something of this region, a great deal of our own ignorance. I must confess, as one who has been in a portion of that region, that I have learned much that has been new to me, and I have been specially interested in the allusion which Mr. Neave made to-night to the character of the native inhabitants of those regions. It is one of the most difficult problems that people in a new country have to deal with, how to make their work fit in, if I may say so, with the native habits, so as not to dislocate the order of ideas to which natives are accustomed too rapidly. We have to develop those territories in the best way possible, so as to make the best use of the material at our disposal. We have to displace the primitive methods of agriculture with something that is better, and to teach methods that will enable natives to satisfy their wants with less effort and better results than is possible at present. That great work, I hope, is being done gradually and effectively by the posts which the Administration of the British South Africa Company is establishing throughout these vast territories, of which you have got an illustration to-night in the admirable photograph which Mr. Neave has shown us of the post which was being established in the extreme north at the time of his visit.

Dr. Arthur Haydon : There is one point we have just heard a little about, and that is of the progress which is being made in the treatment of sleeping-sickness. We have seen various models of houses, and some example of the inoculation treatment. I should like to know what progress is being made in the control of the disease under the present conditions.

Mr. Neave : I think I might say very stringent regulations are being made in Northern Rhodesia to prevent the spreading of it, but I think it is more a question to be answered by the Administration of the country than by myself.

The President (after the paper): Mr. Neave has shown us how the highlands separate the country into three districts; how they prevent migration of animals from one part to another; and how they have created districts where the process of evolution has run different courses. To-night's paper is, in fact, the account of a Boundary Commission dealing with the boundaries between various animal kingdoms, and I am sure you will wish me in your name to thank Mr. Neave for the charming description he has given of his labours in this direction. All the speakers have joined in wishing good luck to Mr. Neave on his coming mission to Africa, and have expressed their sincere hope, in which we all join, that these labours will be successful.

THE CYCLE OF MOUNTAIN GLACIATION.*

By Prof. **WILLIAM HERBERT HOBBS**, University of Michigan.

CONTENTS.

---

* Read before the Section of Geography of the British Association for the Advancement of Science at the Winnipeg meeting, August 27, 1909. When not otherwise credited, the views reproduced in this paper are from photographs taken by the author, mainly during the summers of 1908 and 1909.

SCULPTURING OF THE UPLAND.

The upland dissected—Modification in the plan of the cirque as maturity is approached—Grooved and fretted uplands—Characteristic relief-forms of the fretted upland—The col and its significance—The advancing hemicycle.

CLASSIFICATION OF GLACIERS BASED UPON COMPARATIVE ALIMENTATION.

Relation of glacier to its bed—Nivation type—Ice-cap type—Piedmont type—Transection type—Expanded-foot type—Valley or dendritic type—Tidewater type—Inherited basin type—Alpine type—Horseshoe type.

TERMINATION OF THE CYCLE OF GLACIATION.

Configuration of the glacier bed when uncovered—Water-erosion within the valley during retirement of the glacier.

THE CIRQUE AND ITS RECESSION.

Introduction.—With the advance of knowledge concerning the sequence of conditions affecting glaciers, it has come to be generally recognized that for any given district the factor of supreme importance is temperature, a very moderate change in the average annual temperature being sufficient to profoundly transform a district, the aspect of which is temperate, and to furnish it with snow-fields and mountain glaciers. These slight variations in average annual temperature involve less important geological changes than must be invoked in order to greatly modify the annual precipitation. Thus it has been recently estimated that a fall of but 3° (Fahr.) in the average annual temperature would result in the formation of small glaciers within the area of the Scottish Highlands, while a like fall of 12° within the Laurentian Lake district of North America would suffice to bring on a period of glaciation.

With the probability that such climatic changes would be initiated slowly, the first visual evidence of the changing condition within all districts of accentuated relief would probably be a longer persistence of winter snows in the more elevated tracts; which accumulations of snow would eventually contribute a remnant to those of the succeeding winter, and so bring on a cycle of glaciation. From this beginning the cycle is an advancing one until a culmination is reached corresponding to the most rigorous of the climatic conditions. A resumption of a more genial climate would result in a reverse series of changes, terminating so soon as the winter's fall of snow is insufficient to produce permanent snow-drifts even in the higher areas. It is therefore proper to speak of the *advancing* and the *receding hemicycles of glaciation.*

Mountain versus *Continental Glaciers.*—The land-forms which result from glaciation within districts of strong relief when not entirely submerged beneath snow and ice, are totally different from those which are sculptured beneath a glacier of continental dimensions. Examination of university text-books and experience with students have alike convinced the writer that this difference has not been sufficiently accented. In part, this may be explained by a rather general tendency to treat the subject of erosion by glaciers in mountains from studies made especially in the lower altitudes.* A quite general neglect of those special conditions of denudation which are operative in high-level areas of glaciers is, it is believed, responsible for an over-emphasis laid upon the U-shaped trunk valley and the hanging tributary valley, important as these features are.† This over-emphasis can, perhaps, be best illustrated by reference to a series of three successive idealistic sketches, executed with great skill by an eminent American geographer, and intended to develop especially the erosion forms which result from mountain glaciers.‡ The low-level sculpturing expressed by these sketches is, in the opinion of the writer, admirable, and a true rendering of nature. It is the failure to recognize any additional process of erosion operative in higher altitudes which destroys the value of the high-level sculpturing displayed.

So far as low-level mountain glaciation is concerned, the erosive processes are pretty well understood to be identical with those of continental glaciers, namely, abrasion and plucking. The larger proportion of projecting rock-masses in the case of mountain glaciers will, however, presume a greater emphasis upon lateral undercutting from the operation of both of these processes acting conjointly. It is the operation of an additional denuding process of the first importance, head-wall erosion, that differentiates all types of mountain glaciers from continental ones. This distinguishing process is responsible for the development of the *cirque* (Ger. *cirkus*), which is known by a variety of names in different glacier districts. In Scotland it has been generally referred to as the *corrie*, in Wales as the *cwm*, and in Scandinavia as the *botn* or *kjedel* (*kessel*). In the scientific literature of the subject, the Bavarian-Austrian word *kahr* has been used with increasing frequency for the same topographic feature. In view of this diversity in resultant topography, and despite their close genetic relationships, we would do well to sharply separate in our discussions continental glaciers from all other types, which latter we may include under the broad term of mountain glaciers.

The Glacial Amphitheatre in Literature.—It is safe to say that no topographic feature is more characteristic of the mountains which have

---

* "The visitor replied that he was a valley climber, not a mountain climber. He found sufficient pleasure at the mountain base, and such was my case also. Mountain-tops are indeed worthy objects of a climber's ambition, but if one wishes to get at the bottom facts, let him examine the valleys" (W. M. Davis, "Glacier Erosion in the Valley of the Ticino," 'Appalachia,' vol. **9**, 1901, p. 137).

† On hanging valleys, see especially W. M. Davis, *Proc. Boston Soc. Nat. Hist.*, vol. **29**, 1901, pp. 273–322; and G. K. Gilbert, 'Harriman Alaska Expedition,' vol. **3**, "Glaciers."

‡ W. M. Davis, "The Sculpture of Mountains by Glaciers," *Scot. Geogr. Mag.*, vol. **22**, 1906, figs. 1–3.

been occupied by glaciers than is the cirque. Approaching a range from a considerable distance, there is certainly no form which so quickly forces itself upon the attention. The U-shaped valley and the hanging side valley, important as these are, are here decidedly less impressive. Yet the great majority of works upon the subject, by ignoring the significance of the cirque, allow the reader to assume that the glaciers discovered the cirques ready formed to gather in the snows for their nourishment. Even the standard work of Chamberlin and Salisbury is open to this objection.*

Despite the attitude of the general texts, which so largely determine what might be called the accepted body of doctrine of a science, there are a number of papers dealing with the origin of the cirque. One of the first to recognize the cirque as a product of glacial erosion was Tyndall, whose keen mind has so illumined the page of mountain glaciation.† In opposition to his view, Bonney published in 1871 a somewhat elaborate article, in which the line of argument was: (1) that the Alpine cirques must have been produced by the same agency which shaped the valleys below them; (2) that the valleys were not moulded by glaciers; and hence, (3) the cirques must have been retained from the pre-glacial land surface.‡ The published discussion of this paper developed no opposition to the view, though Doctor, now Sir Archibald, Geikie stated that he could not see his way to account for the vertical walls surrounding the cirque. On the other hand, the Italian Professor Gastaldi recognized the work of the ice in the shaping of cirques in the Italian Alps, § as Helland did in those of Norway. The latter believed that excessive weathering in the rock above the *névé* played an important *rôle*, though abrasion by the ice upon the floor was the larger factor.‖ Later, Russell in America,¶ Wallace in England,** and de Martonne on the continent, †† further advocated the glacial origin of cirques. Penck has explained the development of cirques as the

---

* 'Geology,' vol. 1: "Processes and their Results," 1904, pp. 272-276, and especially fig. 250. See also 'College Geology,' by the same authors, 1909, p. 256.

† John Tyndall, "On the Conformation of the Alps," *Phil. Mag.*, Ser. 4, vol. **24**, 1862, pp. 169-173.

‡ T. G. Bonney, "On the Formation of 'Cirques,' with their Bearing upon Theories attributing the Excavation of Mountain Valleys mainly to the Action of Glaciers," *Quart. Jour. Geol. Soc.*, vol. **27**, 1871, pp. 312-324.

§ B. Gastaldi, "On the Effects of Glacier-erosion in Alpine Valleys," *ibid.*, vol. **29**, 1873, pp. 396-401.

‖ Amund. Helland, "Ueber die Vergletscherung der Färöer, sowie der Shetland und Orkney Inseln," *Zeitsch. d. Deutsch. Geol. Gesellsch.*, vol. **31**, 1878, pp. 716-755, especially pp. 731-733.

¶ I. C. Russell, "Quarternary History of Mono Valley, California," '8th Ann. Rept. U.S. Geol. Surv.,' 1889, pp. 352-355.

** A. R. Wallace, "The Ice Age and its Work," *Fortnightly Review*, vol. **60**, 1893, especially p. 757.

†† E. de Martonne, "Sur la période glaciaire dans les Karpates méridionales," *C. R. Acad. Sci. Paris*, vol. **129**, 1899, pp. 894-897; *ibid.*, vol. **132**, 1901, p. 362.

result of sub-glacial weathering—alternate thawing and freezing—beneath glaciers during the incipient stage particularly ("hanging glaciers").* This eroding process, he considered, would be greatest toward the middle of the glacier, so that the original concavity of the slope beneath it would be more and more deepened. It must be evident that this explanation does not properly account for the steepness of the cirque walls, which it will be remembered could not be accounted for by Geikie.

Attention was again directed to the process of cirque shaping by an important paper of Richter's published in 1896.† His studies having been made in Norway, where a country rounded and polished by the continental glacier had been only partly invested by mountain glaciers, the cirques from the latter formed individual "niches" in the uplands. Following Gastaldi, the form of these niches was happily likened to that of an armchair (see Fig. 1).‡ Richter observed that the steep walls of the cirque were the only surfaces unglaciated, and hence he concluded that they were not to be ascribed to ice-abrasion, but to weathering. The moulding of the cirque floor he ascribed to abrasion, and, referring to the cirque walls, said—

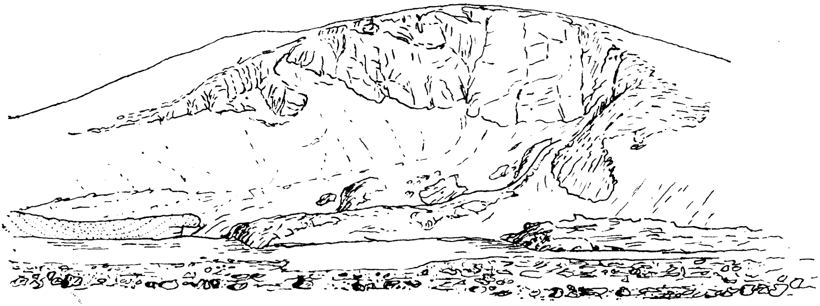

FIG. 1.—A GLACIAL CIRQUE EXCAVATED FROM THE PLEISTOCENE GLACIATED SURFACE OF NORWAY. THE NORTHERN KJEDEL ON GALDHÖPIG. (AFTER E. RICHTER.)

"The material loosened by weathering is removed by the glacier or slides off over the *névé* to form either actual moraines, or, at least, *névé* moraines. These walls do not bury themselves in their own *débris*, and in consequence continually offer fresh surfaces for attack. Finally, the wearing away of the cirque floor by the glacier co-operates to keep the cirque walls on a steep angle and facilitates avalanching."

---

* Albrecht Penck, 'Morphologie der Erdoberfläche,' vol. **2**, 1894, pp. 307–308, figs. 17–20.

† E. Richter, "Geomorphologische Beobachtungen aus Norwegen," *Sitzungsber. Wiener Akad., Math.-Naturw.-Kl.*, vol. **105**, 1896, Abt. I., pp. 152–164, 2 pls. and 2 figs.

‡ See topographic definition of the cirque by De Martonne ("La periode glaciaire dans les Karpates meridionales," *C.R.*, 9$^{\text{e}}$ Cong. Geol. Intern., Vienna, 1903, pp. 694, 695).

In a more extended and later paper,[*] treating especially the formation of cirques, Richter has explained that his view differs from that of Helland only in ascribing greater importance to weathering upon the cirque walls and less to abrasion upon the cirque floor. Inasmuch as the excessive weathering of cirque walls, as maintained by Richter, is above the surface of the *névé*, a horizontal plane of denudation should develop at that level. No evidence of this plane being discovered, its absence is explained by Richter through abrasion from the snowbank which would collect upon it so soon as formed. This is the fatal weakness of the Richter hypothesis.

Relation of Cirque to Bergschrund.—Up to the beginning of the twentieth century, as we have seen, few geologists had greatly concerned themselves with the erosion conditions at high levels, the work of Richter being on the whole the most comprehensive. The whole subject of cirque erosion was rather generally ignored, as it is indeed to-day. Sir Archibald Geikie, referring to the corries of the Scottish Highlands,[†] wrote—

"The process of excavation seems to have been mainly carried on by small convergent torrents, aided of course by the powerful co-operation of the frosts that are so frequent and so potent at these altitudes. Snow and glacier ice may possibly have had also a share in the task."

