDIAL MORAINES. IN THE BACK GROUND ARE THE MOTHER MOUNTAINS.

Photo by Geo. V. Caesar.

shield the contained ice mass from the sun By its very form, moreover, it tends to prolong the glacier's life, for the latter lies compactly in the hollow with a relatively small surface exposed to melting. The cirque, therefore, is at once the product of the glacier and its generator and conserver.

Of the lower course of the Carbon Glacier, little need here be said, as it does not differ materially from the lower courses of the glaciers already described. It may be mentioned, however, that toward its terminus the glacier makes a steep descent and develops a series of parallel medial moraines (fig. 16), and that it reaches down to an elevation of 3,365 feet, almost 600 feet lower than any other ice stream on Mount Rainier. A beautiful cave usually forms at the point of exit of the Carbon River. (Fig. 17.)

MOWICH LAKE AND THE EMPTY CIRQUES AT THE MOUNTAIN'S FOOT.

West of the profound canyon of the Carbon River, there rises a craggy range which the Indians have named the Mother Mountains. (Fig. 16.) From its narrow backbone one looks down on either side into broadly open, semicircular valley heads. Some drain northward to the Carbon River, some southward to the Mowich River. Encircling them run attenuated rock partitions, surmounted by low,

FIG. 17.—ICE CAVE AT LOWER END OF CARBON GLACIER, FROM WHICH THE CARBON RIVER ISSUES.
Photo by Geo. V. Caesar.

angular peaks; while cutting across their stairwise descending floors are precipitous steps of rock, a hundred feet in height. On the treads lie scattered shallow lakelets, strung together by little silvery brooks trickling in capricious courses.

Most impressive is the basin that lies immediately under the west end of the range. Smoothly rounded like a bowl, it holds in its center an almost circular lake of vivid emerald hue—that mysterious body of water, Mowich Lake, formerly known as Crater Lake. (Fig. 18.) The former appellation was an unfortunate misnomer as the basin is not of volcanic origin. It lies in lava and other volcanic rocks, to be sure, but these are merely spreading layers of the cone of Mount Rainier. Ice is the agent responsible for the carving of the hollow. It was once the cradle of a glacier, and that ice mass, gnawing headward and deploying even as the Carbon Glacier does to-day, enlarged its site into a horseshoe basin, a typical glacial cirque. The lake in the center is a strictly normal feature; many glacial cirques possess such bowls, scooped out by the eroding ice masses from the weaker portions of the rock floor; only it is seldom that such features acquire the symmetry of form exhibited by Mowich Lake. The lake-

