Reports

Pleistocene Glaciation in the Blue Ridge Province, Southern Appalachian Mountains, North Carolina

Abstract. *Glacial polish, grooves, and striations discovered at an elevation of 1370 meters in the headwaters of Boone Fork on Grandfather Mountain, North Carolina, indicate the former existence of alpine glaciation at a latitude of 36°07′N. The Boone Fork glacier was located 890 kilometers south of the previously recognized southern limit of alpine glaciation in the Appalachian Mountains, and 350 kilometers southeast of the nearest point on the Laurentide ice sheet. This find has significant implications for studies of Pleistocene geomorphology, paleobiology, and paleoclimatology in the eastern United States.*

Alpine glaciation in the eastern United States has not been reported south of the Catskill Mountains in New York, near 42°N (Fig. 1). The Laurentide ice sheet extended only a short distance south of the Catskills, ending in northern New Jersey and Pennsylvania between 40° and 41°N. The possibility of glacial activity in the Appalachian Mountains south of Pennsylvania apparently has been rejected or ignored by most earlier workers. Even reported periglacial features have been questioned by some investigators (*1*).

Wayne (*2*), Peltier (*3*), and Brunnschweiler (*4*) have reviewed the evidence of periglacial conditions extending hundreds of miles south of the Laurentide ice margin, both in the Appalachians and on the Atlantic seaboard. Evidence of periglacial conditions includes block streams, involutions, congeliturbates, ice-wedge casts, polygonal soil structures, and frost-thaw basins (*1–8*). Paleontological evidence of a southerly displacement of biotopes includes the following: palynological indications of southern occurrences of white spruce (*Picea glauca*) (*1, 2, 9, 10*) and fossils of typical boreal animals [for example, musk-ox (*Ovibos moschatus*), caribou (*Rangifer tarandus*), and woolly mammoth (*Mammuthus primigenius*)] (*9, 11*).

The only previously reported evidence of possible glacial activity in the southern Appalachians consists of striated boulders and cobbles that are locally abundant in Pleistocene river gravels of North Carolina and Tennessee (*12, 13*). Although these striated clasts are indistinguishable from glacially striated clasts (*12*), their origin has been ascribed to the actions of river ice (*12, 14, 15*).

In February 1973, during our investigation of periglacial and possible glacial phenomena on Grandfather Mountain, North Carolina (Fig. 1), an outcrop with glacial polish, grooves, striations, and chatter marks was discovered at an elevation of 1370 m (Figs. 2 and 3) in the headwaters of Boone Fork, a tributary of the Watauga and Holston rivers. This occurrence provides the first tangible physical evidence of Pleistocene glaciation in the Blue Ridge Province of the Appalachian Mountains. The glaciated outcrop, at 36°07′N, is 890 km south of any previously known alpine glaciation in the Appalachians and is 350 km southeast of the nearest point reached by the Laurentide ice sheet.

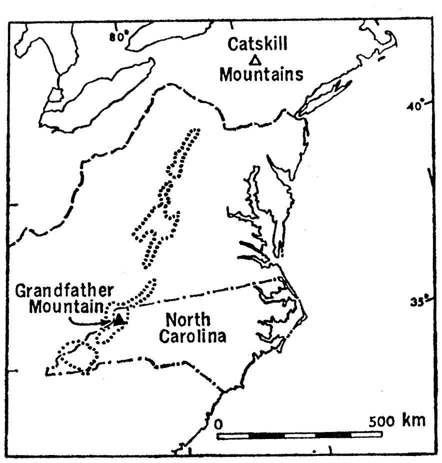

Fig. 1. Sketch map of the eastern United States showing the approximate southern limit of the Laurentide ice sheet (dashed line south of the Great Lakes), the location of glaciated Grandfather Mountain, and additional areas (dotted) of suspected alpine glaciation (suspicion based upon elevations, temperature gradients, and distribution of striated cobbles in Pleistocene river terraces).

Boone Fork heads west of the town of Blowing Rock, North Carolina, on the northeastern flank of Grandfather Mountain. The headwaters lie in a U-shaped trough having a bedrock floor near an elevation of 1210 m, with enclosing ridges attaining elevations of 1490 to 1810 m. Postglacial mass-wasting processes such as solifluction, slope wash, and debris-avalanches have alluviated the floor of the presumed cirque basin to an estimated depth of 140 m and graded the formerly steep headwall to a gentler angle of 13 deg. Similar mass-wasting on the northwestern side of Grandfather Mountain has produced maximum gradients of 15 to 35 deg. In this area thick unsorted deposits of rock and soil conceal most of the bedrock of the lower slopes. Such deposits, as well as the topography of Grandfather Mountain, suggest that it has reached the stage of late youth in the periglacial cycle of Peltier (*3*). Prominent frost-riven bedrock pinnacles (tors) give the higher ridges of the mountain a jagged appearance and indicate the lack of maturity of the erosion processes.