Writing in the same year, Reusch ascribed the Norwegian cirques to the action of surface water descending through the crevasses over falls in the continental glacier which, in Pleistocene times, overrode the country;[‡] and the following year, Bonney reiterated his view that cirques were the product of water-erosion.[§] Only a few years before, Gannett had curiously explained the origin of cirques through the wear of avalanched snow and ice upon the cirque floor, likening the erosive process to that which takes place beneath a waterfall.[||]

The discovery of the method by which the glacier excavates its amphitheatre must be credited to a keen American topographer-geologist, Mr. Willard D. Johnson of the United States Geological Survey.[¶] In

---

[*] E. Richter, "Geomorphologische Untersuchungen in den Hochalpen," *Pet. Mitt.*, Ergänz. Heft 132, 1900, pp. 1–103, pls. 1–6.

[†] 'Scenery of Scotland,' p. 183 (revised in 1901).

[‡] H. Reusch, 'Norges Geologiske Undersögelse,' No. 32, Aarbog for 1900, 1901, pp. 259, 260.

[§] "Alpine Valleys in Relation to Glaciers," *Quart. Jour. Geol. Soc.*, vol. **58**, 1902, p. 699.

[||] "The effect is precisely like a waterfall. The falling snow and ice dig a hollow depression at the foot of the steep descent just as water does" (*Nat. Geogr. Mag.*, vol. **9**, 1898, p. 419).

→ W. D. Johnson, "An Unrecognized Process in Glacial Erosion" (read before the Eleventh Annual Meeting of the Geological Society of America), *Science*, N.S., vol. **9**, 1899, p. 106; also "The Work of Glaciers in High Mountains" (lecture before the National Geographic Society), *ibid.*, pp. 112, 113. The first public formulation of the doctrine by Mr. Johnson was in an address before the Geological Section of the Science Association of the University of California, delivered September 27, 1892.

fact, to him and to another American topographer, Mr. François E. Matthes, we owe the most of what is known from observation concerning the initiation and the development of the glacier cirque. Reasoning that abrasion was incompetent to shape the amphitheatre, Johnson early surmised that the great gaping crevasse which so generally parallels the cirque wall and is termed the *Bergschrund*, went down to the rock beneath the *névé*, and that it was no accident that glaciated mountains alone "abound in forms peculiarly favourable to snowdrift accumulation." These observations were made as early as 1883, and in order to test his theory, Johnson allowed himself to be lowered at the end of a rope 150 feet into the Bergschrund of the Mount Lyell glacier until he reached the bottom. He found a rock floor to stand upon, and rock extended up for 20 feet upon the cliff-side. We may here quote his terse sentences, since too little attention has been accorded this important observation.*

"The glacier side of the crevasse presented the more clearly defined wall. The rock face, though hard and undecayed, was much riven, the fracture planes outlining sharply angular masses in all stages of displacement and dislodgment. Several blocks were tipped forward and rested against the opposite wall of ice; others quite removed across the gap were incorporated in the glacier mass at its base."

Everywhere in the crevasse there was melting, and thin scales of ice could be removed from the seams in the rock. The bed of the glacier, elsewhere protected from frost-work, was here subjected to exceptionally rapid weathering. By maintaining the rock wall continually wet, and by admitting the warm air from the surface during the day, diurnal changes of temperature here resulted in very appreciable mechanical effects, whereas above the *névé* only the seasonal effects were important.

This observation of Johnson is, it will be observed, in contrast with the suppositions of Richter, who believed that the maximum sapping upon the cirque wall occurred above the surface of the *névé*. The function of the Bergschrund, which separates the stationary from the moving snow and ice within the *névé*, is thus found to be of paramount importance in the shaping of the amphitheatre.

The Schrundline.—That a sharp line is observable in abandoned cirques separating the accessible from the non-scalable portions of the wall, has been pointed out by Gilbert, who has given his support to the view of Johnson, and confirmed it by observations of his own.† Penck, on the other hand, the following year revived the view of Richter that excessive sapping occurs upon the cirque walls *above* the *névé* surface,

---

* W. D. Johnson, "Maturity in Alpine Glacial Erosion," *Jour. Geol.*, vol. **12**, 1904, pp. 569-578 (read at Intern. Congr. Arts and Sciences, St. Louis, 1904).

† G. K. Gilbert, 'Systematic Asymmetry of Crest-lines in the High Sierras of California," *Jour. Geol.*, vol. **12**, 1904, pp. 579-588. See also E. C. Andrews, *ibid.*, vol. **14**, 1906, p. 44.

though he calls in the Bergschrund in order to gather in and remove the rock fragments which fall from the cliff.*

Initiation of the Cirque—Nivation.—Johnson's studies upon the processes of cirque shaping, had shown how a nearly perpendicular cirque wall is steadily cut backward through basal sapping at the bottom of the Bergschrund. The problem of how the snowbank, which was the inevitable forerunner of the glacier, had transformed the relatively shallow depression which it presumably discovered into the steep-walled amphitheatre, he did not attempt to solve. Yet the nourishing catchment basin is a prerequisite to the existence of the normal glacier. The solution of this problem has been suggested by another American topographer, Mr. F. E. Matthes.† In the Bighorn mountains of Wyoming he has found exceptional opportunities for this study. Owing to the low precipitation within the region and the consequently inadequate nourishment of glaciers, a large part of the pre-glacial surface still remains. There is, therefore, represented within the district every gradation from valleys which were occupied by snow during a portion only of the year to those which were the beds of glaciers many miles in length. Both small glaciers and high-level drifts of snow still remain in a number of places.

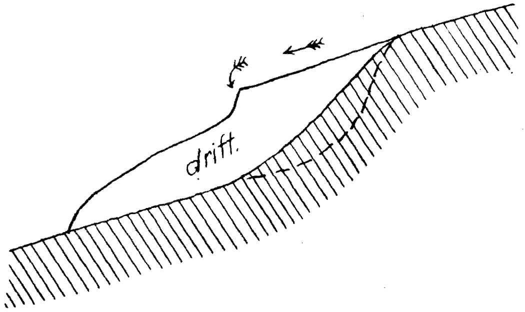

FIG. 2.—CROSS-SECTION OF A STEEP SNOWDRIFT SITE, SHOWING RECESSION BY NIVATION. (AFTER MATTHES.)

Mr. Matthes has demonstrated that the snowbanks without movement steadily deepen the often slight depressions within which they lie by a process which he has called *nivation*—excessive frost-work about the receding margins of the drifts during the summer season. The ground being continually moist in this belt due to the melting of the snow, the water penetrates into every crevice of the underlying rock, so that it is rent during the nightly freezing. Rock material thus broken up and eventually comminuted is removed by the rills of water from the melting snow.‡ By this process the original depression is deepened, and, if upon a steep slope, its wall becomes recessed (see Fig. 2).

---

* Albrecht Penck, "Glacial Features in the Surface of the Alps," *Jour. Geol.*, vol. **13**, 1905, pp. 15–17.

† François E. Matthes, "Glacial Sculpture of the Bighorn Mountains, Wyoming," '21st Ann. Rept. U.S. Geol. Surv.,' 1899–1900, pp. 167–190.

‡ Mainly in later seasons.

The occupation of a V-shaped valley by snow, as Matthes has further shown, tends through the operation of this process to transform it into one of U-section, since the weathered rock material upon the slopes is transported by the rills and deposited upon the floor. All gradations from nivated to glaciated forms are to be found in the Bighorn range.

During the past field season the writer has taken the opportunity to examine *névé* regions and high-level snowbanks in a number of districts, with the result of confirming the importance of the nivation process as outlined by Matthes. In Figs. 3 and 4 are shown two snowbanks which were photographed on July 25 near the summit of Quadrant mountain, in the Gallatin range of the Yellowstone National Park. The gently sloping surface of this mountain represents the pre-Glacial upland unmodified by Pleistocene glaciation. Though between 9000 and 10,000 feet in height, it supports a rich herbage, and is a favourite grazing-ground of the elk. In Fig. 3 the snowbank is seen surrounded by a wide zone within which no grass is growing, but where a finely comminuted brown soil is becoming a prey to the moving water. Fig. 4 exhibits another bank lying in the depression which it has largely hollowed. At its lower end (at the left) is seen an apron of fine brown mud deposited by the over-burdened stream as it issues from beneath the drift.

An interesting question is at what point the snow-field or *névé* will, by taking on a motion of translation, assume the functions of a glacier. At this stage of transition the Bergschrund should first make its appearance. Comparison of nivated and glaciated slopes in the Bighorn mountains led Matthes to think that upon a 12 per cent. grade the *névé* must attain a thickness of at least 125 feet before motion is possible. Another possible method of approaching this problem has suggested itself to the writer. In mountains like the Selkirks, with steep slopes terraced by the flatly dipping layers in the rock, a peculiar type of small cliff glacier is nourished high above the larger snow-fields of the range and avalanched upon the lower shelves so as to leave vertical sections open to study (see Fig. 5). Perhaps because of their small size these cliff glaciers have not developed cirques, though a Bergschrund parallels the generally straight head-wall. Examined through a powerful glass, the snow in the lower layers can be seen to have lost its brilliant whiteness, though it does not yet appear as ice. A number were examined with a view to determine the approximate minimum thickness of the glacier, but all exceed the minimum estimate of Matthes by at least 100 feet. This is not regarded as in any way discrediting his figure, but rather as suggesting the possibility of more thorough examination along the same line.

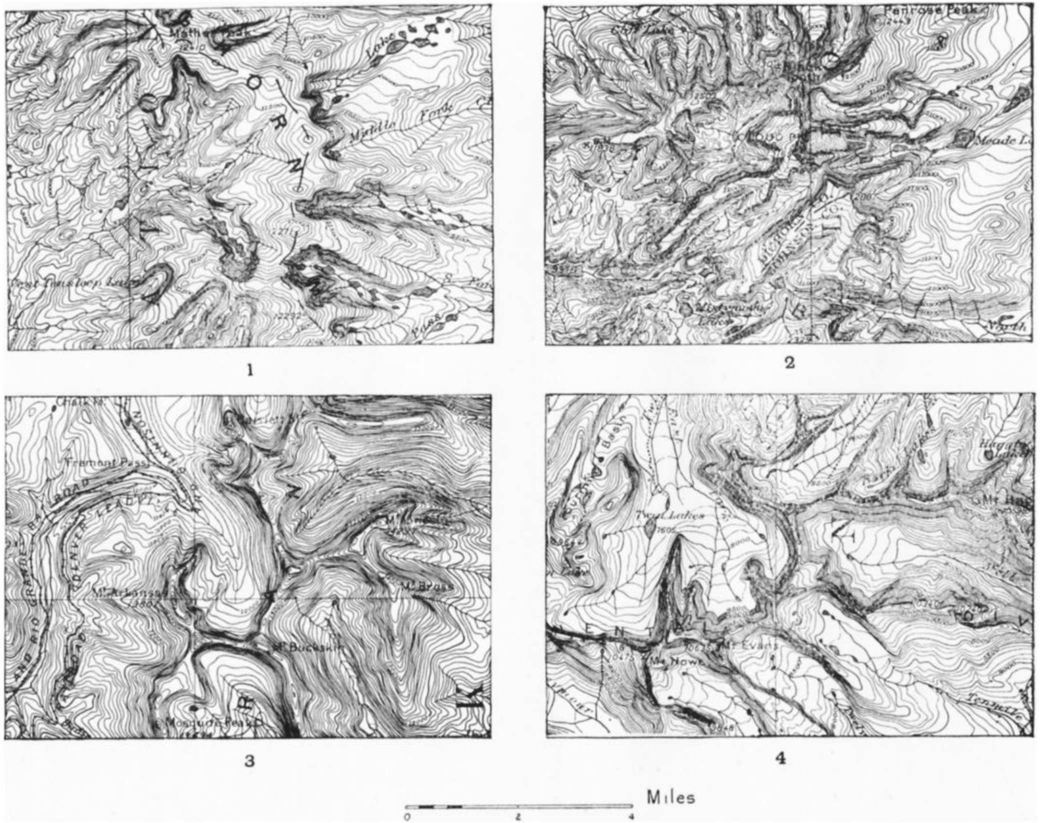

PLATE I.—SERIES OF FOUR MAPS TO ILLUSTRATE THE PROGRESSIVE DISSECTION OF AN UPLAND BY MOUNTAIN GLACIERS.

Fig. 1.—Early stage of glaciation (Cloud Peak Quadrangle, Wyoming).
Fig. 2.—Further investment of the upland, producing a *grooved upland* (Cloud Peak Quadrangle, Wyoming).
Fig. 3.—Early maturity (Leadville Quadrangle, Colorado).
Fig. 4.—Complete dissection at maturity, producing a *fretted upland* (Philipsburg Quadrangle, Montana).

FIG. 3.—SUMMER SNOWBANK SURROUNDED BY BROWN BORDER OF FINELY COMMINUTED ROCK. QUADRANT MOUNTAIN, Y.N.P.

FIG. 4.—SNOWBANK LYING IN A DEPRESSION LARGELY OF ITS OWN CONSTRUCTION. NOTE STREAM OUTWASH OF FINE MUD AT THE LEFT. QUADRANT MOUNTAIN, Y.N.P.

SCULPTURING OF THE UPLAND.

The Upland dissected.—Having obtained a clear conception of the process of head-wall erosion through basal sapping, Johnson was in a position to account for the topography which he encountered in the High Sierras of California. This topography is best described in his own words *—

"In ground plan the canyon heads crowded upon the summit upland, frequently intersecting. They scalloped its borders, producing remnantal table effects. In plan as in profile, the inset arcs of the amphitheatres were vigorously suggestive of basal sapping and recession. The summit upland—the pre-Glacial upland beyond a doubt—was recognizable only in patches, long and narrow and irregular in plan, detached and variously disposed as to orientation, but always in sharp tabular relief and always scalloped. I likened it then, and by way of illustration I can best do so now, to the irregular remnants of a sheet of dough on the biscuit board after the biscuit tin has done its work."

In a portion of the region where Johnson's studies were made, his views have received verification by Lawson in a beautifully illustrated paper.† Davis has furnished an excellent example from the Tian Shan mountains of the operation of the same cirque-cutting process, recording his adhesion to the Johnson doctrine,‡ though his later papers would indicate that he does not ascribe large importance to the discovery.§

With little doubt the failure to generally recognize the importance of this process of cirque recession, clearly here a more effective agent than abrasion, is to be explained by the fact that in Europe generally, and in the Alps in particular, one looks in vain for evidences of the earlier and more significant stages of the process. Glaciation was here so vigorous as to cause the removal of all summit upland. Within the arid regions of the western United States, a more fruitful field for study is to be found. Here the work of Johnson has been supplemented by that of Gilbert ‖ and Matthes.¶ Perhaps nowhere are the early stages of the process so clearly revealed as in the Bighorn mountains of Wyoming (see Fig. 6).

A somewhat more advanced stage of the same process is to be found in the Uinta mountains of Wyoming, recently described in a valuable monograph by Atwood, though here without consideration of the

---

* W. D. Johnson, *Jour. Geol., loc. cit.*

† A. C. Lawson, "The Geomorphogeny of the Upper Kern Basin," *Bull. Dept. Geol. Univ. Calif.*, vol. 3, No. 15, especially pp. 357–362 and pls. 32 and 45.