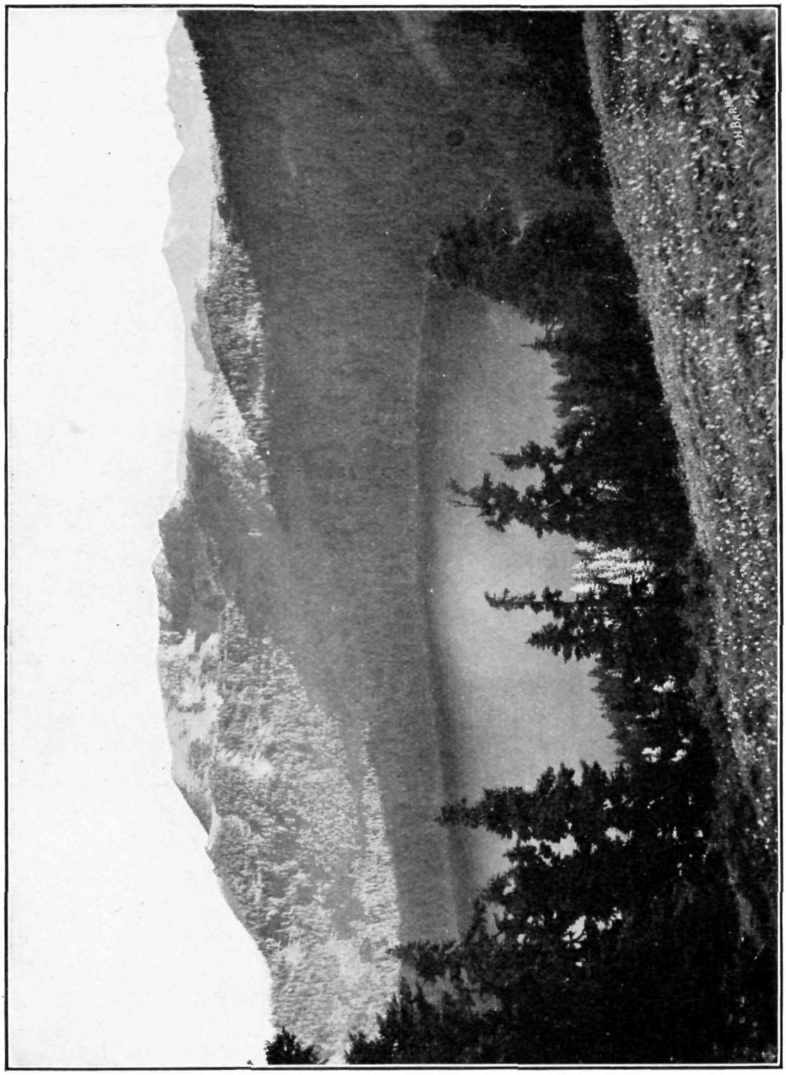

Fig. 18.—Mowich Lake, a glacier basin in the bosom of an abandoned "cirque." The feature is not of volcanic origin, as was once supposed.

Photo by Barnes.

lets observed in the neighboring valley heads—all of which are abandoned cirques—are of similar origin.

As for the skeleton character of the dividing crests, it will be readily seen to be the outcome of the headward gnawing of opposing cirques. In some places, even, the deploying process has attenuated the ridges sufficiently to break them through. West of Mowich Lake is an instance of a crest that has thus been breached.

It is a significant fact that the empty cirques about the Mother Mountains lie at elevations ranging between 4,500 and 6,000 feet; that is, on an average 5,000 feet lower than the cirques on Mount Rainier which now produce glaciers. Evidently the snow line in glacial times lay at a much lower level than it does to-day, and the

Fig. 19.—The northwest side of Mount Rainier and Spray Park, viewed from the Mother Mountains. The sharp white summit is Liberty Cap (14,112 feet).

Copyrighted photo by Curtis.

ice mantle of Mount Rainier expanded not merely by the forward lengthening of its ice tongues but by the birth of numerous new glaciers about the mountain's foot. The large size of the empty cirques and canyons, moreover, leads one to infer that many of these new glaciers far exceeded in volume the ice streams descending the volcano's sides. The latter, it is true, increased considerably in thickness during glacial times, but not in proportion to the growth