The maximum area of the Boone Fork cirque is 1800 by 1400 m, and it narrows eastward to a width of about 800 m in a V-shaped canyon marking the probable eastern limit of ice corrasion. A part of the north-facing slope above this point is covered by a block field (felsenmeer) between elevations of 1290 and 1410 m. This block field, measuring 150 by 360 m, contains jumbled slabs, some as large as 7 m in diameter, of blocky metasandstone of the Precambrian Grandfather Mountain formation (*13*). Published records of similar evidence of periglacial activity in the mountains of North Carolina have not previously appeared. However, Michalek (*16*) has described a number of such features. We expected to find periglacial features in the mountains because Kerr (*5*), Eargle (*7*), and Bryan (*8*) had described solifluction phenomena on the Piedmont of the Carolinas, where elevations are much lower.

The preserved glaciated surface in the Boone Fork cirque occurs atop a bedrock exposure on the lower end of a spur that projects from the northern

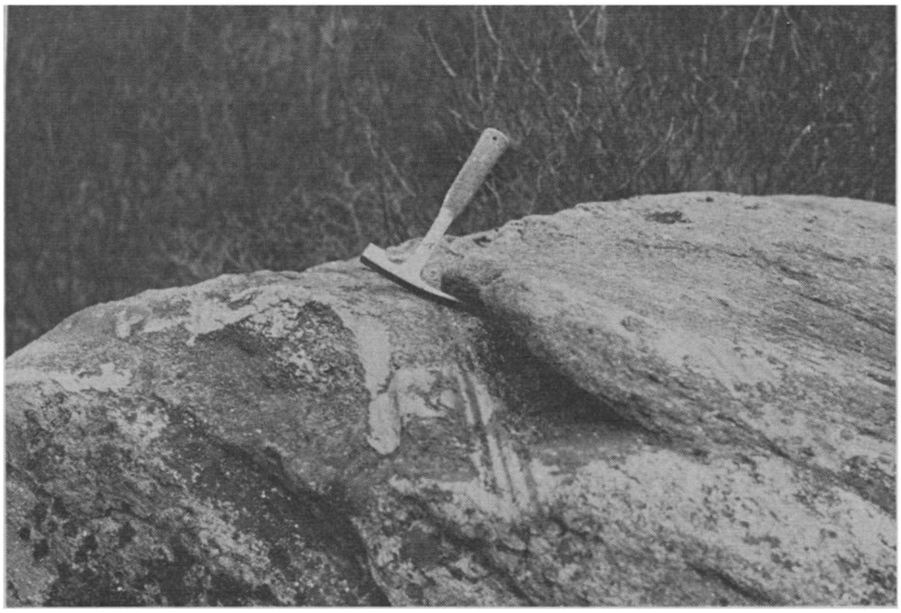

Fig. 2. Photograph at an elevation of 1400 m of the uppermost glacial grooves and polished bedrock in the Boone Fork cirque, northeastern Grandfather Mountain, North Carolina. The largest groove, containing the hammerhead, measures about 15 cm wide by 10 cm deep. The trend of the grooves is S60°E directly toward the cirque outlet. [Photograph by J. O. Berkland]