‡ W. M. Davis, "A Flat-topped Range in the Tian Shan," 'Appalachia,' vol. **10**, 1904, pp. 279–280.

§ *E.g.*, cf. *Scot. Geogr. Mag.*, vol. **22**, 1906, pp. 76–89.

‖ *Jour. Geol., loc. cit.*

¶ *Ibid., loc. cit.*

cirque-cutting process in accounting for the present topography.* Yet nowhere, so far as the present writer is aware, has a view been reproduced which so well illustrates the remnantal tableland and the "biscuit-cutting" process of cirque recession (see Fig. 7).† The present writer has photographed other examples of the same type in the Yellowstone National Park (see Figs. 8 and 14). Remnants of the pre-Glacial surface will, in any given district, be large or small according as nourishment of the glaciers has been insufficient or the reverse. The Uinta range, which extends in an east-west direction, and, like the Bighorn mountains, has a core of homogeneous granitic rock, displays this fact. An examination of Atwood's map ‡ shows that to the eastward, where the precipitation has been least, the remnants of the original upland are more considerable. This qualifying condition

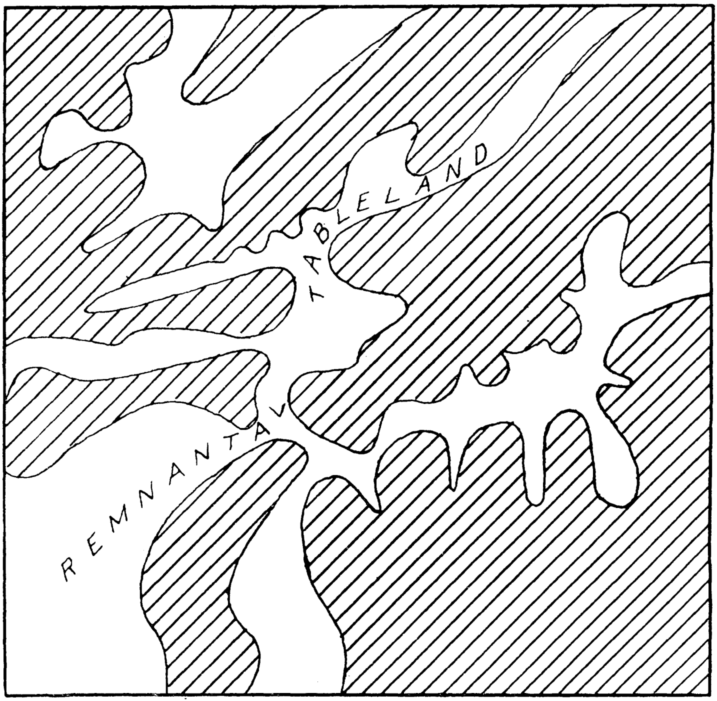

FIG. 6.—PRE-GLACIAL UPLAND INVADED BY CIRQUES, "BISCUIT CUTTING" EFFECT, BIGHORN MOUNTAINS, WYOMING.

---

* Wallace W. Atwood, 'Glaciation of the Uinta and Wasatch Mountains,' Prof. Paper, U.S. Geol. Surv., No. 61, 1909, pp. 1-96, pls. 1-15.

† Other apt illustrations have been furnished by Lawson in a photograph taken the Upper Kern region of the California Sierras (*loc. cit.*, pl. 32 B), and by Davis in sketch made in the Tian Shan mountains ('Appalachia,' vol. **10**, 1904, p. 279).

‡ *Loc. cit.*, pl. iv.

FIG. 5.—VIEW OF THE YOHO GLACIER AT THE HEAD OF THE YOHO VALLEY, SHOWING TO THE RIGHT A SERIES OF THREE SMALL CLIFF GLACIERS. CANADIAN ROCKIES.

FIG. 7.—VIEW OF THE SCALLOPED TABLELAND WITHIN THE UINTA RANGE, AND NEAR THE HEAD OF THE WEST FORK OF SHEEP CREEK. (AFTER ATWOOD.)

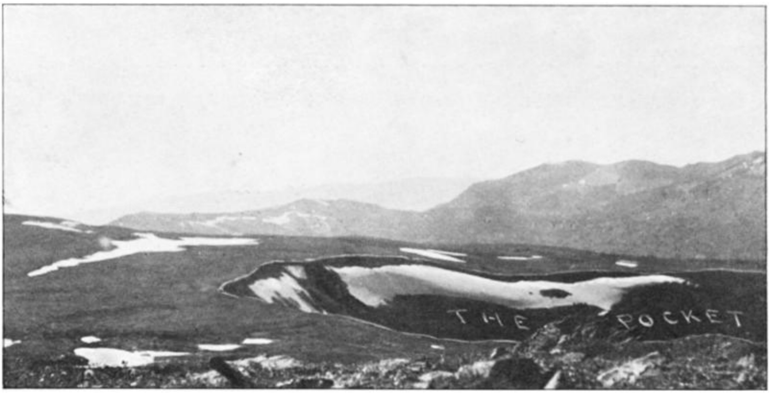

FIG. 8.—PRE-GLACIAL UPLAND ON QUADRANT MOUNTAIN, Y.N.P., INVADED BY THE CIRQUE KNOWN AS THE "POCKET."

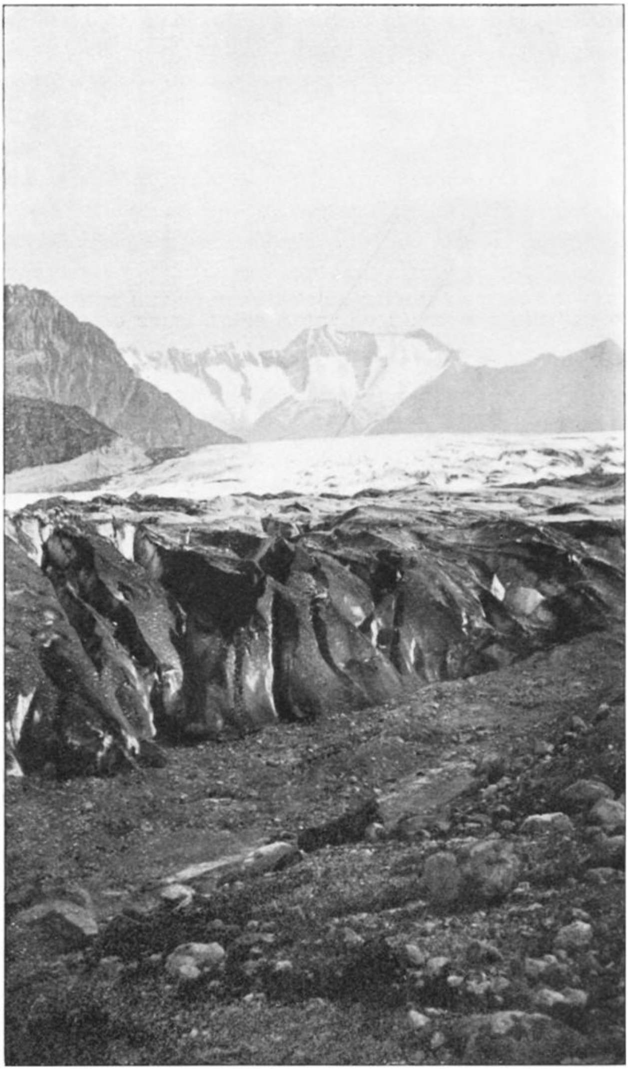

FIG. 11.—MULTIPLE SECONDARY CIRQUE ON THE WEST FACE OF THE WANNEHORN SEEN ACROSS THE GREAT ALETSCH GLACIER, TO WHICH IT IS TRIBUTARY.

of glacier nourishment will be subject to some modification because of peculiarities in snow-distribution. As shown by Gilbert, the first glaciers within any mountain district will probably appear upon that side of the divide which is in the lee of the prevailing winds. This fact is particularly well brought out in Fig. 9.

Modification in the Plan of the Cirque as Maturity is approached.—Owing to the fact that the sapping process within the cirque operates on all sides, its early plan, when the upland surface is supplying snow from all directions, will approach the circle (see Figs. 6 and 8). Moreover, in this stage the cirque will be but little, if any, wider than

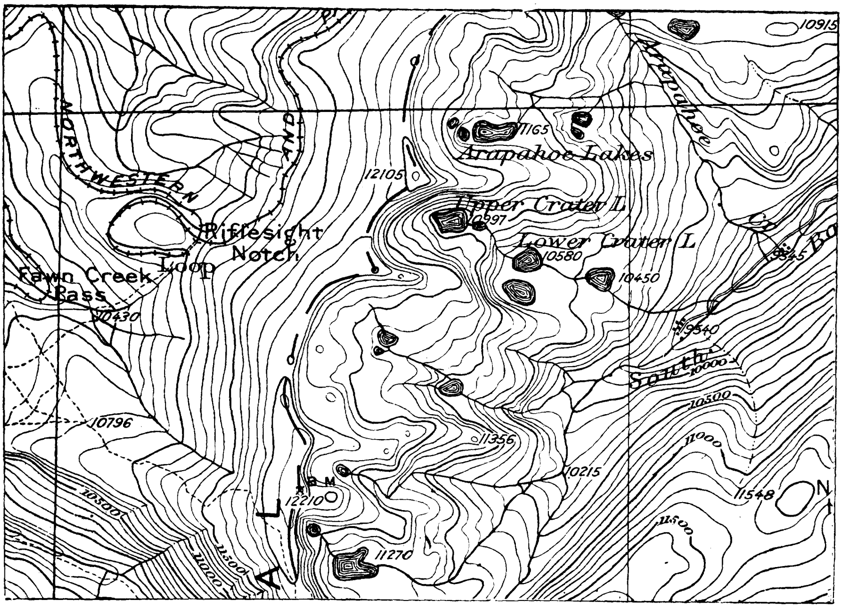

FIG. 9.—SERIES OF SEMICIRCULAR GLACIAL AMPHITHEATRES, WHOSE SCALLOPED CREST FORMS PART OF THE DIVIDE OF THE NORTH AMERICAN CONTINENT. CENTRAL CITY SHEET, TOPOGRAPHICAL ATLAS, U.S. GEOLOGICAL SURVEY.

the deepened and widened valley below (see Plate I., Figs. 1 and 2). Later, with the continuation of the sapping process, the cirque becomes enlarged to such an extent that its sides form recesses in the walls of the valley. Thus, in the plan, the glacial valley of this stage bears some resemblance to that of a nail with a large rounded head.

As the upland is still further dissected, the cirque becomes more irregular in outline and widens into a roughly elliptical form, not infrequently allowing it to be seen that it is in reality composite or made up of several cirques of a lower order of magnitude (Figs. 10–12).

Grooved and Fretted Uplands.—The new emphasis put upon topographic expression of character in the maps issued by Government bureaus during the past few years, has furnished physiographers a tool of which they are hardly yet fully aware. Before, the aim of topographers seemed to be to suppress all character through a rounding off of angles and an averaging of the data. Perhaps nowhere has the change been more noteworthy than in the maps issued by the United States Geological Survey,* and the later sheets particularly, when relating to glaciated mountain districts, afford us the opportunity of tracing the successive steps in the dissection of such upland districts by the cirques of mountain glaciers. For Plate I. four areas have been selected to represent successive stages in such a progressive dissection.

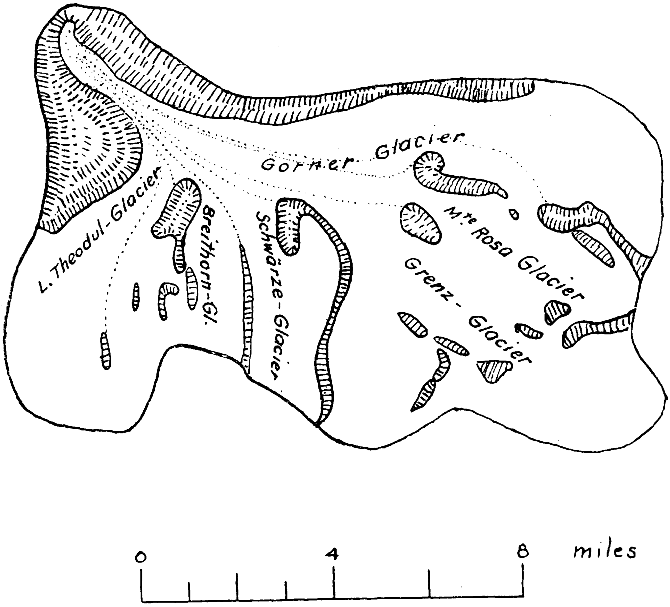

FIG. 10.—OUTLINE PLAN OF ONE OF THE ELLIPTICAL MINOR CIRQUES AT THE HEAD OF THE NICOLAI VALLEY, SWITZERLAND.

An early product in which large remnants of the upland surface still remain, may well be designated a *grooved* or *channelled* surface (see Fig. 13 (*a*)).

As the hemicycle advances, it will be observed that on the flanks of the range are found the largest remnants of the original upland surface (see Fig. 14),† owing to the tendency of the cirque to push

---

* See D. W. Johnson and F. E. Matthes, 'The Relation of Geology to Topography.' Reprint from Breed and Hosmer's 'Principles and Practice of Surveying,' chap. vii. Wiley & Co., N.Y., 1908.

† Other quadrangles of the U.S. Geological Survey which display the upland surface more or less completely dissected by mountain glaciers are the following: *Early stage*: Younts peak (Wyoming), Marsh peak (Utah-Wyoming), and Georgetown

FIG. 12.—MULTIPLE CIRQUE OF THE DAWSON GLACIER, HAVING A MAJOR SUBDIVISION INTO HALVES, WHICH ENCLOSE RESPECTIVELY THE DAWSON AND THE DONKIN NÉVÉS. THE VIEW IS FROM THE ASULKAN PASS, SELKIRK MOUNTAINS.

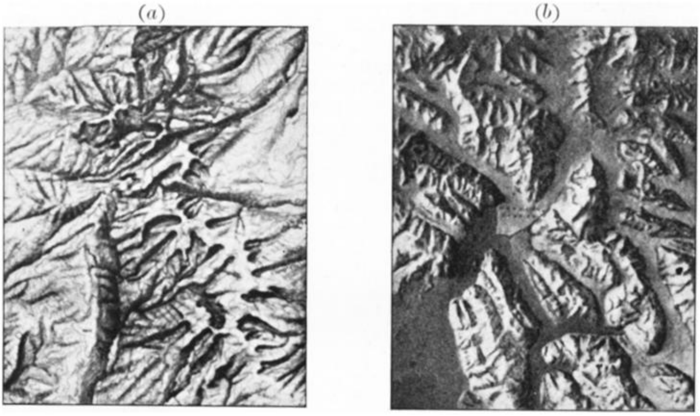

FIG. 13.—(*a*) A GROOVED UPLAND IN THE BIGHORN MOUNTAINS, WYOMING. (*b*) A FRETTED UPLAND, ALASKA.