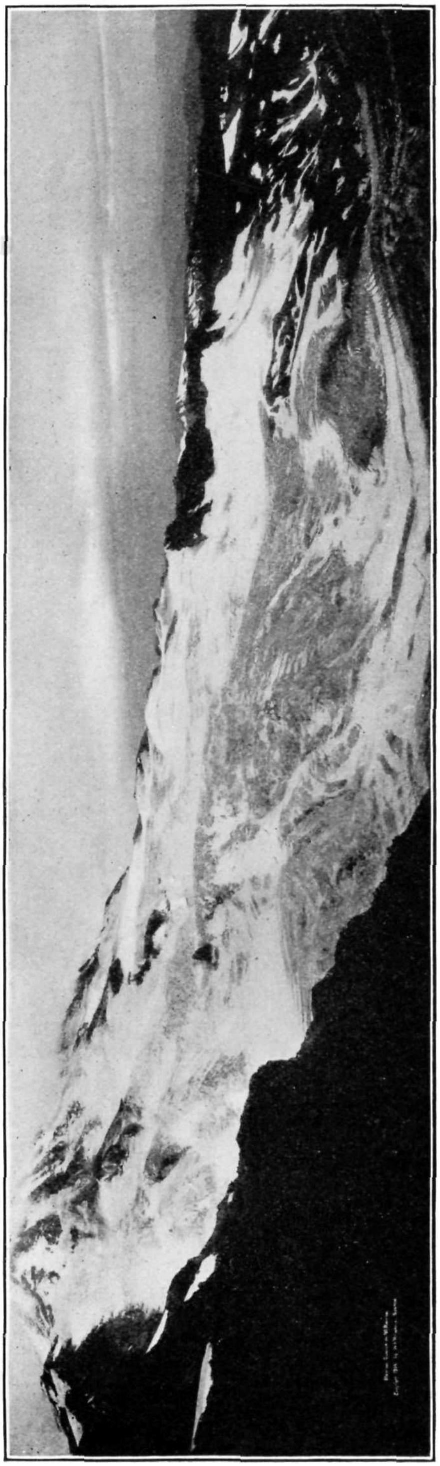

FIG. 20.—THE NORTH MOWICH GLACIER AND THE ICE FIELDS TO THE SOUTH OF IT.
Copyrighted photo by Curtis.

of the low-level glaciers. Nor is this surprising in view of the heavy snowfalls occurring on the mountain's lower slopes. There is good reason to believe, moreover, that the cool glacial climate resulted in a general lowering of the zone of heaviest snowfall. It probably was depressed to levels between 4,000 and 6,000 feet. Not only the cirque glaciers about the Mother Mountains, but all the neighboring ice streams of the glacial epoch originated within this zone, as is indicated by the altitudes of the cirques throughout the adjoining portions of the Cascade Range. By their confluence these ice bodies produced a great system of glaciers that filled all the valleys of this mountain belt and even protruded beyond its western front.

To these extensive valley glaciers the ice flows of Mount Rainier stood in the relation of mere tributaries. They descended from regions of rather scant snowfall, for the peak in those days of frigid climate rose some 10,000 feet above the zone of heaviest snowfall, into atmospheric strata of relative dryness. It may well be, indeed, that it carried then but little more snow upon its summit than it does to-day.

NORTH MOWICH GLACIER.

The North Mowich Glacier is the northernmost of the series of ice bodies on the west flank of Mount Rainier. (Figs. 20 and 21.) Like the Carbon Glacier, it heads in a cirque at the base of the Liberty Cap massif, fed by direct snow precipitation, by wind drifting, and by

Fig. 21.—Telephoto view of west side of Mount Rainier, taken from Electron, at a distance of 20 miles. The main summit, composed of two new cinder cones (14,408 feet) is seen in the center. To the left is Liberty Cap (14,112 feet), and to the right is Point Success (14,150 feet), both remnants of the old crater rim. The glaciers in view are 1, North Mowich; 2, Edmunds; 3, South Mowich; 4, Puyallup; 5, Tahoma.

Photo by Curtis.

avalanches. The cirque is small and shallow, not as capacious even as either of the twin recesses in the Carbon Glacier's amphitheater. As a consequence the ice stream issuing from it is of only moderate volume; nevertheless it attains a length of $3\frac{3}{4}$ miles. This is due in part to the heavy snows that reenforce it throughout its middle course and in part to overflows from the ice fields bordering it on the south. These ice fields, almost extensive enough to be considered a distinct glacier, are separated from the North Mowich Glacier only by a row of pinnacles, the remnants evidently of a narrow rock partition or "cleaver," now demolished by the ice. The lowest and most prominent of the rock spires bears the appropriate name of "Needle Rock" (7,575 feet).

The débris-covered lower end of the glacier splits into two short lobes on a rounded boss in the middle of the channel. This boss, but a short time ago, was overridden by the glacier and then undoubtedly gave rise to an ice dome of the kind so numerous farther up on the North Mowich Glacier and also characteristic of the Winthrop Glacier.

SOUTH MOWICH GLACIER.

