DATE OF LOCAL GLACIATION IN THE WHITE MOUNTAINS.

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In a series of excellent descriptions of White Mountain physiography published some twenty years ago J. W. Goldthwait[1] suggested among other things that the cirques of this region were completed by local glacial erosion *before* the coming of the continental ice sheet. The present writer[2] later noted evidence that local glacial erosion and deposition *followed* the last withdrawal of the ice. As such evidence was observed not only in the White Mountains but also in the Adirondacks and Catskills,[3] and as R. S. Tarr[4] had described similar evidence of recent local glaciation on Mount Ktaadn in Maine, the writer closed his paper with the statement that "these considerations justify further study of White Mountain physiography" before one can accept the theory that cirque cutting was completed prior to the advance of the continental glacier.

One such further study has briefly been described by A. C. Lane.[5] He accepts Goldthwait's theory of an early date for the completion of cirque cutting, referring to "evidences of the glaciated rims of the cirques as given by him (Goldthwait)" and expressing the view that it is "natural that the local glaciers . . . should have been the forerunners of the great ice sheet," and that during wasting of the ice "deposition rather than erosion is the order of the day." He believes "the disposal of a great ice sheet needs a milder climate than that

[1] Goldthwait, J. W., Following the Trail of Ice-Sheet and Valley Glacier on the Presidential Range, Appalachia, **13,** 1-23, 1913.

Glacial Cirques near Mount Washington, this Journal, **35,** 1-19, 1913.

Remnants of an Old Graded Upland on the Presidential Range of the White Mountains, this Journal, **37,** 451-463, 1914.

[2] Johnson, Douglas, Date of Local Glaciation in the White, Adirondack, and Catskill Mountains, Bull. G. S. A., **28,** 543-552, 1917.

[3] Kemp, J. F., Geology of the Lake Placid Region, N. Y. State Museum Bull. **5,** No. 21, 51-67, 1898.

Ogilvie, I. H., Glacial Phenomena in the Adirondacks and Champlain Valley, Jour. Geol., **10,** 397-412, 1902.

Rich, J. L., Local Glaciation in the Catskill Mountains, Jour. Geol. **14,** 113-121, 1906.

Notes on the Physiography and Glacial Geology of the Northern Catskill Mountains, this Journal, **39,** 137-166, 1915.

[4] Tarr, R. S., Glaciation of Mount Ktaadn, Maine, Bull. G. S. A., **11,** 433-448, 1900.

[5] Lane, A. C., White Mountain Physiography, this Journal, **1,** 349-354, 1921.

in which one would just appear," and concludes: "Thus we should not then (during waning of the ice sheet) expect any local centers of glaciation, especially when, as we shall see, the mountains were nearly a thousand feet lower than at present." Lane did not discuss the significance of moraines and other evidences of late-Wisconsin or post-Wisconsin local glaciation reported from the Adirondacks, Catskills and Mount Ktaadn by Ogilvie, Rich, Tarr, Johnson and others, doubtless because these areas lay far outside the field upon which he was reporting. As we shall see, the presence of such features in neighboring ranges as well as in the White Mountains has an important bearing upon the general problem.

A more extended study of this question has recently been published by Ernst Antevs,[6] as part of a broader discussion of the "Alpine Zone of Mt. Washington Range." Antevs devotes a special chapter to the question: When were the glacial cirques formed? He is of opinion that "each glacial epoch of the Pleistocene or the Last Ice Age could have caused the development of local glaciers in the White Mountains both during its stage of rise and during its stage of decline . . . . If there were four glacial epochs, there were eight potential ages of valley glaciation. Actually there must have been several." This seems sound reasoning. I know of no method of excluding the possibility of early and repeated progressive cirque cutting, and my treatment of the question, previously cited, is defective in that it does not specifically recognize this possibility. My discussion was directed primarily to presenting evidence indicating that local glaciers existed in the White Mountains after the disappearance of the ice sheet, for my object, as stated, was "not to disprove the theory (of early completion of the cirques), but to question the validity of certain arguments presented in its support, and so to keep the minds of other students of the region alive to the possibility that the greater part of the cirque cutting may, after all, have been accomplished after the continental ice has disappeared from the higher peaks."[7] While this last possibility should be kept in mind, it is unduly emphasized in my paper, especially in view of the strong theoretical probability that much of the cirque cutting occurred earlier. The problem of the cirques,

[6] Antevs, Ernst, Alpine Zone of Mt. Washington Range, Auburn, Maine, 118 pp., 1932.