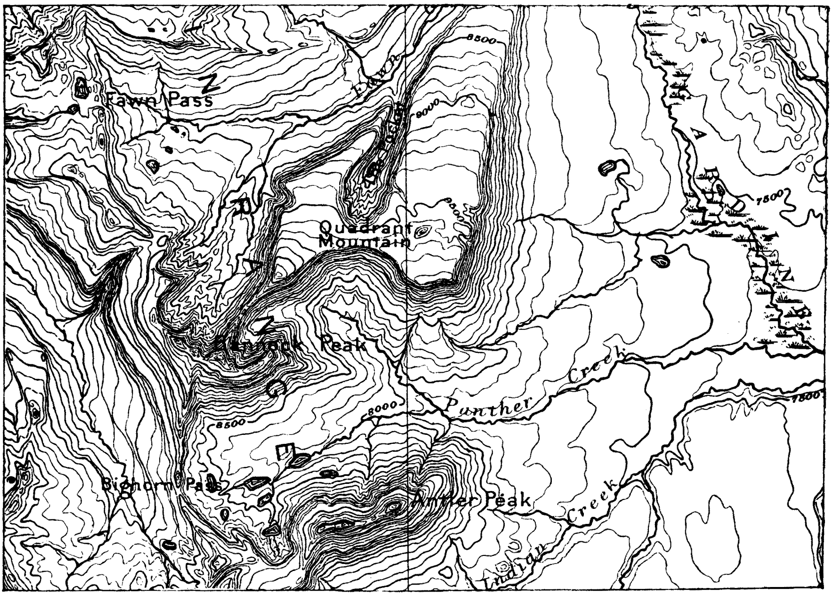

FIG. 14.—MAP OF QUADRANT MOUNTAIN, A REMNANT OF THE PRE-GLACIAL UPLAND ON THE FLANKS OF THE GALLATIN RANGE, YELLOWSTONE NATIONAL PARK.

FIG. 15.—FRETTED UPLAND OF THE ALPS AS SEEN LOOKING NORTH-EASTWARD FROM THE SUMMIT OF MONT BLANC, JULY 25, 1908. THE CIRQUE TO THE LEFT IS THAT OF THE GLACIER DE TALÈFRE, WITH THE JARDIN IN ITS CENTRE, AND DISTANT ABOUT 10 MILES. BOUNDING THIS TO THE LEFT ARE THE ALGUILLE DU MOINE AND THE AIG. VERTE; AT THE REAR ARE THE AIG. LES DROITES AND LES COURTES; AT THE RIGHT IS THE AIG. DE TRIOLET; AND TO THE FRONT THE AIG. DE TALÈFRE, AIG. DE L'EBOULEMENT, AND AIG. DE LESCHAUX.

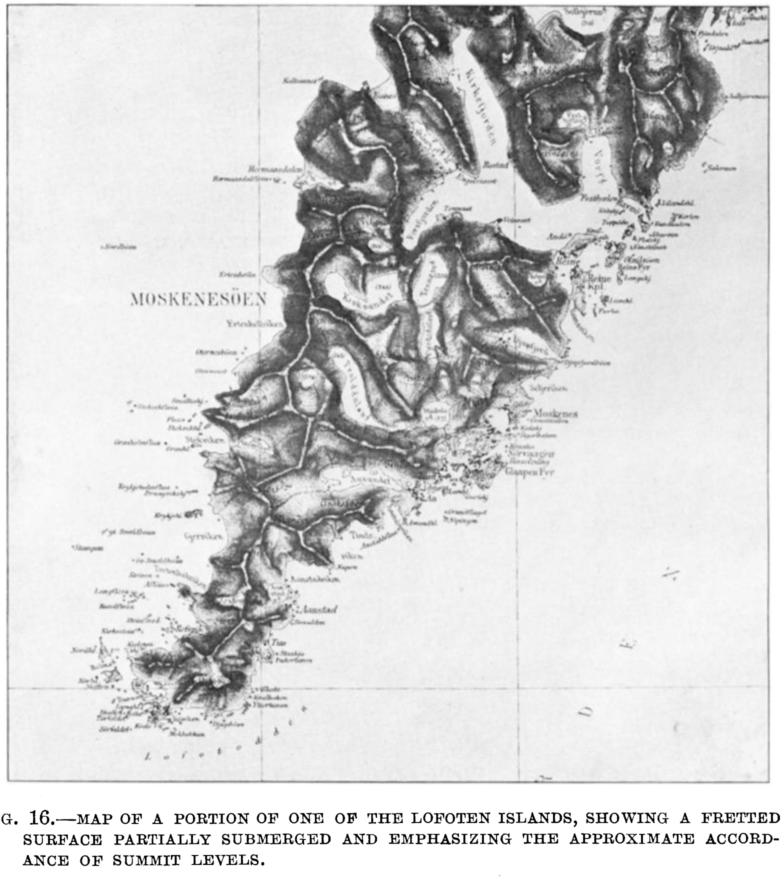

FIG. 16.—MAP OF A PORTION OF ONE OF THE LOFOTEN ISLANDS, SHOWING A FRETTED SURFACE PARTIALLY SUBMERGED AND EMPHASIZING THE APPROXIMATE ACCORDANCE OF SUMMIT LEVELS.

its side walls out beyond the limits of the U-shaped valley below. With complete dissection of the plateau no tabular remnants are to be discovered. The general level of the district has now been lowered, but above this irregular surface project one or more narrow pinnacle ridges, which at fairly regular intervals throw off lateral palisades having crests which fall away in altitude as they recede from the trunk ridge. In general terms, and describing the major features only, we have here to do with a gently domed surface, on which is a fretwork of comb-like ridges projecting above it. This surface may be designated a *fretted upland* (see Fig. 13 (*b*)). Such a condition is realized in the Alps, and is seen to special advantage from the summit of Mont Blanc (see Fig. 15).

The transition from the grooved to the fretted upland is well brought out in two views taken by Lawson in the High Sierras of California (*loc. cit.*, Plate 45, A and B). The fretted upland differs from the grooved upland of an earlier stage of the cycle in the complete dissection of the surface. The character of the fretted surface is well brought out by the topography of the Lofoten Islands off the arctic coast of Norway, where the effect is somewhat heightened through the submergence and consequent obliteration of the irregularities in the floor (see Fig. 16).

At this stage there is undoubtedly a general accordance of level in the crests of the frets upon the domed surface, as Daly, taking due account of the cirque-cutting process, has claimed.* Moreover, the existence of such a series of frets as are to be found in the Alps, forces us to conclude that such an accordance of summits persists for a considerable time. Were this not the case, we should find a larger number of low cols and a longer persistence of the semicircular form of the cirque. It seems probable, therefore, that a very definite relationship obtains between the plan of the cirque and that of the near-lying upland remnants that contribute snow to its basin. So soon as cirques approach from opposite sides of a divide, the portions of their basins which are more nearly adjacent receive less snow, and, in consequence, accomplish less sapping than the walls on either side where snow is lodged in a quantity but slightly diminished. This self-regulating process will tend to broaden the cirque and eventually give it irregularities of outline dependent primarily upon the initial positions and the individual nourishments of its near-lying neighbours.

Characteristic Relief Forms of the Fretted Upland.—In the earlier stages of mountain glaciation the upland is channelled by valleys U-shaped in

---

(Colorado); *partial dissection*: Mount Lyell and Mount Whitney (California), Grand Teton (Wyoming), Gilbert peak and Hayden peak (Utah-Wyoming), and Silverton and Anthracite (Colorado); *complete maturity:* Kintla Lakes (Montana).

* R. A. Daly, "The Accordance of Summit Levels among Alpine Mountains: the Fact and its Significance," *Jour. Geol.*, vol. 13, 1905, pp. 117–120.

their upper stretches, and somewhat broadened into steep-walled amphitheatres at their heads. With the complete dissection of the upland, the coalescence of the many cirques at last cuts away every remnant of the original surface and yields relief-forms which are dependent mainly, as already stated, upon the initial positions of the cirques.*

If there be a highest area within the upland, the snow will be carried farthest from it by the wind, and this will be in consequence the last to succumb to the cirque-cutting process. The dome of Mont Blanc in the midst of a forest of pinnacles, no doubt owes its peculiar form to the fact that it dominated the pre-Glacial upland. Elsewhere within the upland the coalescence of cirques has produced comb-like palisades of sharp rock-needles which have long constituted the *aiguille*

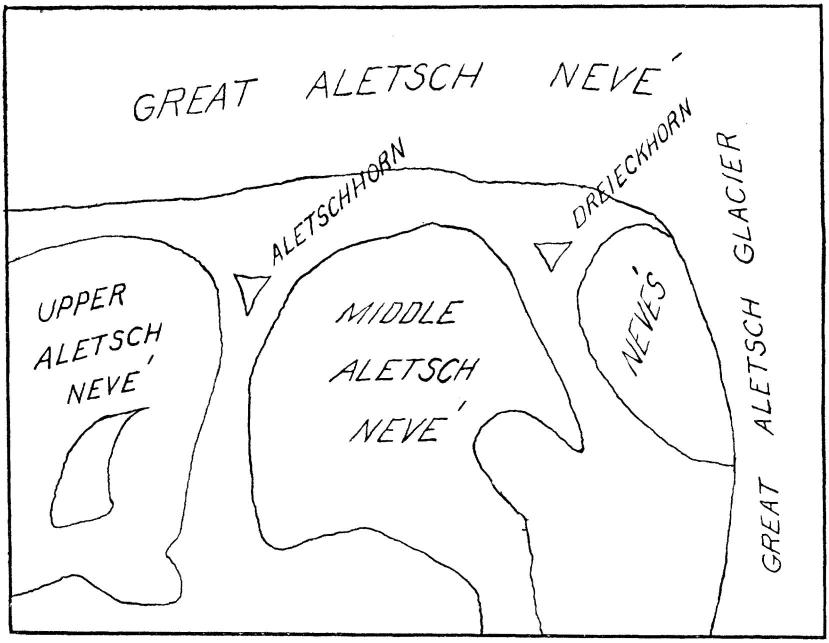

FIG. 17.—POSITION OF THE ALETSCH- AND DREIECKHORNS BETWEEN THE UPPER, MIDDLE, AND GREAT ALETSCH NÉVÉS.

---

* The analogy with the forms produced by etching upon crystal faces is so striking that it may be helpful to note it in comparison. The first effect of a reagent in its attack upon the plane of a crystal face is the excavation of deep pits which have a similar and wholly characteristic form, though the surface in other places remains unchanged. These pittings later increase in number, as they do in size, and eventually they mutually coalesce, destroying utterly the original plane surface, and leaving in relief a series of hills and ridges (etch-hills) projecting above a somewhat irregular floor, whose average level is a measure of the average depth of the excavations made by the process. The noteworthy difference between this process and that of cirque recession in glaciated uplands is that the glacial etch-figures are relatively longer and narrower.

type of mountain ridge. In the literature of physiography, such ridges have perhaps most frequently been designated by the term *arête* (fish-bone), though in the Alps the term *grat*[*] (edge) has been applied especially to the smaller and lateral ridges of this type. I propose to use for all such palisades of needles derived by this process the name comb-ridge[†] as the best English term available. The frequent occurrence of lateral arms joined to the main palisade of needles suggests a differentiation into main and lateral comb-ridges.

In every mountain district maturely dissected by glaciers, are to be found sharp horns of larger base and especially of higher altitude than the individual minaret-like teeth of the comb-ridges. They are further in contrast with the latter by having an approximately pyramidal form, and a base most frequently a triangle with flatly incurving sides. They appear most frequently at the junction points of the comb-ridges between three or more important snow-fields (see Fig. 17). Such forms are generally termed *horns* in the Alps, and the word being of the same form in English, it may well be retained as a technical expression. The Matterhorn in Switzerland is the type *par excellence* (see Fig. 18), though similar and almost equally striking examples are numerous, as, for example, the Weisshorn and Gross Glockner in the Alps, Mount Assiniboine in the Canadian Rockies, or Mount Sir Donald in the Selkirks. The triangular base and pyramidal form are so common to this feature that they have found expression in the local names, as Dreieckhorn, Deltaform peak, etc.

The Col and its Significance.—The prominent horns of any glaciated mountain district no doubt occupy positions corresponding in the main to the more elevated areas in the original upland surface, since such positions would be earliest cleared of snow, and hence latest attacked by the cirques. After complete dissection of the upland the comb-ridges which fret its surface will be attacked from opposite sides, and their crests will be first lowered at the points of tangency of the adjacent cirques—generally near the middle points of their curving outlines. The sky-line of the ridge will thus be lowered in a beautiful curve forming a pass or *col*. Inasmuch as the cirque approaches in its form an inverted and truncated cone of acuminated type, the curve to which the rim of the col approximates will be furnished by the intersection of two cones of revolution with the same apical angle and having parallel axes (see Figs. 19 and 20). This curve is approximately a hyperbola, the

---

[*] Very likely originally from *gräte*, fish-bone.

[†] The use of *combe* in the Jura and the Cote d'Or for different types of valley, or of *coombe* in the Southern Uplands of Scotland for a glacial valley, being each essentially local and having further no relation to the toothed article which suggests the name comb-ridge, does not constitute a serious objection to this choice. Mr. Matthes (and possibly others) have already used the expression comb-ridge in the above described sense ('Appalachia,' vol. **10**, 1904, p. 260).

eccentricity of which will be largely dependent upon the relative sizes of the two cirques in question.

The corries of the Scottish Highlands, being generally of small size, have coalesced to produce a very characteristic scalloping of the horizon line seen to advantage in Ben Nevis, or, better still, in the sculptured gabbro of the Cuchulin hills in Skye.[*] To judge from views, also, such forms are found in North Wales, features which in many respects are different from those found in the Alps or in the North American mountains.[†]

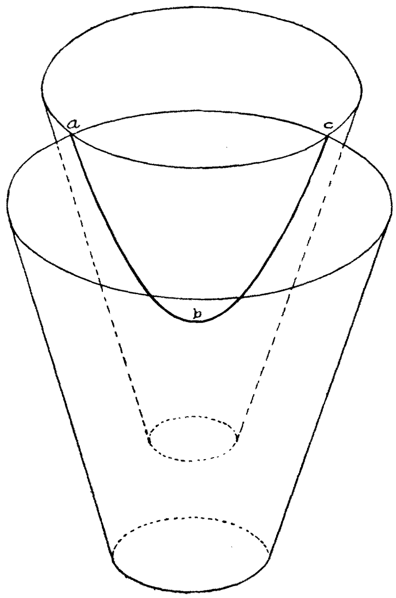

FIG. 19.—ILLUSTRATION OF THE FORMATION OF COLS THROUGH THE INTERSECTION OF CIRQUES.