Separated from the ice fields of the North Mowich Glacier by a great triangular ice field (named Edmunds Glacier) lies the South Mowich Glacier, also a cirque-born ice stream, heading against the base of the Liberty Cap massif. (Fig. 21.) It is the shortest of the western glaciers, measuring only a scant 3 miles. Aside from the snows accumulating in its ill-shaped cirque it receives strong reenforcements from its neighbor to the south—the Puyallup Glacier.

Toward its lower end it splits into two unequal lobes, the southernmost of which is by far the longer. Sharp-cut rock wedges beyond its front show that when the glacier extended farther down it split again and again.

The north lobe is of interest because the stream that cascades from the Edmunds Glacier runs for a considerable distance under it. In the near future the lobe is likely to recede sufficiently to enable the torrent to pass unhindered by its front.

PUYALLUP GLACIER.

What especially distinguishes the Puyallup Glacier from its neighbors to the north is the great elevation of its cirque. The Carbon, North Mowich, and South Mowich Glaciers all head at levels of about 10,000 feet, but the Puyallup Glacier has its source in the Sunset Amphitheater a full 2,000 feet higher. Encircled by a great vertical wall (fig. 22) that cuts into the Liberty Cap platform from the south, this amphitheater has developed evidently through glacial sapping from a hollow of volcanic origin. From it the Puyallup Glacier descends by a rather narrow chute. Then it expands again to a width of three-fourths of a mile and sends a portion of its volume to the South Mowich Glacier. In spite of this loss it continues to expand, reaching a maximum width of a mile and a total length of

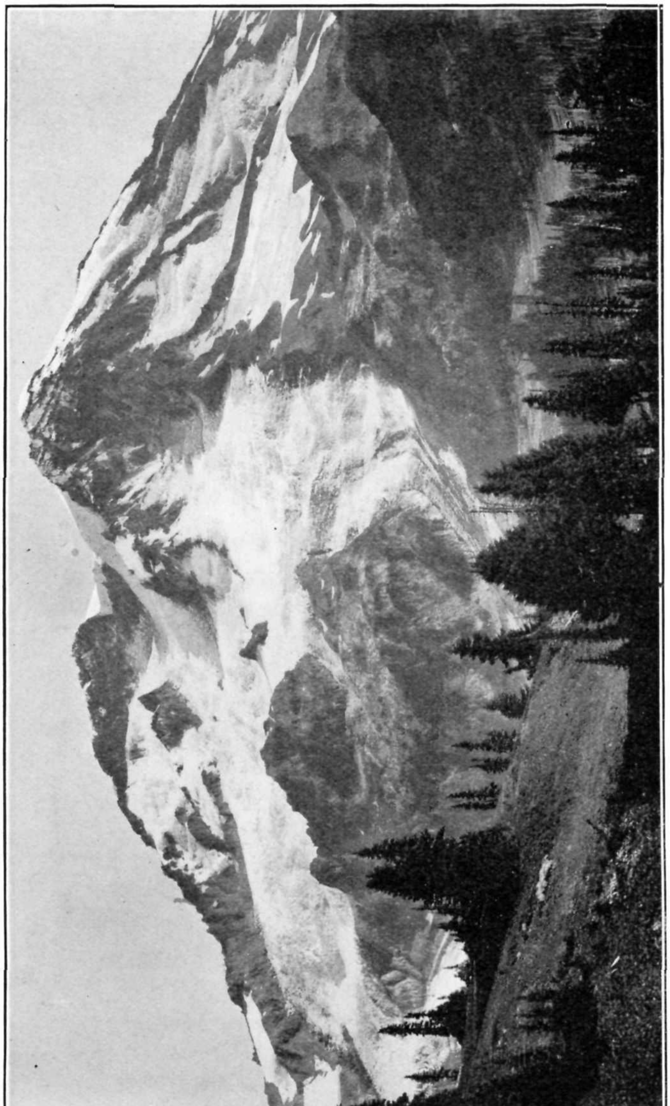

Fig. 22.—The southwest side of Mount Rainier, seen from Indian Henrys Hunting Ground. The highest summit in view is Point Success (14,150 feet). From the cirque under it flows the South Tahoma Glacier. To the left of the peak is the breach through which the Tahoma Glacier descends. The wall under the left summit (Liberty Cap) encircles the Puyallup Cirque. Parting the Tahoma and South Tahoma Glaciers is Glacier Island at whose base the two ice streams meet again.

