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THE GLACIERS OF MOUNTAIN AND CONTINENT[1]

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GLACIERS are found to-day in practically all latitudes, but are found larger and more amply nourished as one recedes from the equator, and also as one approaches those coasts of the continents where moisture-laden winds advance from the sea athwart lofty mountain ranges. Within the torrid zone the glaciers retreat into the higher portions of very lofty mountains. Of altogether exceptional development are the low-latitude glaciers of the Himalayan region in Southern Asia, due to the extreme altitude, in combination with the heavy precipitation brought in by the monsoon winds from the heated Indian Ocean.

All glaciers are fed by moisture in the form of snow, or in some cases of rime, which becomes compacted into ice under its own weight and through recrystallization. They are always of fresh-water ice, in which respect they are in contrast with sea-ice and floe-ice, which are formed by the freezing of the surface layers of the sea. Glaciers, moreover, are land *born,* as they are quite generally land *borne,* though with important exceptions within the high latitudes.

Living in a world of glaciers, it has been natural for us to apply Lyell's phrase, "the present is the key to the past," and to assume that glaciers have been characteristic of all past geological ages as well as of the present; but the evidence from both geology and paleontology is that for the greater part of geological time there have apparently been no glaciers, and the climate from the equator to at least near the poles

[1] Introductory portion of the address of the retiring vice-president of the Section of Geology and Geography, American Association for the Advancement of Science, delivered at Cambridge, Massachusetts, on December 27, 1933. The full paper is to appear in the *Zeitschrift fuer Gletscherkunde.*

has been without marked climatic zones but, uniform, mild and humid, much as is the subtropical climate of to-day. The normal condition of our planet has thus been quite unlike the relatively brief and wholly abnormal glacial period in which we are living.

Of widely extended glaciation we know of but three periods, namely, at or just before the beginning of the Cambrian, in the Permo-Carboniferous and in the Pleistocene-Present. Of the latest of these there have been already four or five separate glaciations, separated by mild interglacial periods. We seem now to be in the receding hemicycle of the latest of these Pleistocene-Present glacial periods; for it is a general rule that the glaciers of to-day are withdrawing their fronts and in other ways making clear that their dimensions are diminishing.

In the development of scientific theories chance has played no insignificant rôle and it was a most unfortunate circumstance that the Pleistocene continental glaciers of North America and Europe should have been studied and their characteristics envisioned before any existing continental glacier had been even seen save from a remote distance. Scheuchzer, De Saussure, Hugi, Venetz and Charpentier, pioneers in the study of Alpine glaciation, had all completed their important researches in the early thirties of the nineteenth century, and Louis Agassiz, the father of the theory of continental glaciation as applied to northern Europe and northern North America, had completed his important studies in the first half of that century. The discovery of the Antarctic continent from the sea was, strangely enough, contemporaneous with the pioneer studies of Venetz, Charpentier and Agassiz, but no landing was made upon the Antarctic glacier until more than another half century had elapsed, and no clear picture of this greatest of existing continental glaciers had been acquired until even later. As regards the other continental glacier, that of Greenland, the first invasions of this area occurred in 1883 (Baron Nordenskiöld), in 1886 (Peary) and in 1888 (Nansen), full forty years or more after the Agassiz conception of Pleistocene continental glaciation had taken form. It is perhaps not strange, therefore, that the model of this conception was the Alpine one, with flow toward the margins from the highest point, with nourishment of the same pattern, and with degradational effects in all essential respects the same. Ideas so imbedded are apt to persist and are not easily uprooted, particularly when actual demonstration in some cases may not be practicable. The result has been that the Pleistocene continental glaciers have been reconstructed from their traces upon the model of the mountain glaciers of the Alps, with which alone the early glacialists were familiar. One of our greatest American students of Pleistocene glaciers was never able fully to appreciate the essential differences between continental and mountain glaciers as respects their modes of nourishment, their internal movements and their reactions with the lithosphere. By him and his students to-day continental and mountain glaciers have been treated as though these vitally important differences were non-existent.

In reality there are to-day three great classes of glaciers which differ rather widely from one another, namely, (1) those of mountains or mountain glaciers, (2) continental glaciers and (3) icecap glaciers, those glaciers in high latitudes which spread over a rock pedestal and may perhaps be regarded as intermediate, connecting the two extreme classes of mountain and continental glaciers. Though distinguished sharply from each other, yet it is possible that many of the icecaps have actually at some time in the past evolved from glaciers of the mountain class, and graded through all intermediate stages to the continental type as a consequence of progressive changes in climate. Thus some of the simpler of mountain types represent the beginnings of glaciation as continental glaciers do its culmination, and as the climatic cycle passes into its receding hemicycle somewhat similar changes succeed to one another, though in the reverse order. Differences of latitude, of altitude and of amount of precipitation are, however, responsible for our discovery of representatives of many of these earlier types to-day during what appears to be a general retrogression of the glacial cycle.