It must be regarded as of deep significance that mountain passes in areas which have supported glaciers are so generally at high levels. Deep glacier-cut valleys available as highways and transecting high ranges are extremely rare; so far as the writer is aware, being known only from the Southern Andes[‡] and Alaska.[§] This fact must have its explanation, it is believed, in a notable and abrupt retardation in the rate of cirque-wall recession, following close upon the dissection of the upland. Whether this is due to the reduced snow accumulation immediately beneath the cirque wall owing to the lack of a near-lying collecting ground, it is as yet too early to say; but a comparison of the acclivities in the marginal snow-slopes on *névés* of the Bighorn and Alaskan districts might yield an answer to the question.

Though the sapping process at the base of cirque walls up to maturity is doubtless far more potent than abrasion and plucking upon the floor of the amphitheatre, it seems likely that in the subsequent stage the reverse is the case. This would at least explain the tendency

---

[*] See Harker, "Glaciated Valley of the Cuchulins, Skye," *Geol. Mag.* (Fig. 4), vol. **6**, 1899, p. 197; also "Ice Erosion in the Cuillin Hills, Skye," *Trans. Roy. Soc. Edinb.*, vol. **40**, 1901–1902, pp. 234–237.

[†] This characteristic form of cirque, partly open at the head, is well brought out in a view published by Sir Andrew Ramsey as early as 1852 (*Quart. Jour. Geol. Soc.*, vol. **8**, p. 375).

[‡] 'Argentine-Chilian Boundary in the Cordillera de los Andes.' 5 vols

[§] R. S. Tarr, "Glaciers and Glaciation of Yakutat Bay, Alaska," *Bull. Am. Geogr. Soc.*, vol. **38**, 1906, p. 149.

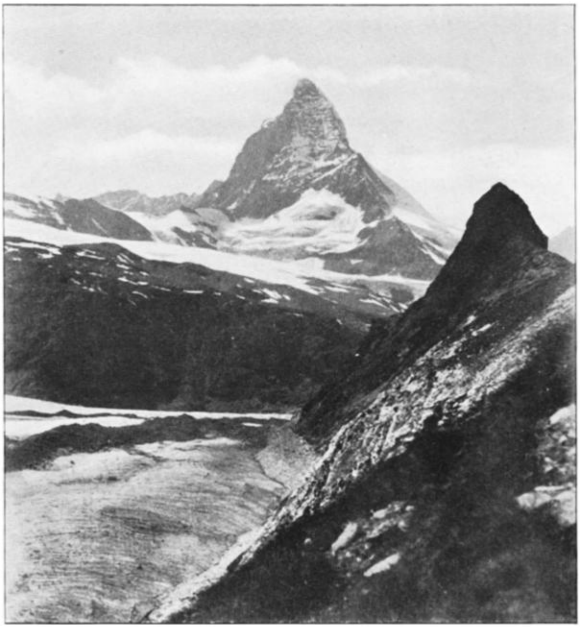

FIG. 18.—THE MATTERHORN FROM THE GORNER GRAT, NEAR THE RIFFELHORN.

FIG. 20.—COL OF THE OVERLOOK LOOKING ACROSS THE FOOT OF THE ILLECILLEWAET GLACIER, SELKIRKS.

of glacier valleys to deepen rapidly in the higher altitudes, or, in Johnson's phrase, to get " down at the heel."

The Advancing Hemi-cycle.—With the augmentation of rigorous climatic conditions within any district where glaciers already exist, the latter will be continually more amply nourished, and must in consequence increase steadily in size. Such climatic changes may even be conceived so considerable that at last the entire range is submerged beneath snow and ice, thus producing an ice-cap.

Direct observation of the successive stages through which glaciers pass from their initiation to their culmination in an ice-cap, is of course impossible, for the reason that we live in a receding hemi-cycle in which practically all known glaciers, instead of expanding, are drawing in their margins; yet a synthetical reconstruction of the life-history is none the less possible. To employ an illustration already used in a different connection, in order to learn the life-history of a particular species of forest tree, it would not be necessary to sit down and observe an individual tree from the germination of its seed to the decadence of the full-grown tree. We may with equal profit go into the forest and observe trees of the same species in all stages of development. In the study of glaciers our opportunity is hardly so fortunate as this, for, as already stated, all glaciers appear to be in the declining stage, whereas it is the advancing hemi-cycle with which we are now concerned. The characters of glaciers as concerns their size and shape depend, however, in so large a measure upon the one element of alimentation, that if we neglect characters of a second order of magnitude, we may by inference construct the history with sufficient accuracy from existing examples.

(*To be continued.*)

SURVEY WORK ON THE BOLIVIA-BRAZIL BOUNDARY.

By Major P. H. FAWCETT, R.A., Chief Bolivian Commissioner.

THE Bolivian Boundary Commission continued its labours in 1909, completing the delimitation of the eastern boundary over the ground explored during the latter half of 1906. A sketch of that exploration, together with a *résumé* of the work already completed, was published in the *Journal* of the Society early in 1909.

The repetition of the work was rendered necessary by the unwillingness of the Brazilian commissioner, partly for political reasons and partly owing to the risks entailed in the breaking of unknown country, to join in an exploration which would have completed in one year of work a delimitation for which seven years had been anticipated. As I think I mentioned in the communication referred to, the party of exploration were speeded from Corumba to the utmost limits of civilization

THE CYCLE OF MOUNTAIN GLACIATION.*

By Prof. **WILLIAM HERBERT HOBBS**, University of Michigan.

The alimentation of glaciers is dependent upon the amount of precipitation and upon the temperature, the former being in large measure determined by the adaptability of the relief for local adiabatic and contact refrigeration of the air. The important factor, temperature, while a function of many variables, yet in a broad way varies directly with latitude and altitude. The size and the form of glaciers is, however, determined not solely by nourishment (mainly in the higher levels), but also to some extent by losses (particularly in the lower levels). In the main, however, the losses are controlled by the same factors as the gains, and maintain to them a determinate proportional relationship. Exceptions to this definite proportion occur when in high latitudes the glacier is attacked directly by the sea (tidewater glaciers), when it is suddenly melted by the heat of a volcanic eruption (Icelandic Jokülls), or when disturbed by a heavy earthquake (Muir glacier in 1899). In form glaciers will be in large degree determined by the existing topography of the upland, which may generally be assumed to be some product of sub-aërial erosion. Starting, therefore, with the puny glaciers of arid regions in low latitudes, and ending with the high latitude glaciers within areas of excessive precipitation, we run almost the whole gamut of glacier alimentation.

The initial forms of glaciers may be described as snowbank, "newborn" or nivation glaciers, and will at first be few in number and located with wide intervening spaces of upland. The continuance of the nivation process will deepen other intermediate small depressions upon the upland, so that with increasing snowfall additional glaciers will appear in the spaces between the first as the latter are developing their amphitheatres. These cirques, at first no wider than the valleys below, will later cut recesses on either side at the same time that the glacier is pushed farther down the valley and occupies its bed to a greater and greater depth. The grooved upland of this stage, through additional cirque recession in the highlands and through abrasion and plucking in the intermediate levels, becomes at last transformed into the fretted upland, with its network of projecting comb-ridges. Up to this point the glacier ice has perhaps been restrained within valleys, which it has discovered and has progressively widened and deepened. If the initial temperature continues to be lowered, there must come a time when the ice feet from the better-nourished glaciers, or from those with the shortest route to the foreland fronting the range, will debouch upon the plain, spreading as they do so into fans or aprons (see Fig. 21).

---

* Continued from p. 163.

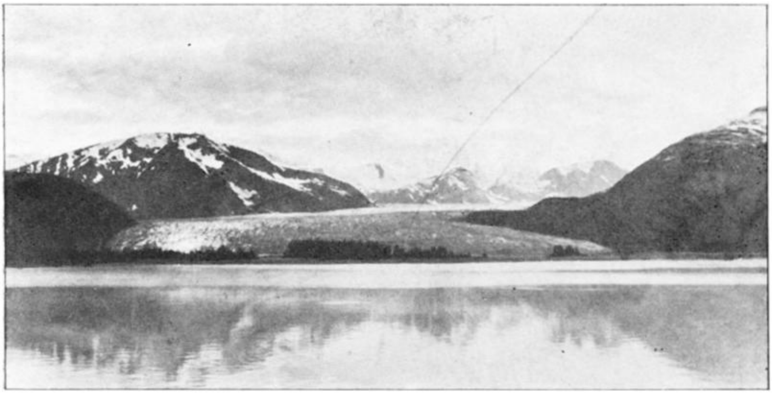

FIG. 21.—EXPANDED FORE-FOOT OF THE FOSTER GLACIER, ALASKA.

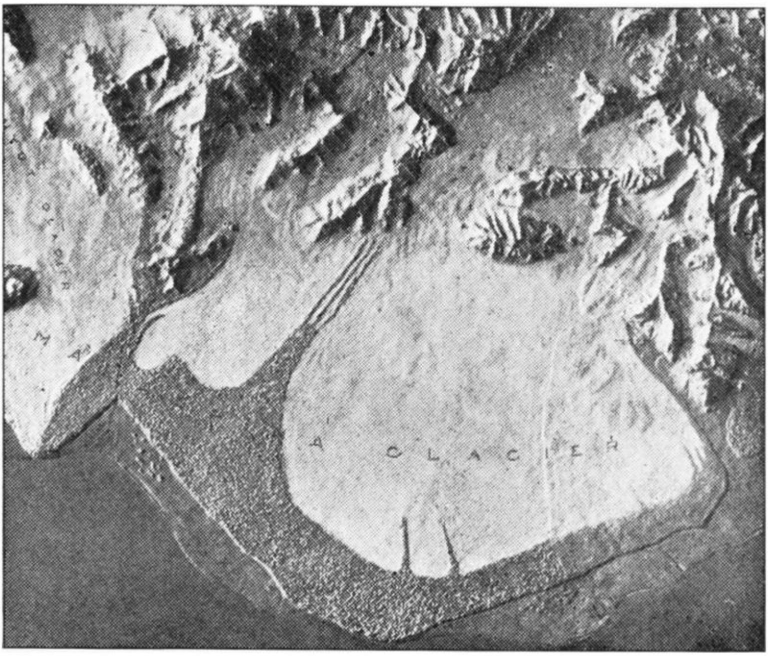

FIG. 22.—TYPE OF PIEDMONT GLACIER.

(*From a photograph of the new model of the Malaspina glacier made under the direction of Lawrence Martin.*)

FIG. 27.—A HANGING TRIBUTARY VALLEY MEETING A TRUNK GLACIER VALLEY ABOVE THE PRESENT WATER-LEVEL ON THE "INSIDE PASSAGE" TO ALASKA.

FIG. 28.—A HANGING GLACIERET, THE TRIEST GLACIER, ABOVE THE LOWER STRETCH OF THE GREAT ALETSCH GLACIER, SWITZERLAND.

Later all neighbouring glaciers may arrive at this stage, and by spreading upon the foreland, coalesce with one another to form a single broad apron, such as may be seen in the Malaspina glacier of Alaska. While the glaciers are thus pushing out upon the foreland they have been deepening in their valleys, and eventually come to overtop portions of the lateral comb-ridges of the fretted upland, thus moulding the sharpened needles into rounded shoulders of rock. In places the glaciers from adjacent valleys will flow together through the irregular depressions, separating peaks and producing islands or *nunataks*.

But the increased size of the individual glaciers of the range has corresponded to increased activity of cirque recession in the high altitudes, and this has resulted in the formation of cols or passes through the range. Snow which has been divided at the summit, as has water by a divide, may now be consolidated into glacier ice over the col before the separation is made. Thus it comes about that without a definite cirque, glaciers will transect the range flowing in opposite directions from a central icefield. Such a broad central icefield is found to-day between Mount Newton of the St. Elias group and Mount Logan to the eastward.*

The advance of the glacier ice up the sides of the valleys, so as partially to submerge the lateral comb-ridges, may not end until all are thus covered and the ice flows away from the central broad area, radiating in many directions. Here the process of cirque recession, which has mainly sculptured the rock in the higher altitudes, comes to an end as we reach the ice-cap stage of glaciation. Transitions toward such ice-cap glaciers are to be found to-day in the Elbruz and in the Kasbek region of the Caucasus, as well as in the Justedalsbräen of Norway, where a central elevated snow-field (fjeld) is the common *névé* of several glaciers radiating in as many directions.† It is of considerable interest to note that in the Caucasus district, at least, there is evidence that rocky comb-ridges are submerged beneath the ice and make their appearance so as to separate the marginal ice-tongues. The persistence of an ice-cap over a mountain region, as is clear from study of the glaciated mountains in Norway, tends to largely obliterate relief forms characteristic of mountain glaciers as they are replaced by the rounded shoulders of *roches moutonnées*. As soon, however, as nourishment has been so far reduced that the higher points once more appear from beneath their snow cover, cirque recession will begin again, and if long continued the evidence of the ice-cap will disappear. Lack of glacial scratches or polish in uplands sapped by this process should not be allowed to weigh too heavily in reconstructing the glacial history of the district.

---

* Filippo di Filippi, 'The Ascent of Mount St. Elias (Alaska),' by H.R.H. Prince Luigi Amadeo di Savoia, Duke of the Abruzzi (English translation). Panorama at end of volume (unnumbered) from an elevation of 16,500 feet.

† H. Hess, 'Die Gletscher. Braunschweig,' 1904, pp. 65–68.

Classification of Glaciers based upon Comparative Alimentation.

Relation of Glacier to its Bed.—From what has been said in the preceding section concerning the changes of glaciers in correspondence to a progressive augmentation of glacial conditions, it must be evident that any attempt to use each circumscribed body of snow and ice as a unit in name or in type will lead to endless confusion. Ice bodies being extremely sensitive to changes in annual temperature, a difference of one degree may be sufficient to join many ice bodies into one, or to differentiate one body into many. If, however, we examine the distribution of snow and ice masses within the valley which they either wholly or partially occupy, it will be seen that there are relatively few distinct glacier types, and that the coalescence of smaller ice masses, or the breaking up of larger ones, does not necessarily alter the type exemplified.