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4 miles. No doubt this is accounted for by the heavy snowfalls that replenish it throughout its course.

Its lower end consists of a tortuous ice lobe that describes a beautiful curve, flanked on the north by a vertical lava cliff. A lesser lobe splits off to the south on a wedge of rock.

TAHOMA GLACIER.

Immediately south of the Sunset Amphitheater the crater rim of the volcano is breached for a distance of half a mile. (Fig. 22.) Through this gap tumbles a voluminous cascade from the névé fields about the summit, and this cascade, reenforced by a flow from the Sunset Amphitheater, forms the great Tahoma Glacier, the most impressive ice stream on the southwest side. Separated from its northern neighbor by a rock cleaver of remarkable length and straightness, it flows in a direct course for a distance of 5 miles. Its surface, more than a mile broad in places, is diversified by countless ice falls and cataracts.

A mere row of isolated pinnacles indicates its eastern border, and across the gaps in this row its névés coalesce with those of the South Tahoma Glacier. Farther down the two ice streams abruptly part company and flow in wide detours around a cliff-girt, castellated rock mass—Glacier Island it has been named. (Fig. 22.) The Tahoma Glacier, about a mile above its terminus, splits upon a low, verdant wedge and sends a lobe southward which skirts the walls of this island rock, and at its base meets again the South Tahoma Glacier. Here the two ice streams merge and form a single densely débris-laden mass, so chaotic in appearance that one would scarcely take it for a glacier. Numerous rivulets course over its dark surface only to disappear in mysterious holes and clefts. Profound, circular kettles filled with muddy water often develop on it during the summer months, and after a brief existence empty themselves again by subglacial passages or by a newly formed crevasse. So abundant is the rock débris released by melting that the wind at times whips it up into veritable dust storms.

Beautifully regular moraines accompany the ice mass on both sides, giving clear evidence of its recent shrinking.

SOUTH TAHOMA GLACIER.

The partner of the Tahoma Glacier, known as the South Tahoma Glacier, heads in a profound cirque (fig. 22) sculptured in the flanks of the great buttress that culminates in Point Success (14,150 feet). It is interesting chiefly as an example of a cirque-born glacier, nourished almost exclusively by direct snowfalls from the clouds and by eddying winds. In spite of its position, exposed to the midday sun, it attains a length of nearly 4 miles, a fact which impressively attests the ampleness of its ice supply.

In glacial times the glacier had a much greater volume and rose high enough to override the south half of Glacier Island, as is clearly shown by the glacial grooves and the scattered ice-worn boulders on that eminence. As the glacier shrank it continued for some time to send a lobe through the gulch in the middle of the island. Even