[7] Johnson, Douglas, Date of Local Glaciation in the White, Adirondack, and Catskill Mountains, Bull. G. S. A., **28**, 547, 1917.

as I understand it, resolves itself into a question as to whether they were completed prior to the coming of the last great ice sheet, or owe their present form, in significant degree, to late-Wisconsin or post-Wisconsin local glaciation.

On this question Antevs offers both opinion and evidence. In the category of opinion we may place the following pertinent quotations: "If these two means of transportation (ice of local glaciers and water formed through their melting) alone had been active, the bulk of the dislodged material should still be found at the mouths of the gulfs (cirques), on their bottoms, and along the upper courses of the issuing brooks and rivers. The dwindling last ice sheet, in which the latest glaciers terminated, could have carried away but little debris for by this time its forward motion had become sluggish. In the short interval after the withdrawal of the last continental glacier the streams could have carried away but little waste. The removal of the enormous masses of debris quarried by the valley glaciers cannot be accounted for in late-Wisconsin and post-Wisconsin time. The valleys (cirques and troughs) must have been largely formed before the last ice sheet enveloped the mountains."

My own opinion with respect to each statement quoted above would be somewhat different from that expressed by Antevs. I should not expect any great proportion of the debris quarried from a cirque to be found at its mouth, on its floor, nor even along the upper courses of the issuing brooks. Cirque cutting is, I should imagine, a slow process during which much of the eroded material is removed in a relatively fine state and transported far from its source. Ordinarily only a small proportion of the debris, especially the coarser parts, so favourably situated as to escape removal, should be expected to remain for our inspection. This expectation seems to accord with field observations. Even in regions untouched by the continental ice, and therefore where the latter cannot be invoked as an agent for sweeping away debris earlier deposited by local glaciers, the morainal and other debris found opposite cirques is usually, although not always, notoriously small. According to De Martonne, in the Carpathian Mountains where no question of continental ice complicates the problem, large moraines are surprisingly rare. He finds that out of ten glacial cirques, on an average not more than one or two would have moraines of appreciable size, while the majority would have no true moraines associated with them. One may,

perhaps, appeal to earlier stream removal of debris deposited in front of these cirques by earlier local glaciations. But in the absence of any satisfactory evidence that local glaciers do commonly leave in or near their cirques and troughs quantities of debris commensurate with that removed, we cannot safely regard absence of such quantities of debris as evidence of an early date for cirque cutting, nor as evidence that the debris was removed by continental ice.

Where continental ice is present about the lower flanks of a mountain range, and local glaciers among the projecting peaks are tributary to it, the amount of debris the continental ice can remove is not necessarily limited by its velocity. Sluggish ice, continuously in slow motion for a long time, may remove as much debris brought down by local glaciers as would swifter ice moving for a shorter period of time. I can see no reason, therefore, to doubt the capacity of the waning ice sheet to remove such debris as local glaciers may have contributed to it. Nor need one doubt the capacity of streams, under favorable conditions, to remove enormous quantities of loose debris in the interval of time elapsed since the withdrawal of the last continental glacier. Extensively aggraded valleys have been pretty thoroughly cleaned out, and rock gorges of considerable magnitude have been eroded, during that period of time. Whether post-Wisconsin stream work is impressive or negligible depends on local conditions. It seems to me that much removal of debris has locally occurred in the White and Adirondack Mountains; but I do not attribute to this circumstance chief responsibility for the fact that debris comparable in quantity to the volume of the cirques is not found in front of the White Mountain gulfs nor in the upper portions of the streams draining from them. It seems more probable that no great quantities of debris were ever deposited in these places; and what moderate quantities (if any) may have been deposited in excess of the amounts actually observed to-day, would seem to present no great task for post-Wisconsin erosion. As for the last sentence quoted above, all would agree that the stream valleys were largely carved before the coming of the last ice sheet. But the facts cited by Antevs do not justify his conclusion that the transformation of valley heads into cirques and troughs, to which his text evidently refers, *must* have taken place before the last ice sheet enveloped the mountains, although one may recognize the possibility, or even the probability, that it may have done so.