The more important types called for by analysis on this basis do not differ greatly from those adopted by Chamberlin and Salisbury,* which seem to be the ones most generally recognized. The genetic relationships of these types are here first brought out, together with distinct and intermediate transitional forms. In the following table, excepting the initial type and the glaciers with inherited basins, the arrangement is in the main one of decreasing alimentation:—

- Nivation type (Bighorn glaciers).
- Ice-cap type (Jökulls of Iceland).
- Piedmont type (Malaspina glacier).
- Transection type (Yakutat glacier).
- Expanded-foot type (Davidson glacier).
- Valley type, normal subtype (Baltoro glacier).
  - Hanging glacierets (Triest glacier).
  - Cliff glacierets (Lefroy cliff glacieret).
- Valley type, Tide-water sub-type (Harriman-Fjord glacier).
- Inherited basin type (Illecillewaet glacier).
  - Reconstructed type (Victoria-Lefroy glacier).
  - Volcanic cone type (Nisqually glacier).
  - Cauldron type (Caldera glacier).
- Alpine type (Nicolaithal glacier).
- Horseshoe type (Mount Lyell glacier).

Nivation Type.—This type of glacier has also been called "new-born" or "snowbank" glacier, and represents the initial stage of glaciation. Though small in size, such glaciers differ markedly from those of the same dimensions which cling to the steep walls of a large cirque (see horseshoe glaciers below), and which Tarr has referred to as "dying glaciers." † Numerous examples of snowbank glaciers are furnished by the Bighorn mountains of Wyoming. Other known types of mountain glaciers are all represented, and follow naturally in sequence during a receding hemicycle of glaciation. In their discussion we shall conceive

---

* 'Geology,' vol. 1, chap. v.

† R. S. Tarr, "Valley Glaciers of the Upper Nugsuak Peninsula, Greenland," *Am. Geol.*, vol. 19, 1897, p. 265 and fig. 2.

a mountain district to pass by slow stages from a culmination of glacial conditions toward a comparatively genial climate.

Ice-cap Type.—Though in form and general characters resembling so-called continental glaciers, the ice-caps by reason of their smaller dimensions form a connecting-link with mountain glaciers, and are usually developed upon small plateaus or uplands. They correspond to conditions of extremely heavy snow precipitation, and in consequence have not been found fully developed outside the Polar regions (see inherited basin glaciers below).

The normal type of ice-cap glacier is represented by the mantle over Redcliff peninsula, north of Inglefield gulf in Greenland.* It suffers no interruption from mountain peaks, but the ice creeps out in all directions from a central area, and sends out marginal lobes or tongues which much resemble, save for their whiter surface, the snouts of valley and alpine glaciers (see below). The Jökulls of Iceland are very similar, and form flatly arched or undulatory domes of ice having short lobes about their margins (see Plate II., Fig. 1). The largest of these, the Vatnajökull, has an area of 8500 square kilometres.† In Scandinavia the small plateau glaciers with marginal tongues of proportionately greater length, such as the Justedalsbräen, serve to connect this type with that of the valley glaciers (see Plate II. Fig. 2).‡ The *Richtofeneis* on Kerguelen island, recently described by the German South-polar Expedition, seems to be very similar.§ According to Meyer, the ice-mass upon the summit of Kilimandjaro in Africa is an "ice carapace," having much resemblance to the ice plateaus of Scandinavia.‖

Piedmont Type.—Piedmont glaciers, like ice-caps, correspond to conditions of exceptionally heavy precipitation, and are only known from polar and sub-polar regions. In contrast to ice-caps, the existing examples are found in connection with mountains of strong relief, so that the snow and ice which in ice-caps find their way slowly out to the margin of a flat or gently sloping plateau, are in the piedmont glacier discharged through valleys from lofty highlands to debouch upon the foreland at the foot of the range. The well-known type is the Malaspina glacier of Alaska, explored and described by Russell (see Fig. 22 and Plate II. Fig. 3).¶ Near it and farther to the west is the

---

* T. C. Chamberlin, "Glacial Studies in Greenland," IV., V., *Jour. Geol.*, vol. **3**, 1895, pp. 199, 470.

† Th. Thoroddsen, "Island, Grundriss der Geographie und Geologie. V. Die Gletscher Islands," *Pet. Mitt.*, Erg. Bd. **32** (Nos. 152–153), 1906, pp. 163–208, map, pl. xii.

‡ H. Hess, 'Die Gletscher' (Map 3).

§ Emil Werth, 'Aufbau und Gestaltung von Kergulen. Sonderabd. aus Deutsch. Südpolar Expeditionen, 1901–1903,' vol. **2**, pp. 93–183, pls. 9–14, 3 maps.

‖ Hans Meyer, 'Der Kilimandjaro, Reisen und Studien,' pp. 436. Berlin, 1898 (reviewed by Rabot).

¶ I. C. Russell, "An Expedition to Mount St. Elias," *Nat. Geogr. Mag.*, vol. **3**, 1891, pp. 52–204, pls. 2–20. See also Filippi, *loc. cit.*

PLATE II.—TYPES OF MOUNTAIN GLACIERS.

Fig. 1.—Ice-cap type, Vatnajökull, Iceland. (After Thoroddsen.)
Fig. 2.—Ice-cap type, Justedalsbräen, Norway. (After Hess.)
Fig. 3.—Piedmont type, Malaspina glacier, Alaska. (After Russell and Kerr.)
Fig. 4.—Valley type, Baltoro glacier, Karakorum-Himalayas. (After W. M. Conway.)
Fig. 5.—Valley type, Tasman glacier, New Zealand. (After v. Lendenfeld.)
Fig. 6.—Valley type (Tidewater glacier), Harriman fjord glacier, Alaska. (After Gannett.)
Fig. 7.—Alpine type, Nicolaithal glacier, Alps. (After Baedeker.)
Fig. 8.—Alpine type, Mer de Glace, Alps. (After Baedeker.)
Fig. 9.—Alpine type, Rathong glacier, Kangchengunga Himalayas. (After Garwood.)
Fig. 10.—Horseshoe type, Lhonak glacier, Kangchengunga Himalayas. (After Garwood.)
Fig. 11.—Horseshoe type, Asulkan glacier, Selkirks. (After A. O. Wheeler.)
Fig. 12.—Horseshoe type, Wenkchemna glacier, Canadian Rockies. (After A. O. Wheeler.)
Fig. 13.—Horseshoe type, Arapahoe glacier, Colorado. (After Fenneman.)
Fig. 14.—Inherited basin type, Great Aletsch glacier, Alps. (After Baedeker.)
Fig. 15.—Inherited basin type, Illecillewaet glacier, Selkirks. (After A. O. Wheeler.)
Fig. 16.—Inherited basin type (reconstructed glacier), Victoria glacier, Canadian Rockies. (After Scherzer.)

Bering glacier of about the same size.* To the east of the Malaspina glacier is the Alsek, a much smaller piedmont glacier.† In Chili south of 42° S. lat. are found other piedmont glaciers, among them the San Rafael.‡ During Pleistocene times piedmont glaciers existed in many mountain districts, notably, however, the Alps § and the Rocky mountains of North America.|| A transition from the piedmont type toward the continental glacier is illustrated by the Friederickshaab glacier in Greenland, which pushes its front out upon the foreland as an extension of the inland ice of that continent.

Above the ice apron and within the range, the piedmont glacier bears a close resemblance to the valley type (see below), though in general it may be said that its valleys are filled to a much greater depth. The largest stream feeding the fan of the Malaspina glacier has been named the Seward glacier, while other tributaries are known as the Agassiz and the Tyndall (see Fig. 2, Plate III.). It is interesting to note that however steep these feeders to the ice-apron may be, the

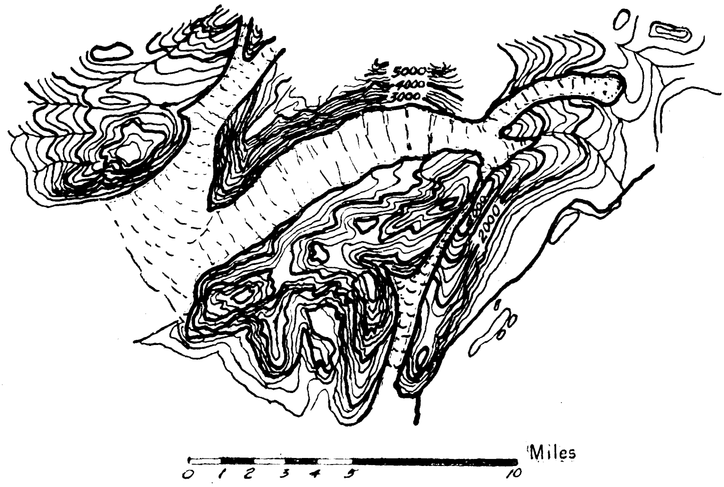

FIG. 23.—MAP OF A TRANSECTION GLACIER. THE SHERIDAN GLACIER NEAR THE COPPER RIVER IN ALASKA. (AFTER G. C. MARTIN.)

---

* Roughly outlined on map of Alaska to accompany "The Geography and Geology of Alaska," by Brooks (Prof. Pap. U.S. Geol. Surv., No. 45, 1906, plate in cover). For details of marginal portion and description, see G. C. Martin, 'Bull. 335 U.S. Geol. Surv.,' 1908, pp. 46–48, and pls. i., ii. and v.

† E. Blackwelder, "Glacial Features of the Alaskan Coast between Yakutat Bay and the Alsek River," *Jour. Geol.*, vol. **15**, 1907, pp. 428–432, map.

‡ See Rabot, 'La Géographie,' vol. **3**, 1901, p 270. See also Hess, 'Die Gletscher,' p. 63.

§ Penck u. Brückner, 'Die Alpen im Eiszeitalter, especially vol. **2**, 1909, map opposite p. 396.

|| Fred H. H. Calhoun, "The Montana Lobe of the Keewatin Ice-sheet" Prof. Pap. No. 50, U.S. Geol. Surv., 1906, pp. 14–21, map pl. i.

latter always shows an exceedingly flat slope, and is, moreover, relatively stagnant.

Transection Type.—In a late stage of augmenting glacial conditions or in an early stage of the receding hemi-cycle, what is essentially one body of ice may be divided over a pass and flow off in opposite directions toward different margins of the range. For this type, exemplified by the nunatak glacier of Alaska, Tarr has used the term "through glacier," * and Blackwelder has instanced the Yakutat glacier and perhaps the Beasley within the same region.† Such glaciers, which may be referred to as the *transection type*, are often the highways which give readiest access to the hinterland. A glacier of this type, which has been carefully mapped, is the Sheridan glacier near the mouth of the Copper river in Alaska (see Fig. 23).‡ An excellent panorama of one of the grandest transection glaciers has been furnished by Sella.§ The glaciation of the Grimsel pass in Switzerland clearly indicates that at one time a glacier of this type was parted over the present divide, one stream passing down the Rhone valley, and the other down the Häsli valley toward Meyringen. Far greater exhibits of the same sort are to be found in the Southern Andes.‖

Expanded-foot Type.—When a piedmont glacier draws in its margin as it shrinks with the coming of a warmer climate, the several ice-streams which feed the apron of ice upon the foreland end in small fans at the mouths of the individual valleys. Perhaps the best known example of such an expanded-foot glacier is the Davidson, on the Lynn canal in Alaska, though the Foster and Mendenhall glaciers of the same district are similar (see Fig. 22). The Miles and Childs glaciers, near the Copper river, are also of this type, and have been mapped by Martin (see Fig. 24 *a*).¶ The transection glacier known as the Sheridan is in the same vicinity, and has an expanded forefoot—a good illustration of the combination of these two types in one (see Fig. 23). A larger example of the expanded forefoot than any thus far mentioned is the Klutlan, in the Yukon basin, whose foot extends a number of miles beyond the front of the St. Elias range (see Fig. 24 *b*).** The Martin river glacier in the Copper river district affords another example, since it expands for a distance of over 20 miles. It is, however, partially restrained by a range of hills rising on its southern margin, and by

---

* *Bull. Am. Geogr. Soc.*, vol. **38**, 1906, p. 149. See also Prof. Pap. No. 64, U.S. Geol. Surv., **1909**, pp. 35-36, 105, pls. vii.-viii.

† *Jour. Geol.*, vol. **15**, 1907, p. 432.

‡ G. C. Martin, 'Bull. 284, U.S. Geol. Surv.,' 1906, pl. 12.

§ Filippi, *loc. cit.*

‖ Argentine-Chilian boundary, maps.

¶ G. C. Martin, *loc. cit.*

** C. W. Hayes, "An Expedition through the Yukon District," *Nat. Geogr. Mag.*, vol. **4**, 1892, pp. 152. See also map of Mendenhall and Schrader, Prof. Pap. U.S. Geol. Surv., No. 15, 1903, fig. 4, p. 41.

Martin has been considered intermediate between the piedmont and valley types.*

Valley or Dendritic Type.—Retiring within the range as warmer temperatures succeed to more rigorous conditions, glaciers are of necessity restricted to individual valleys and their tributaries. They come thus to have a plan as truly arborescent as that of water-drainage, and they may in this stage be called dendritic or valley glaciers. Unfortunately, the term "valley glaciers," in every way appropriate, has been generally applied to glaciers which occupy valley heads only, and hence the term must be redefined in its natural rather than its inherited significance. This glacier type geographers are most familiar with in restorations of Pleistocene glaciers,† but it is none the less a common form to-day in districts more distant from commercial centres, and hence less easily accessible for study. From the Karakoram Himalayas, the Baltoro, Hispar, and Biafo glaciers, all of this type, have been described and carefully mapped by Sir Martin Conway.‡ An outline map of the Baltoro glacier is reproduced in Plate II. Fig. 4, and one of the Hispar glacier in Fig. 25. Other valley glaciers, generally less extensive, have

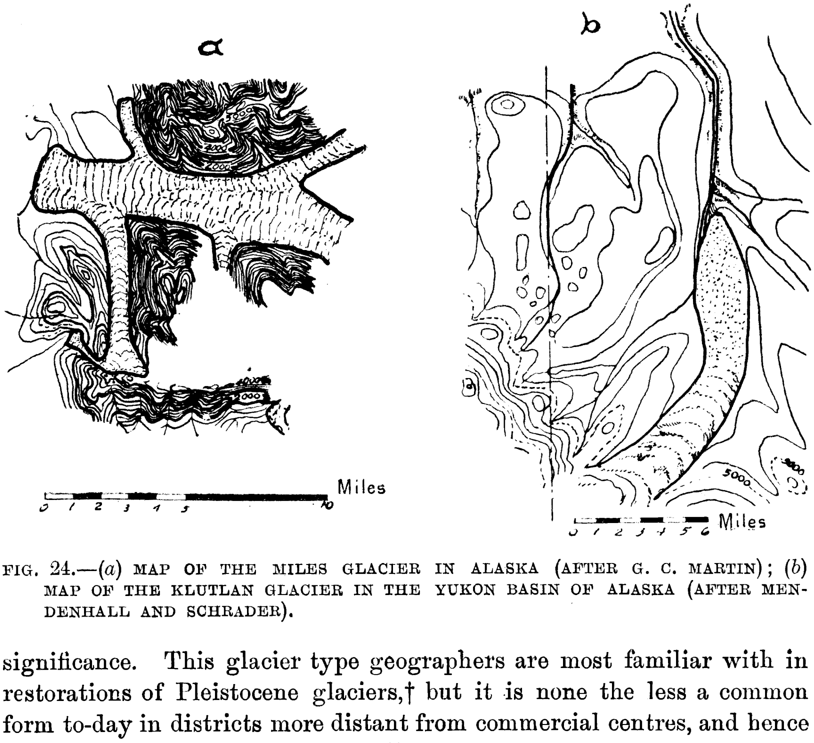

FIG. 24.—(*a*) MAP OF THE MILES GLACIER IN ALASKA (AFTER G. C. MARTIN); (*b*) MAP OF THE KLUTLAN GLACIER IN THE YUKON BASIN OF ALASKA (AFTER MENDENHALL AND SCHRADER).