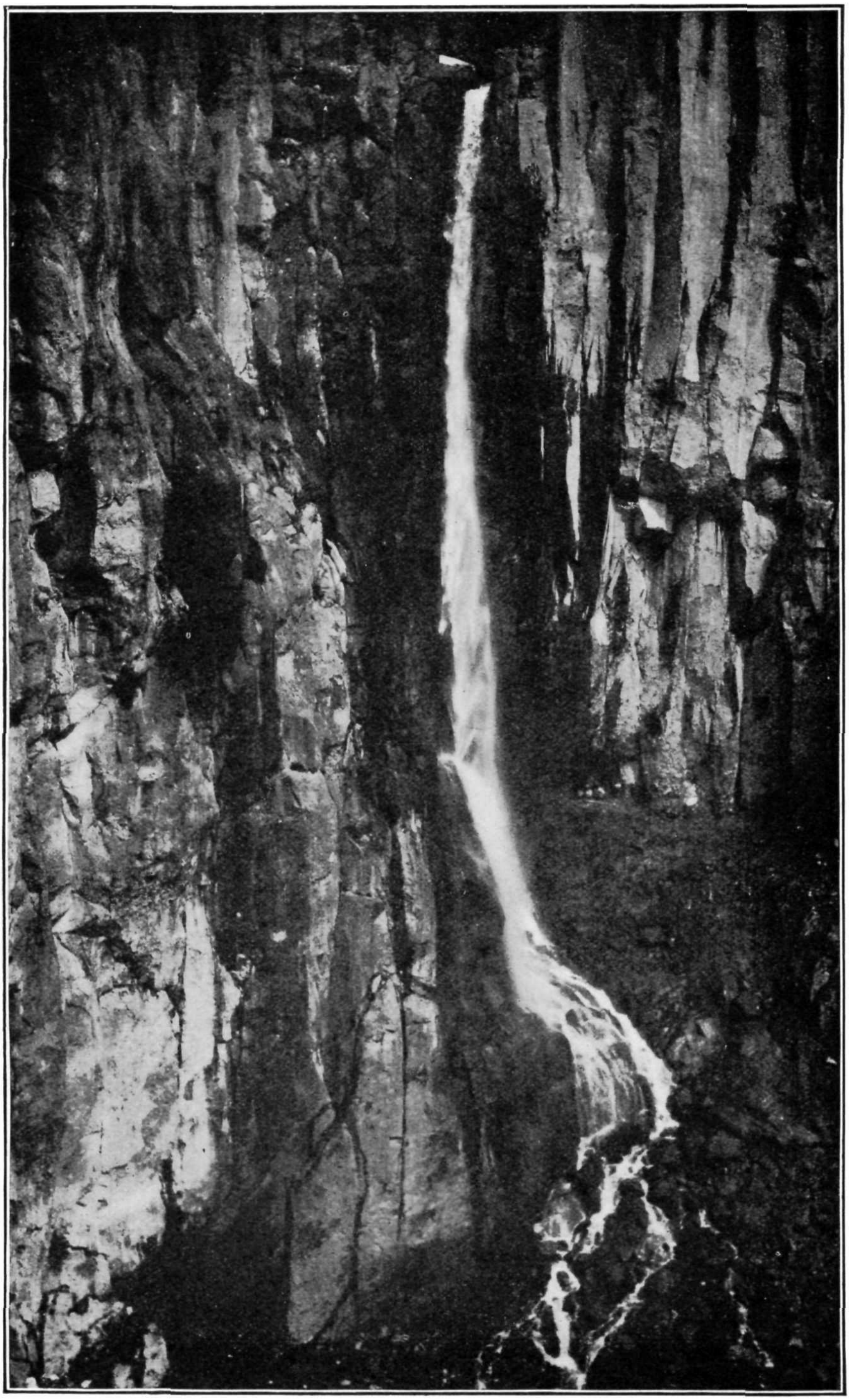

FIG. 23.—PEARL FALLS, A SPECTACULAR PLUNGE OVER A VERTICAL CLIFF OF COLUMNAR BASALT UNDER PYRAMID GLACIER. THE COLUMNS ARE SOLID AND UNBROKEN FOR 200 FEET.

Photo by Curtis.

now a portion of this lobe remains, but it no longer connects with the Tahoma Glacier.

An excellent nearby view of the lower cascades of the South Tahoma Glacier may be had from the ice-scarred rock platform west

FIG. 24.—THE LOWER END OF KAUTZ GLACIER IN ITS BOX CANYON, SEEN FROM THE HEIGHTS OF VAN TRUMP PARK. NOTE THE STRONG MEDIAL MORAINE THAT GRADUALLY DEVELOPS INTO A RIDGE 100 FEET HIGH ABOVE THE ICE; ALSO THE RIVULETS ON THE SURFACE OF THE GLACIER.