It is pretty clear that, were we living in the advancing hemicycle of glaciation, we should find examples of some types of glacier not now represented, and it would be natural for purposes of discussion to consider the types of glacier in the order in which they made their appearance within the glacial cycle, and later their disappearance. Deficiency in alimentation has within some districts held back the evolution of the glacier and so preserved for us traces of types which belong in the advancing hemicycle even when the glaciers themselves are not in existence today. They are in some cases to be reconstructed from the land sculpture they have left behind.

Before proceeding to develop upon this basis the types of mountain glaciers, it would be well to consider the general characteristics of the two contrasted classes of mountain and continental glaciers and the intermediate type of icecaps. The essential differences in the main classes relate to (1) size, (2) figure, (3) mode of nourishment, (4) internal movement and surface processes which make or retain the figure, and (5) sculpture of the terrane beneath and about the glacier. In all these particulars the two main glacier classes are strikingly contrasted. We shall consider these particulars *seriatim.*

(1) *Size.* The mountain glaciers range in size from those that are hardly more than glorified snowdrifts, a fraction of a mile only in length, to the glaciers of the Pamir and Himalaya Highlands, as yet but partially surveyed, where they in some instances reach extreme dimensions of 100 miles or more. Upon the other hand, continental glaciers of to-day have continental magnitude with extreme dimensions of 1,500 miles (Greenland) and 3,000 miles (Antarctic), with those of the Pleistocene of the same order of magnitude but considerably larger.

(2) *Figure.* As regards the figure of mountain glaciers, despite the wide range represented, this is in most cases determined by the form of the container of rock within which the glacier is included. As in liquid containers generally the walls here rise above the contained material, but the containers are inclined (dished) so that there is always a higher and an opposed lower side. On the lower side the container wall is generally lacking, but the concentrated wastage of the glacier toward that margin makes the containing wall unnecessary.

A few glaciers inherit a container, such, for example, as the crater of a volcano, and these comprise a separate group of a few types only. Together they may be referred to as the class of *inherited basin glaciers.* By contrast with the mountain glaciers the continental glaciers are not contained, but spread broadly over vast areas uncontrolled by the terrane and assume figures determined by their own properties. This figure is a greatly flattened dome which bears closest resemblance to a round watch crystal or watch cover of the traditional variety.

(3) *Mode of Nourishment.* All mountain glaciers of whatever type owe their origin and continued nourishment to accumulated snow, which is derived from *ascending* moisture-laden air currents. Through large adiabatic refrigeration these air currents are forced to deposit their moisture content in the higher mountain levels as snow. In strongest contrast continental glaciers receive their contribution of snow (and rime) from *descending* air currents within an overlying glacial anticyclone, where adiabatic elevation of temperature is a consequence, and the precipitation is apparently the immediate result of abstraction of heat by the cold surface of the glacier from near-surface air layers. The centrifugal (and downward) direction of the surface winds over the glacier quite precludes the possibility of nourishment by ascending air currents, as is the case with mountain glaciers.

(4) *Internal Movement and Surface Changes which Make and Retain the Figure.* Since the pioneer studies upon mountain glaciers, it has been recognized that these glaciers are nourished chiefly in their higher levels, from which the ice has a gravitational downward movement toward their lowest levels, where wastage by melting is concentrated. Mountain glaciers have thus an internal movement downward throughout and are differentiated into an upper region of alimentation and a lower region of wastage. Their figure is in part determined by this differentiation, and as climate becomes more genial the glacier alimentation decreases as the wastage increases, and the front of the glacier retires until its last stand against extinction is made along the wall at its head. This law, on which the intermediate glacier types are based, depends upon the prevalence of above-freezing, and therefore wasting, air temperatures within the lower levels of the atmosphere. Within the Antarctic region, however, where above-freezing temperatures are not experienced even in midsummer, save within highly localized areas and for brief periods only, the law does not hold, and so there are new and special Antarctic glacier types.

As already pointed out, the Pleistocene continental glaciers were the first to be studied and reconstructed from their now abandoned beds upon the model of the mountain glaciers of the Alps. To-day we are able to say that internal movement goes on along the steep front of continental glaciers and as far back from the front as their appreciable slopes extend. This seems to be proven by the crevassed surface, always a consequence of differential internal ice movements. That back of this marginal zone there is internal movement of the ice there is no evidence whatever. The prevalent misconception is an inheritance from the picture formed of Pleistocene continental glaciers before existing continental glaciers had been observed. The glaciated rock surface overridden by the continental glaciers, bears a record of the erosional work beneath the *marginal zone only,* which both during the advance and the retreat of the ice-front has moved in turn over all parts of the entire glaciated area. It thus supplies no warrant whatever for supposing that such action has gone on beneath the vast central area.