---

* G. C. Martin, "Geology and Mineral Resources of the Controller Bay Region, Alaska," Bull. No. 335, U.S. Geol. Surv., 1908, pp. 48-49, pl. i., ii., and v.

† One of the best maps of such a restored valley glacier of Pleistocene age is that of the Kern valley of California (see Lawson, *loc. cit.*, pl. xxxi.).

‡ W. M. Conway, 'Climbing and Exploration in the Karakoram Himalayas,' maps and scientific reports. 1894.

been mapped by Garwood[*] from the Kangchenjunga Himalayas. In the Central Tian Shan mountains are other glaciers of this type.[†] In

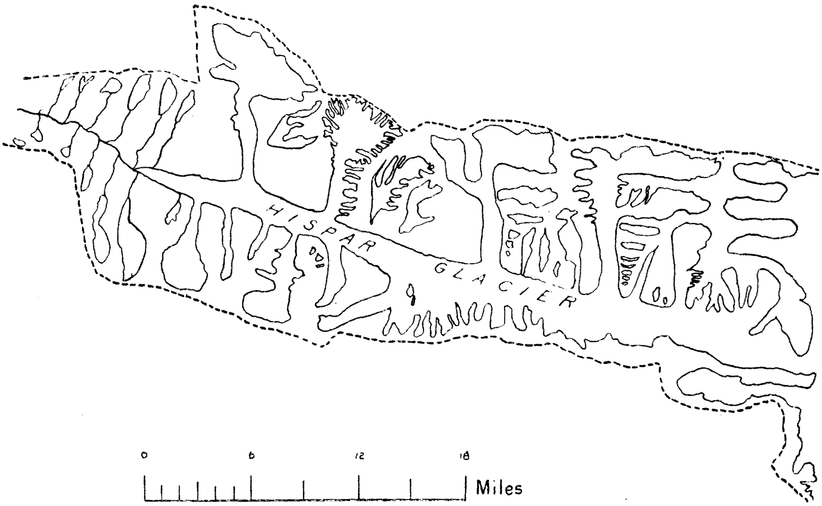

FIG. 25.—OUTLINE MAP OF THE HISPAR GLACIER, KARAKORAM HIMALAYAS. (AFTER CONWAY.)

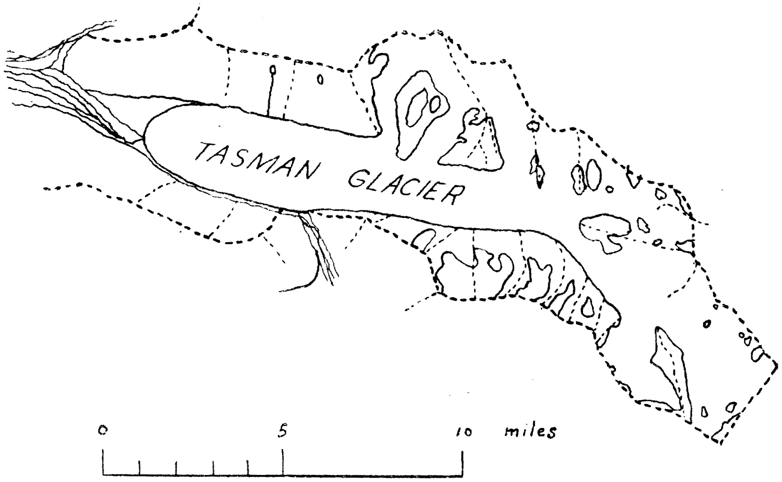

FIG. 26.—OUTLINE MAP OF THE TASMAN GLACIER, NEW ZEALAND. (AFTER V. LENDENFELD.)

---

[*] E. J. Garwood, "Notes on Map of the Glaciers of Kangchenjunga, with Remarks on some of the Physical Features of the District," *Geogr. Journ.*, vol. 20, 1902, pp. 13–24, plate.

[†] Max Friederichsen, "Die heutige Vergletscherung des Khan-Tengri-Massives und die Spuren einer diluvialen Eiszeit im Tiën-schan," *Zeit. f. Gletscher K.*, vol. 2, 1908, pp. 242–257.

the New Zealand Alps the Tasman glacier furnishes another example of the same valley type* (see Fig. 26 and Plate II., Fig. 5). Still other examples have been described from the mountains of Alaska, such, for example, as the Kennicott and Chistochina glaciers.†

Comparison of a number of examples of valley glaciers may illustrate as many different stages in the retreat of the glacier from a position in which it occupied its entire valley to the retirement almost within the mother cirque at the head. The examination of the vacated valley has taught us that the tributary glaciers erode their beds less deeply than the trunk stream lying in the main valley. It is the surfaces of the ice-streams only that are accordant, and hence a lack of accordance in the bed-levels has yielded the so-called hanging valleys with their characteristic ribbon falls. Nowhere can the hanging valleys be observed in greater perfection or on a grander scale than in the troughs, now largely abandoned of ice which enter the great fjords of the "inside passage" to Alaska (see Fig. 27).‡

As the foot of the trunk glacier retires up its valley, the lateral tributaries which are nearest the mouth of the valley are at first separated from it and develop their own front moraines. Later they are left high above the main stream as a series of *hanging glacierets* (see Fig. 28).§ The series of hanging glacierets, as will be observed in the maps of the Baltoro and Hispar glaciers, often persist above the main valley well below the foot of the trunk stream.

Inherited Basin Type.—The valley type of glacier hardly appears in the Alps at all, though the Great Aletsch glacier might perhaps be regarded as a small and imperfect example. The size and characters of the latter are, however, for the district in which it lies, abnormal and to be accounted for by the existence of a natural interior trough lying between the Berner Oberland on the one side and the high range north of the Rhone valley upon the other, from which basin small outlets only are found through the southern barrier (Plate II. Fig. 14). A

---

* R. v. Lendenfeld, "Der Tasman Gletscher und Seine Umrandung," *Pet. Mitt.* Erg. Bd., vol. **16**, 1884, pp. 1–80, map, plate I.

† W. C. Mendenhall and F. C. Schrader, "The Mineral Resources of the Mount Wrangell District, Alaska," Prof. Pap. U.S. Geol. Surv., No. 15, 1903, pl. iv. and ix. See also Brooks, Prof. Pap. U.S. Geol. Surv., No. 45, map, plate xxxiv.

‡ R. S. Tarr, "Glacier Erosion in the Scottish Highlands," *Scot. Geogr. Mag.* vol. **24**, 1908, pp. 575–587.

§ The term "hanging glacier," now used in a variety of senses, is, it is believed, best retained with this restricted meaning. The term "cliff glacier," generally considered synonymous, may be restricted to the long strips of incipient glacier ice which sometimes parallel the main valleys on narrow terraces above precipitous cliffs which are primarily determined by the rock structure (see *ante*, p. 154; and also Matthes 'Appalachia,' vol. **10**, 1904, p. 262). In the sense here employed, a hanging glacier is the equivalent of the *Kahr Gletscher*, a term quite generally employed in Germany. The term "horseshoe" glacier we have here suggested for an essentially different type of glacieret (see below, p. 280).

better example, however, of this special type of glacier, in which the inherited topography has exercised a greater influence upon the glacier form than has the auto-sculpture, is furnished by the Illecillewaet glacier of the Selkirks (see Fig. 29), which, from a roughly rectangular snow-icefield lying between parallel ridges, sends out short tongues leading in different directions. A glacier of this type, with a moderate increase only of alimentation, would produce a small ice-cap.

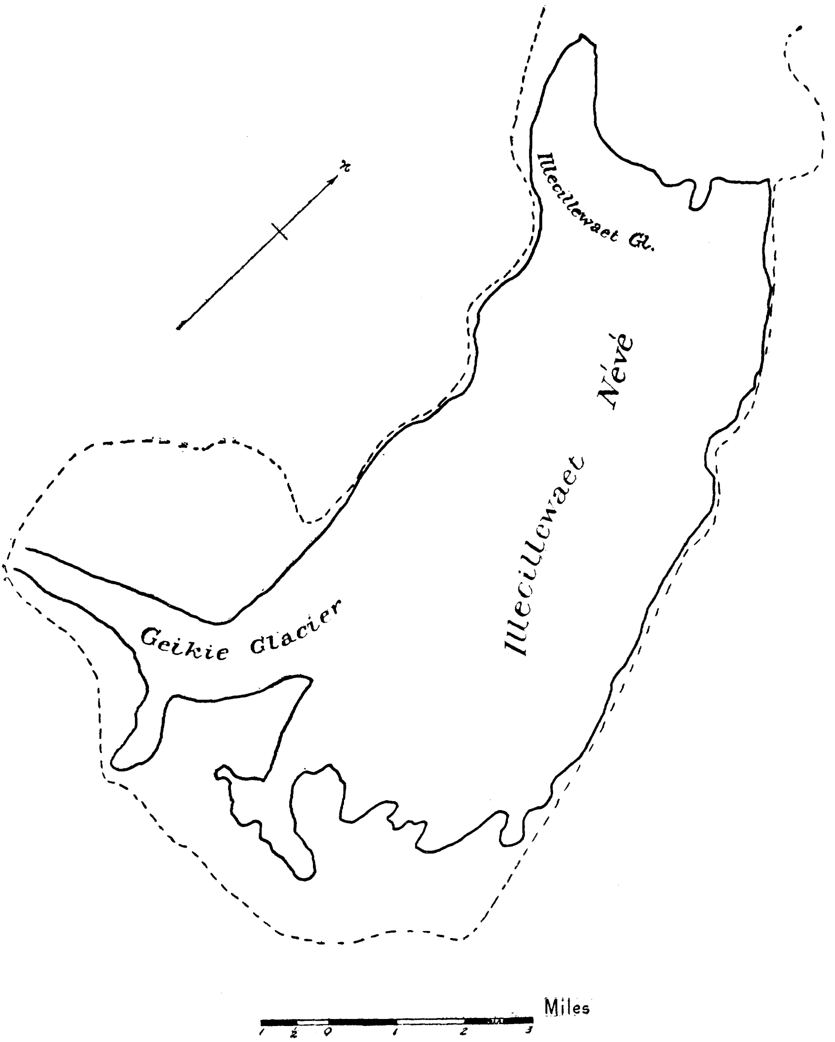

FIG. 29.—OUTLINE MAP OF AN INHERITED BASIN GLACIER, THE ILLECILLEWAET GLACIER OF THE SELKIRKS. (AFTER WHEELER.)

Another abnormal form of glacier due to the peculiarities of the basin which it inherited, is illustrated by the Victoria glacier in the

Canadian Rockies, a glacier having no cirque, but only a couloir (the so-called "death-trap") in its stead (see Fig. 30). In this case the *névé* which feeds the glacier is found high above upon the cliff—a true cliff glacieret—and this *névé* avalanches its compacted snow upon the surface of the Victoria glacier, which thus well illustrates the *reconstructed type.*[*]

Again, glaciers may develop, not upon a gently domed and variously moulded pre-glacial upland such as we have thus far had under consideration, but upon the sharply conical volcanic peaks which in temperate and tropical regions push their heads from the mountain upland far up above the snow-line. In such cases, regular cirques cannot develop at the heads of the radiating ice-streams, but, on the contrary, very irregular and mutually destructive forms will result (see Fig. 31).[†] This is the more true because of the loosely consolidated tuffs of which such cones are always built up. If sufficiently lofty, the result may be a small carapace or ice-cap such as is found to-day upon the summit of Kilimandjaro in Africa. On the other hand, a partially ruined crater may furnish a *natural* basin or cauldron for a small glacier—*Cauldron Type.*[‡]

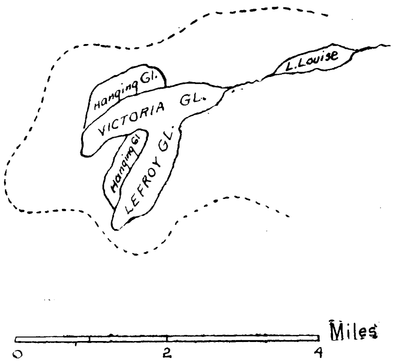

FIG. 30.—OUTLINE MAP OF RECONSTRUCTED GLACIER—THE VICTORIA AND LEFROY GLACIERS IN THE SELKIRKS. (AFTER WHEELER.)

Tide-water Type.—In high latitudes glaciers sometimes descend to the level of the tide-water in fjords which continue their valleys. In such cases, the glacier front is attacked mechanically by the waves and is further melted in the water. In place of the convexly rounded nose, so characteristic of the other types, there develops a precipitous cliff of ice from which bergs are calved, and the glacier front in consequence is rapidly retired (Plate II. Fig. 6). Unhappily, the local term "living glaciers" has been applied to this type in Alaska; "dead glaciers," in the same usage, being applied to glaciers which yield no icebergs. The slopes of the glacier surface and the measure of projection of the ice above the water-level both render it probable that in most cases, at least, the ice-foot everywhere rests on a solid basement.

---

[*] See map and description of this glacier by Scherzer, "Glaciers of the Canadian Rockies and Selkirks," Smith Contrib., No. 1692, 1907, chaps. 2-3.

[†] Cf. I. C. Russell, "Glaciers of Mount Ranier," 18th Ann. Rept. U.S. Geol. Surv., 1898, pp. 329-423.

[‡] Hans Meyer, "Der Calderagletscher des Cerro Altar in Equador," *Zeit. f. Gletscherk.*, vol. 1, 1906-7, pp. 139-148.