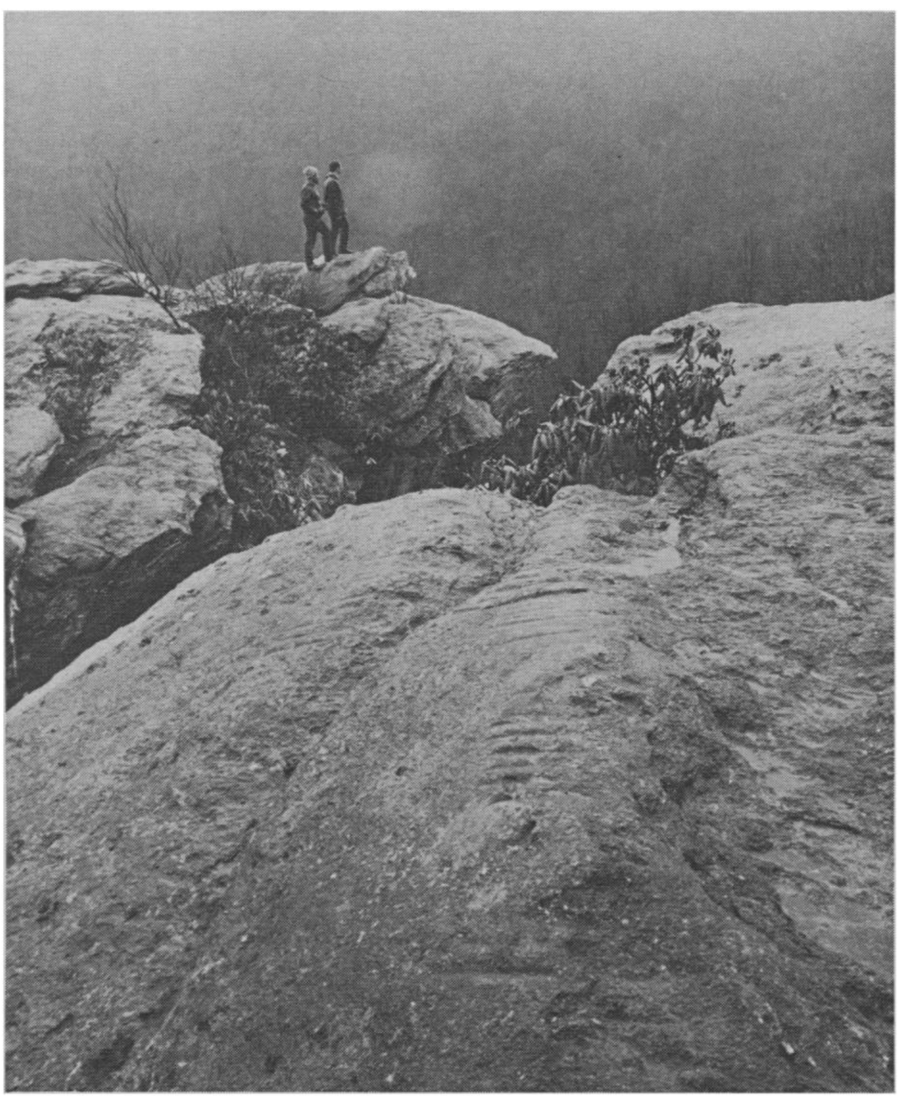

Fig. 3. View south along the glaciated outcrop across the Boone Fork cirque basin. J. O. Berkland (left) and L. A. Raymond (right) are shown standing on the edge of the overhanging outcrop. Grooves trend S60°E. Foliation strikes N40°W and dips 35°NE. [Photograph by Hugh Morton]

wall of the cirque about 1200 m east of the headwall. The bedrock is arkosic metasandstone and conglomeratic metasandstone assigned by Bryant and Reed (*13*) to the Grandfather Mountain formation. Foliation in the outcrop strikes N40°W and dips 35°NE. The glaciated surface is considerably weathered, but grooves and polish are visible on about 5 percent of the top of the outcrop (900 m^2). The longest continuous grooves are about 1 m long, 15 cm wide, and 5 cm deep. At least 60 grooves are known and adjacent grooves are parallel, although groove swarms gradually change their trend from S80°E to S40°E from the southern to the northern part of the exposure. This change reflects divergent trends of two lobes of ice which formerly coalesced at the site of the outcrop and preserved it as a bastion. A number of bedrock slopes, oversteepened to 45 to 55 deg, lie along the northern and southern edges of the U-shaped valley. These smooth, bare slopes lie mainly between elevations of 1430 and 1580 m and they have a striking resemblance to ice-abraded surfaces, although none has been found to exhibit grooves or polish. If these surfaces were indeed carved by ice, the maximum thickness of ice in the cirque was about 300 m. The minimum thickness is known to have been at least 100 m, because the grooved outcrop at an elevation of 1400 m is directly above the alluviated valley floor at 1300 m and the alluvium at this point is probably more than 30 m thick.

No moraine was observed at the cirque outlet. However, cirques in the northern Appalachians and elsewhere (*17*) commonly have little or no morainal debris, and the apparent absence of a moraine here is not considered significant. A probable recessional moraine does appear about 3.2 km north of the Boone Fork cirque along the course of a separate lobe of ice which apparently moved down the canyon of Moody Mill Creek. This stream drains the nothern slopes of Grandfather Mountain, and the lower valley bottom is marked by thick deposits of unsorted bouldery debris and a hummocky topography to elevations as low as 970 m.