Photo by Curtis.

of Pyramid Rock. From that point, as well as from the other heights of Indian Henrys Hunting Ground, one may enjoy a panorama of ice and rock such as is seen in only a few places on this continent. (Fig. 22.)

KAUTZ GLACIER.

East of the South Tahoma Glacier, heading against a great cleaver that descends from Point Success, lies a triangular ice field, or interglacier, named Pyramid Glacier. It covers a fairly smooth, gently sloping platform underlain by a heavy lava bed, and breaking off at its lower edge in precipitous, columnar cliffs. Into this platform a profound but narrow box canyon has been incised by an ice stream descending from the summit névés east of Point Success. This is the Kautz Glacier, an ice stream peculiar for its exceeding slenderness. (See title page.) On the map it presents almost a wormlike appearance, heightened perhaps by its strongly sinuous course. In spite of its meager width, which averages about 1,000 feet, the ice stream attains a length of almost 4 miles and descends to an altitude of 4,800 feet. This no doubt is to be attributed in large measure to the protecting influence of the box canyon.

It receives one tributary of importance, the Success Glacier, which heads in a cirque against the flanks of Point Success. This ice stream supplies probably one-third of the total bulk of the Kautz Glacier, as one may infer from the position of the medial moraine that develops at the point of confluence. In the lower course of the glacier this medial moraine grows in width and height until it assumes the proportions of a massive ridge, occupying about one-third of the breadth of the ice stream's surface.

A singularly fascinating spectacle is that which the moraine-covered lower end of the glacier presents from the heights of Van Trump Park. (Fig. 24.) A full 1,000 feet down one looks upon the ice stream as it curves around a sharp bend in its canyon.

A short distance below the glacier's terminus, the canyon contracts abruptly to a gorge only 300 feet in width. So resistant is the columnar basalt in this locality that the ice has been unable to hew out a wider passage. Not its entire volume, however, was squeezed through the narrow portal; there is abundant evidence showing that in glacial times when the ice stream was more voluminous it overrode the rock buttresses on the west side of the gorge.

VAN TRUMP GLACIER.

The name of P. B. Van Trump, the hardy pioneer climber of Mount Rainier, has been attached to the interglacier situated between the Kautz and the Nisqually glaciers. This ice body lies on the uneven surface of an extensive wedge that tapers upward to a sharp point—one of the remnants of the old crater rim. A number of small ice fields are distributed on this wedge, each ensconced in a hollow inclosed more or less completely by low ridges. (See title-page.) By gradually deploying each of these ice bodies has enlarged its site, and thus the dividing ridges have been converted into slender rock walls or cleavers. In many places they have even been completely consumed and the ice fields coalesce. The Van Trump Glacier is the most extensive of these composite ice fields. The rapid melting which it has suffered in the last decades, however, has gone far toward dismembering it; already several small ice strips are threatening to become separated from the main body.

In glacial times the Van Trump Glacier sent forth at least six lobes, most of which converged farther down in the narrow valleys traversing the attractive alpine region now known as Van Trump Park. This upland park owes its scenic charm largely to its manifold glacial features and is diversified by cirques, canyons, lakelets, moraines, and waterfalls.

CONCLUSION.

In the foregoing descriptions the endeavor has been to make clear how widely the glaciers of Mount Rainier differ in character, in situation, and in size. They are not to be conceived as mere ice tongues radiating down the slopes of the volcano from an ice cap on its crown. There is no ice cap, properly speaking, and there has perhaps never been one at any time in the mountain's history, not even during the glacial epochs.

Several of the main ice streams head in the névés gathering about the summit craters, but a larger number originate in profound amphitheaters carved in the mountain's flanks, at levels fully 4,000 feet below the summit. In the general distribution of the glaciers the low temperatures prevailing at high altitudes have, of course, been a controlling factor; nevertheless in many instances their influence has been outbalanced by topographic features favoring local snow accumulation and by the heavy snowfalls occurring on the lower slopes.

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