On the other hand, the Turner glacier, debouching into Disenchantment bay, Alaska, shows a flat and relatively low front section, which is separated from the remaining and sloping portion of the glacier by a steep ice-fall. This has led Gilbert to think that the lowest terrace is floated in the water.*

Alpine Type.—A good deal of misunderstanding is current in regard to alpine glaciers, often unhappily referred to as valley glaciers. Examination of any good map of Switzerland suffices to show that with the possible exception of the Great Aletsch, an abnormal type, Swiss glaciers hardly extend into valleys at all. We have too long held the alpine glacier close before the eye, and so have much exaggerated its importance. When Alaskan, Himalayan, and New Zealand glaciers are brought into consideration, the real position of the Swiss type becomes apparent. In reality the glaciers of the Alps, far from occupying valleys, do not even fill the mother cirques at the valley heads. Here they lie, side by side, joined to one another like the radiating sticks within a lady's fan, for which reason they have been called *Zusammengesetzte Gletscher* (see Fig. 10 and Plate II., Fig. 7). The *mer de glace*, next to the Great Aletsch the largest in Switzerland, with its numerous tributaries, it is true, completely fills a cirque, but only that of a tributary valley (Plate II. Fig. 8).† Alpine glaciers are hence sheaves of small glaciers which are wholly included within the mother cirques, or which fill and extend out from the secondary or tributary cirques. In the Nicolai Valley of Switzerland, the Gorner glacier and its several tributaries (see Fig. 10), with the Findelen and Längenfluh, the Theodul, Furgen, and Z'Mütt glaciers together, but partially fill the mother cirque of which Zermatt is the centre. Lining the valley below upon either side are eighteen to twenty glacierets, all resting upon the *albs*, or high mountain meadows.

High up in the Chamonix valley, below the debouchure of the *mer de glace*, similar glacierets are lodged upon the ledge below the sharp needles of de Charmoz, de Blatière, du Plan, and du Midi, their frontal moraines making a continuous series of scallops above the shoulder of the valley. Similar but smaller series are shown in Figs. 20 and 32.

Horseshoe Type.—The final representative type in our series, unlike the alpine glacier, is no longer made up of streams joined together in

---

* G. K. Gilbert, 'Harriman Alaska Expedition,' vol. 3, "Glaciers," 1904, pp. 67–68. See also Tarr, "The Yakatat Bay Region, Alaska, Physiography and Glacial Geology." Prof. Paper No. 64, U.S. Geol. Surv., 1909, pp. 39, 40, pl. x*a*.

† This valley is a large hanging valley tributary to the Chamonix valley, which latter alone is comparable in size to those that form the beds of the Baltoro, Hispar, and Tasman glaciers. If at first it seems that confusion may result from the introduction of valleys of different orders of magnitude, a second thought suffices to show that the difficulty is of theoretical rather than of practical importance, at least so far as existing examples of glaciers are concerned.

FIG. 31.—IRREGULARLY BOUNDED NÉVÉS UPON THE VOLCANIC CONE OF MOUNT RANIER.

FIG. 32.—SERIES OF HANGING GLACIERETS WHICH EXTEND THE ASULKAN GLACIER IN THE SELKIRKS.

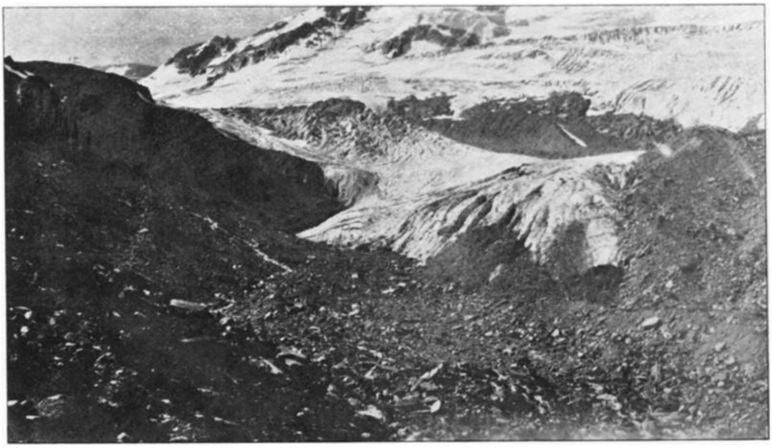

FIG. 33.—VIEW OF THE ASULKAN GLACIER, A HORSESHOE GLACIER IN THE SELKIRKS.

FIG. 35.—VIEW LOOKING DOWN THE VALLEY OF FISH CREEK FROM THE ASULKAN GLACIER, THE HERMIT RANGE IN THE DISTANCE. SELKIRK MOUNTAINS.

FIG. 37.—VIEW OF THE WENKCHEMNA GLACIER AT THE HEAD OF THE VALLEY OF THE TEN PEAKS IN THE CANADIAN ROCKIES.

sheaves. With further shrinking of alpine glaciers corresponding to higher air temperatures, the glacier front retires until it approaches the cirque wall. It now takes on, either as an individual or as a collection of small remnants, a broadly concave margin, which is in contrast to the convex or convexly scalloped front characteristic of all other glacier types. This type of glacieret has been sometimes described under the names hanging and cliff glaciers.* Reasons have been presented for restricting both these terms to special and different varieties of small glaciers or glacierets. It is proposed to use here the term "horseshoe glacier" for these last remnants of larger glaciers hugging the wall of the cirque. Most of the glaciers of North America outside of Alaska belong in this class. As already implied, they are generally broader than long, and usually have concave frontal margins. Excellent examples of this type are furnished by the "Horseshoe glacier" at the head of the Paradise valley in the Canadian Rockies and by the Asulkan glacier in the Selkirks (see Figs. 32–34.) The Mount Lyell glacier, long known and cited from the High Sierras of California, is, however, an equally good type.† For further illustration of the type the Wenkchemna glacier in the Canadian Rockies has been chosen (see

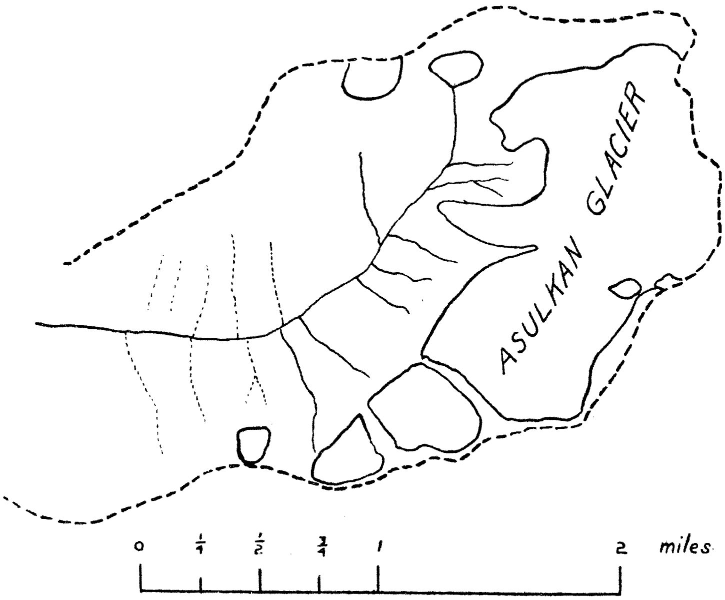

FIG. 34.—OUTLINE MAP OF THE ASULKAN GLACIER IN THE SELKIRKS.

---

* See footnote on p. 277.

† I. C. Russell, "Existing Glaciers of the United States," 5th Ann. Rept. U.S. Geol. Surv., 1885, pp. 314–328, pl. 40.

Figs. 36, 37 and Plate II. Fig. 12). The Asulkan and Wenkchemna glaciers have both been described by Scherzer as belonging to the piedmont type. The former hugs the cirque wall with an incurving frontal margin, and is extended by a series of small hanging glacierets (see Fig. 32). Unlike the piedmont glaciers, it has no foreland on which to expand, but lies at the head of a typical U-shaped valley (see Fig. 35). The Wenkchemna glacier occupies a similar position in the great cirque outlined by the Ten Peaks at the head of a tributary valley to the Bow (see Figs. 36, 37).*

In Plate II. the various types of glacier are shown on approximately the same scale, and from this it will be appreciated that the size, directly dependent upon the alimentation of the glacier, must be a determining factor in classification. The ice-cap and piedmont glaciers will in this respect overlap, being differentiated by the accentuation of the relief of the land, though in the main the ice-cap is the larger. For the other types the proportion of the glacier-carved valley which is still occupied by the ice will determine the form and the more important characters of the existing glacier. It is important, therefore, in order to determine the type to which an individual glacier belongs, to map the divide surrounding the valley, as well as the boundaries of the glacier which lies within it.

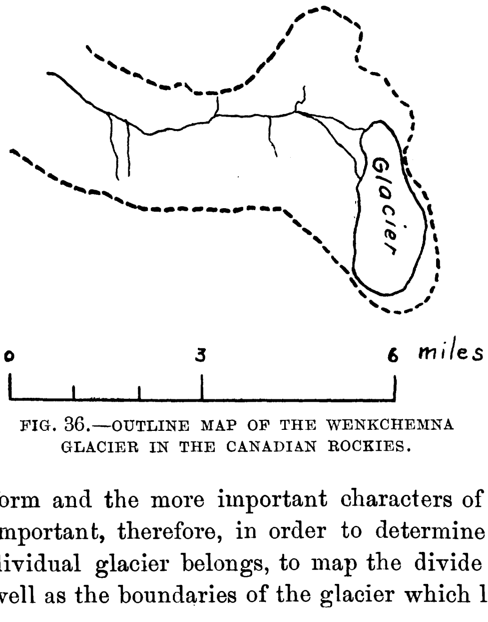

FIG. 36.—OUTLINE MAP OF THE WENKCHEMNA GLACIER IN THE CANADIAN ROCKIES.

Termination of the Cycle of Glaciation.

Configuration of the Glacier-bed when uncovered.—No one who has climbed a mountain glacier to its *névé* has failed to be struck by the alternation of plateau and precipitous slope, for the surfaces of mountain glaciers are, with few exceptions, broken into broad terraces. Each steep descent is well understood to overlie a corresponding fall in the glacier-bed. Perched upon the high cliffs which overlook the Pinnacle pass

---

* Sherzer, Smith Contrib., No. 1693, 1907, chaps. iv. and vii. The only resemblance to the piedmont glacier is in the shape. Neither glacier expands upon a foreland, but both lie in cirques at the heads of U-shaped valleys. They have no appreciable tributaries, and, as already pointed out, piedmont glaciers are necessarily of large size, corresponding to excessive precipitation.

during his first attack upon Mount St. Elias, the late Professor Russell wrote of these terraces *—

"Were the snow removed and the rock beneath exposed, we should find terraces separated by scarps sweeping across the bed of the glacier from side to side. Similar terraces occur in glaciated cañons in the Rocky mountains and the Sierra Nevadas, but their origin has never been explained. The glacier is here at work sculpturing similar forms, but still it is impossible to understand how the process is initiated."

The generalized description of uncovered glacier-beds within the High Sierras of California—perhaps as well as any that has been penned—lays the emphasis upon the more essential and impressive characters †—

"The amphitheatre bottom terminated forward in either a cross cliff or a cascade stairway, descending, between high walls, to yet another flat. In this manner, in steps from flat to flat, common enough to be characteristic, the canyon made descent. In height, however, the initial cross cliff at the head dominated all. The tread of the steps in the long stairway, as far as the eye could follow, greatly lengthened in down-canyon order."

The grade in the treads of the giant stairway is often reversed, so that they come to be occupied by the characteristic rock-basin lakes, long and ribbon-like, or strung along the valley like pearls upon a thread.

Since Russell's meditation above the Pinnacle pass, nearly a score of years ago, considerable study has been given to the subject of erosion upon the glacier-bed. In the Alps Penck and Brückner have enunciated their "law of adjusted cross-sections." The glacier, on invading the mature river-valley, characterized by uniformly forward grades and by accordance of trunk with side valleys, will, in general, be so modified that a small cross-section corresponds to a deepening of the valley.‡ Thus will be brought about the hanging side valley, and a local modification of, and perhaps even a reversal of, direction in the grade of the main valley.

If the rock be not homogeneous throughout, or if it be unequally intersected by joint planes, further abrupt changes in grade will result. The two processes which are effective in deepening the bed of the valley are well recognized to be abrasion and plucking. Greater softness in the rock will correspond to greater depth of abrasion, while the perfection of the parting planes will directly determine the amount of quarrying in the rock by plucking. Abrasion being greatest on the

---

* I. C. Russell, "Expedition to Mount St. Elias," *Nat. Geogr. Mag.*, vol. **3**, 1891, pp. 132-133.

† Johnson, *Journ. Geol.*, vol. **12**, 1904, pp. 570-571.

‡ A. Penck, *Journ. Geol.*, vol. **12**, 1904, pp. 1-19.

upstream side of any irregularity in the bed, and plucking being largely restricted to the downstream side, the tendency of these processes working together will be to produce steps of flat tread but steep riser, the latter coinciding with the nearly perpendicular planes of jointing.

It is further probable that the cliffs at the lower margins of the terraces are in many cases, at least, considerably recessed through the operation of a sapping process in every way analogous to that which obtains at the base of the Bergschrund, or *Randspalte.* So soon as the rock-cliff has been formed, either below a narrowing of the valley or where a hard layer of rock transects it, the glacier will descend over it in an ice-fall, showing gaping transverse crevasses. These fissures in the ice may be sufficiently profound to admit the warm air at midday to the rock joints, and so bring about with the nightly fall of temperature a mechanical rending of the rock.

Basal cliff sapping being downward as well as backward, the reversed grades of the treads in the staircase could be thus explained. In the Alps, Penck distinguishes especially one larger cliff in the staircase which separates the head cirque from the trough valley (*Trogthal*).

Water-erosion within the Valley during Retirement of the Glacier.—The staircase left by the ice, with its rock-basin lakes high up in the valley and its morainal lakes in the lower reaches, undergoes a rapid transformation under the influence of running water so soon as the ice has largely vacated the valley. Flowing from the waning remnant of the glacier, this water is overburdened with sediment. Its current is sluggish on the treads of the steps, but develops a cascade over the cliffs between. The coarser *débris* which it carries is thus quickly dropped upon the treads to fill the lake-basins, and with the aid of the finer material, the rock obstructions are cut through in narrow cañons and with a marvellous rapidity. Where a barrier of more resistant rock has hemmed in a portion of the valley (*Riegel*), narrow picturesque gorges have been cut, such as the *Aarschlucht* and the gorge of the Gorner.* The lateral moraines, having slid down their slopes with the retirement of the ice, are rapidly buried under the talus of the rock-slides from the steep valley walls, thus partially obscuring the characteristic U of the valley section. Sufficiently clear marks are left, however, so that there is seldom serious difficulty in restoring the main outlines of the glacial history of the district.

---

* Some of the Swiss gorges were described by Tyndall (' Hours of Exercise in the Alps,' pp. 224–230).