It is when he passes from the realm of opinion to that of concrete evidence that Antevs makes the most valuable contribution to the problem. To this part of his discussion we may now turn our attention. "Moraines referable to normal valley glaciers seem to occur in King Ravine and Tuckerman Ravine (two of the principal White Mountain cirques) . . . . Although the entire accumulation of debris (in King Ravine) could have been brought down by slides, the bulk of the waste was more probably carried down by a glacier during the stage of waning of the last ice sheet." In the double cirque called Tuckerman Ravine is "a belt of irregular ridges and hillocks of gravel and till with intervening depressions, two of which hold ponds, the Hermit Lakes. This knob-and-kettle belt may be the moraine of a valley glacier of late-Wisconsin age. . . . The probability of independent valley glaciers in these twin cirques is strengthened by the fact that snow now lingers later in summer at the head wall of Tuckerman Ravine than in any other place on the Presidential Range." Thus Antevs clearly recognizes the presence of true independent valley glaciers in the White Mountains after waning of the last ice had uncovered the main peaks, although as previously noted he accepts the small quantity of morainal and other debris as evidence of limited erosion at that time. He finds evidence of "late-Wisconsin glaciers" in most of the other cirques of this region, but because in these no moraines were observed he thinks "most of these probable glaciers may have been ramifications of the ice sheet" and "may have done little except to undermine and steepen the (cirque) walls." Where cirque walls are not precipitous as in Oakes Gulf, he thinks they may have suffered erosion by the continental glacier, and have held no active valley glacier in late-Wisconsin time.

One may ask whether absence of moraines is not more difficult to explain on the theory that the valley glaciers (in most of the cirques) were ramifications of the great ice sheet, especially when we consider that debris carried by ice tongues advancing into the valleys would not have the same chance for removal as would ice tongues flowing out of the valleys to join the southward-bound continental ice. Be that as it may, the important thing is Antevs' recognition of the fact that some at least of the White Mountain cirques harbored true local valley glaciers in late-Wisconsin time, and that as these moved outward from the cirques they gathered some debris and fashioned it into small morainal deposits which are still

preserved. This brings the White Mountain evidence into harmony with that from the Adirondacks, Catskills, and Mount Ktaadn. In all of these areas moraines of local valley glaciers were formed after the disappearance of the last ice. How much work these late-Wisconsin glaciers accomplished remains a debatable question.

On this last point Antevs contributes valuable data based on his observations in the Ktaadn region. "Various conditions show that South Basin and North Basin (cirques) held alpine glaciers after the mountain protruded through the melting last ice sheet. The evidence includes precipitous walls, Knife Edge Ridge, kettles in the basins, and distinct moraines outside their mouths . . . . only a very narrow ridge, the Knife Edge, separates the (South Basin) cirque from the precipitous southern wall of the mountain. *This ridge could not have survived the last ice sheet,* which other conditions show to have buried the mountain, *but must be of later development. South Basin must have been eroded back considerably by a glacier in late-Wisconsin time* . . . because of *vigorous expansion and erosion by the South Basin glacier,* North Basin also gradually became a hanging tributary valley to the South Basin glacial trough. . . . Thus, late-Wisconsin glaciers occurred in South Basin and North Basin and possibly in Great Basin and Northwest Basin."

In the foregoing quotations I have italicized those parts of Antevs' text which bear upon the vigor and extent of local glaciation after waning of the continental ice had uncovered the higher levels of Ktaadn. The fact that such vigorous activity occurred in late-Wisconsin time at levels of between 3,000 and 4,000 feet in the Ktaadn region (latitude 45° 55′ N) would lead us to expect appreciable activity during the same period at higher levels, 3,500 to 5,000 feet, in the White Mountain cirques (latitude 44° 15′ N). If, as is supposed, the general deglaciation of Mount Washington preceded that of Mount Ktaadn, we should expect more rigorous conditions during the earlier deglaciation, unless it can be shown that at just the right time during waning of the ice sheet there was a notable and long recrudescence of cold in the Ktaadn district which did not cause local glaciers to develop in the higher region of Mount Washington.

The steepness of the cirque walls and the sharpness of their edges in the White Mountain area strongly suggests late-Wisconsin glaciation of considerable vigor. It seems difficult

to explain these features as the work of ice tongues ramifying from the continental ice sheet and projecting *into* the cirque basins; but they are readily explicable as the work of independent local glaciers operating at the same time and in the same manner as those so effectively described by Antevs for the Ktaadn area. That moraines are scanty in the White Mountain region is a fact in harmony with conditions normally observed in even more strongly glaciated mountains in many parts of the world; while the subdued margins of certain White Mountain cirques finds reasonable explanation[8] in the structural planes of weakness which intersect this range.

The interesting observations set forth by Antevs cover a much wider field than the limited problem here discussed. In the field of this problem his observations as a whole seem to support the conclusion that the White Mountain cirques, like those in the Adirondacks, Catskills and the Ktaadn district, owe the present freshness of their forms to local glaciation in late-Wisconsin time, after waning of the continental ice had uncovered the mountain peaks. That much of the cirque cutting was accomplished earlier is a wholly reasonable hypothesis, but one which is, in the very nature of the case, difficult of demonstration.

[8] Johnson, Douglas, Date of Local Glaciation in the White, Adirondack, and Catskill Mountains, Bull. G. S. A., **28,** 546-547, 1917.

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