The distribution of the fine snow that falls over the continental glacier from descending and centrifugally directed surface currents, is redistributed by these currents and so is carried outward toward their margins in quantities measured literally by the millions of tons. It is this gigantic centrifugal snow-broom which appears to have contributed to give shape to the watch-like figure of existing, and presumably of all, continental glaciers.

(5) *Sculpture of the Rock beneath and about the*

Glacier. It is a consequence of the fact that mountain glaciers are in all cases essentially streams of ice which pursue definite courses, whereas continental glaciers spread broadly over all the country; that the former have excavated steep-walled trenches and vast amphitheaters to produce the most rugged topography that is anywhere known; while continental glaciers by sharpest contrast have employed the erosional processes only to pare down elevations and fill in depressions, so as to "iron out" the existing features and reduce the accent of the relief. Eventually they produce a broadly undulating surface from which all earlier characters have been effaced.

Résumé. Mountain glaciers are of moderate proportions, are held within rock containers, are nourished by ascending air currents, have internal movement throughout and transform the topography into the most rugged type that is known. Continental glaciers are of vast proportions, are not contained but take on always a flatly domed surface, are nourished by descending air currents within a glacial anticyclone, have their internal gravitational movement apparently restricted to the marginal zone, and produce some of the most monotonous flatly undulating topography that is known.

The icecaps of high latitudes occupy a position intermediate between the mountain and continental glacier classes, and they doubtless represent an intermediate stage through which the continental glacier in some cases at least has evolved from earlier mountain glaciers. In size the icecaps are intermediate, but nearer the mountain glacier. In form they differ little from the continental glacier, save only that the dome is much less flat. They rest upon rock pedestals and in all cases are of depth sufficient to fill and overwhelm all the inequalities of their rock floor. As regards their mode of nourishment also, icecaps seem to occupy an intermediate position. The smaller ones are in part at least nourished by ascending currents after the manner of mountain glaciers, whereas the larger ones are able to develop a local centrifugal surface-air circulation for at least much of the time. The largest of all, that of Northeast Land in Svalbard, has been shown to possess a glacial anticyclone which, however, for short periods—during the passage of a strong cyclone—loses its domination, only to snap back into position so soon as the depression has passed on. In respect to shaping the rock beneath, icecaps are more allied to the continental glacier, with its restriction to the employment of plucking and abrasion only. Along their borders icecaps and continental glaciers alike send out tentacles of ice which possess many of the properties of the true mountain glaciers, and those of the icecaps particularly have often a scalloped margin due to a series of amphitheatral basins upon their borders.

OBITUARY

ROBERT HENRY WOLCOTT

AFTER a long and fruitful career, prominently in connection with the University of Nebraska, Professor Robert Henry Wolcott died on January 23, of carcinoma of the liver. Previously in robust health, he had been ill for only a few months before his death. At that time he was chairman of the department of zoology in the University of Nebraska and acting chairman of the department of bacteriology and pathology.

Dr. Wolcott was born at Alton, Illinois, on October 11, 1868. He spent most of his early life in Grand Rapids, where his father was prominently associated with the furniture industry. He was early brought into contact with a group of naturalists and acquired a love for outdoor studies which played a prominent part in his later life. He went to Michigan for his college work and was naturally drawn into the biological field. He was given the B.L. degree in 1890 and the B.S. in 1892 but during this time he was also concerned with studies in medicine. In 1893 he was granted the degree of M.D. but never engaged in active practise. His interest was in the scientific aspects of the biological field and he embraced an opportunity offered to participate in the biological survey of Michigan waters then under way with especial reference to the features involved in the maintenance and increase of the fish supply. He served as a member of the party of biologists working at New Baltimore in the summer of 1893 and at Charlevoix in 1894. It was as a member of the first party under the leadership of Professor Jacob Reighard and as director of the survey the following summer that I became familiar with Wolcott's ability as a field naturalist and his desire to follow his interest in that field through teaching and study. Consequently when a vacancy opened in the department of zoology at Nebraska in 1894 I offered him the place. From that time for forty years he served the university and the state with enthusiasm and success in a variety of different positions.

The first year he was an assistant and at its close received the degree of M.A. and an appointment to an instructorship. In 1898 he was made an adjunct professor and in 1902 associate professor of zoology in charge of the work in anatomy. Nineteen hundred and five brought him the professorship in anatomy. With a change in the personnel of the department