It would be surprising if positive evidence of mountain glaciation in the southern Appalachians is present only on the northern portion of Grandfather Mountain, but special conditions make this locality unusual. Erosion has been comparatively slow on the northern flank of the mountain because drainages are graded with respect to the old (Miocene?) surface upon which the Watauga and New rivers flow northward. Immediately south of Boone Fork lies the edge of the Blue Ridge escarpment. The Johns River and other actively downcutting south-flowing tributaries to the Catawba River have been denuding the eastern face of Grandfather Mountain, perhaps destroying completely the evidence of glaciation. Even at Boone Fork it appears likely that the remaining evidence will be lost by erosion within a few hundred years.

Whether or not further proof of alpine glaciation is discovered in the higher elevations of the southern Appalachian Mountains of North Carolina and Tennessee, the Boone Fork occurrence has important implications (*18*). Evidence of alpine glaciation in northern North Carolina suggests a glacial origin for abundant polished and striated boulders in the southeastern states. This alternative to the action of river ice was offered by Wentworth (*12*) but has been ignored by later investigators. The existence of periglacial features reported in the southern and central Appalachian Mountains, the Piedmont, and the Atlantic coastal plain are strongly supported. A periglacial origin for the Carolina Bays is brought into focus (*4, 19*). The paleoclimatic and paleobotanical maps of the southern Appalachian area must include local Pleistocene glacial conditions, along with the tundra and boreal conditions suggested by some workers (*3, 4, 10, 15*). Finally, the genus of "warm-water walruses" (*Trichechodon*), suggested by Pleistocene fossils from the southern Atlantic states (*11*), is more likely the ordinary circumboreal genus (*Odobenus*). These Arctic animals probably migrated with the cold water that flowed farther south during glacial maxima, as evidenced by the ostracod studies of Hazel (*20*).

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Rates of Late Cenozoic Uplift, Baldwin Hills, Los Angeles, California

Abstract. *Radiocarbon ages for the marine late Pleistocene stratigraphic units of the Baldwin Hills are 36,200 ± 2,750 years and 28,450 ± 2,600 years, respectively, defining the termination of marine deposition in this area of the Los Angeles Basin at less than 28,000 years ago. Faunas of the older sample suggest that water depths were about 100 meters at the time of deposition. Shoaling of waters by deposition resulted in very shallow marine to nonmarine conditions about 28,000 years ago. The average rates of uplift for the past 36,000 years have been between 0.5 and 0.8 meter per 100 years.*

A report on ground rupture in the Baldwin Hills (Fig. 1) has pointed to little or no regional uplift in the area during the past half-century (*1*). Other workers have calculated recent rates of uplift of as much as ~0.9 m per 100 years for the same area (*2*). We have evidence that there has been more than 178 m of uplift in the Baldwin Hills within the past 36,000 years, which likely resulted from alternating episodes of uplift and quiescence. The past half-century or so may be one of the stable intervals.

A late Pleistocene phase of marine deposition, in the area of the Baldwin Hills, is dated at 36,200 ± 2,750 years ago [sample I-4867 (*3*)]. The sample contains marine mollusks and foraminiferans; it is from the west side of La Cienega Boulevard, west of the trace of the Newport-Inglewood fault; and it was collected at an elevation of about 78 m on the central graben of the hills. Fossil species of this sample have living representatives largely to the north of Point Conception. These modern representatives include species that are definitive of water depths of about 100 m or more, but not as deep as 200 m (*4*). Thus, about 36,000 years ago this fossil horizon, now at an elevation of about 78 m above present sea level, was forming at water depths of about 100 m; sea level at that time has been interpreted as being about the same as its present level for the Atlantic coast and as much as 100 m below its present level in other areas (*5*). Using these maximum and minimum values for sea level at that time, we calculate the amount of uplift in the past 36,000 years as a minimum of 178 m and a maximum of 278 m. The approximate average rate of uplift in that time ranges from 0.5 to as much as 0.8 m per 100 years, depending on the position of sea level.

An early phase of late Pleistocene shallow marine to nonmarine deposition in the central Los Angeles Basin is represented by littoral or fluviatile deposits and deposits of coalescing alluvial fans building southward from the Santa Monica Mountains. Deposits of a similar character containing clasts similar to the Santa Monica slate were exposed by trenching to a depth of 3.66 m in the summit of the hills, just south of the Baldwin Hills Reservoir at an elevation of about 145 m above sea level. Carbonized wood fragments (sample I-4766) collected from a brown sand bed exposed in the trench, have