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# The Alpine Zone & Glacial Cirques of Mt. Washington & the Northern Presidential Range, New Hampshire

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**75<sup>th</sup> Annual Reunion**  
**Northeastern Friends of The Pleistocene**

**June 1 - 3, 2012**

**Pinkham Notch, New Hampshire**

**The Alpine Zone and Cirques of  
Mt. Washington and the Northern Presidential Range,  
White Mountains, New Hampshire**



# 75<sup>th</sup> Annual Reunion

## Northeastern Friends of The Pleistocene

### Leaders

**Brian K. Fowler, Mount Washington Observatory**  
**P. Thompson Davis, Bentley University**  
**Woodrow B. Thompson, Maine Geological Survey**  
**J. Dykstra Eusden, Bates College**  
**Ian T. Dulin, Bates College**

### Hosts

**MT. WASHINGTON AUTO ROAD**  
**MOUNT WASHINGTON OBSERVATORY**  
**MT. WASHINGTON STATE PARK**

The field trips of this Reunion updated The Friends on glacial, geomorphological, geochronological, and paleoenvironmental research within and below the alpine zone of Mt. Washington and the northern Presidential Range. These field trips were the first return of The Friends to this area since the 33<sup>rd</sup> Reunion in 1970. Those trips were led by Dick Goldthwait, Brian Fowler, Don Bailey, and Tom Goldthwait.

### IMPORTANT

Portions of these field trips cover tree-less alpine terrain with often very cold, windy, and wet conditions that can be unsafe if you are not properly equipped with **sturdy water-resistant footwear, a hat with ear protection, warm gloves or mittens, extra sweater or fleece, warm jacket, and wind/water-proof outer shell and pants**. Wind-driven rain, sleet, snow, and sub-freezing temperatures are frequent on Mt. Washington in all seasons of the year.

### Guidebook

To reduce the cost of this Reunion (like Reunions of old in tough economic times), a formal guidebook was not published. Instead, background information, trip logs, and hand-outs were combined into this stand-alone document.

### Cover Photograph

The Great Gulf cirque with post-glacial colluvium deposits on its floor, looking north from the crest of its headwall on Mt. Washington, across the Federally-designated Great Wilderness toward the northern Presidential Range, with Mounts Jefferson, Adams, and Madison from left to right. The Great Gulf and subsidiary “feeder cirques” (left side and to the north: Sphinx and Jefferson Ravines and Madison Gulf) comprise the largest cirque complex on the Presidential Range. Photograph, B. K. Fowler.

## REFERENCES AND MAPS

The following references and maps are helpful before and during the field trips.

Ackerly, S.C., 1989, Reconstructions of mountain glacier profiles, northeastern United States. Geological Society of America Bulletin, v. 101, p. 561-572.

Davis, P.T., 1999, Cirques of the Presidential Range, New Hampshire, and surrounding alpine areas in the northeastern United States. *Geographie physique et Quaternaire*, v. 53, no. 1, p. 25-45.

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U.S. Geological Survey, 1983, Carter Dome 7.5-Minute Quadrangle.

U.S. Geological Survey, 1995, Mt. Washington (East) 7.5-Minute Quadrangle.

Washburn, B., 1988, Mount Washington and the heart of the Presidential Range, New Hampshire (map; 1:20,000). Appalachian Mountain Club, Boston, Massachusetts.

Copies of Davis, 1999 and Thompson, *et al.*, 1999 are available free of charge on-line at <http://www.erudit.org/revue/gpq/2006/v60/n3/index.html>. Copies of Eusden, 2010 and Fowler, 2011 are available on-line at ([www.durandpress.com](http://www.durandpress.com)).

Proceeds from the sale of the last two items go to Funds established to support expenses of student research at Bates College (Eusden) and volunteer mapping for the NH Geological Survey's USGS STATEMAP Program (Fowler). This volunteer activity partially replaces the recently cut State of NH match for this program in the region, and helps keep the NH Geological Survey viable until Legislative match-budgeting improves. **Thank you in advance for your support of these worthy causes!**

## **THE FIELD TRIPS**

### **The Great Gulf Cirque and Its Possible Late- to Post-Glacial Features**

This pre-meeting field trip requires hiking over very rugged terrain and some strenuous climbing to visit the headwall of the Great Gulf, by far the region's largest cirque, and then a newly-identified feature created by what is proposed by Fowler (2011) to have been a reactivated late- to post-glacial cirque ice mass within the Great Gulf. Participants must be properly equipped and in excellent physical condition. Trip groups are limited to 10 persons because the field trip traverses the Great Gulf Wilderness. The Great Gulf headwall portion of this trip should be attempted only if weather conditions on Mt. Washington permit.

### **Mt. Washington and the Alpine Zone of the Presidential Range**

This field trip reviews the results of field work in this area during the past 40 years. The following subjects are included:

- the possibility that the last ice sheet was not as thick in the region as its predecessors;
- the reason that the summits of the Presidential Range above 5,200 ft. appear as "rockpiles" and not bedrock promontories;
- the presence and age implications of enigmatic deposits of reworked till and/or diamict on Mt. Washington; and,
- the relative age of surficial features in the alpine zone. Also included was a tour of the world-famous Mt. Washington Observatory and its Summit Museum.

### **Upper Peabody River Valley and Its Late- to Post-Glacial Features**

This field trip examines new features identified in Pinkham Notch possibly associated with newly-proposed late- to post-glacial ice activity in the Great Gulf cirque (Fowler, 2011). These features include a possible terminal moraine and an ancestral glacial lake dammed by that moraine. The results of ongoing clast provenance studies and detailed mapping on these features are presented.

# 75<sup>th</sup> Annual Reunion, Northeastern Friends of the Pleistocene

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## **BACKGROUND INFORMATION**

### **INTRODUCTION**

Field trips for this reunion review and update the late- and postglacial surficial geology of the alpine zone of Mt. Washington and the northern Presidential Range in New Hampshire. Much has been learned and some ideas rethought in this field area since the 1960's, but controversies persist because of the area's rugged terrain, dense vegetation, and frequently unfavorable weather conditions. Our understanding of the Late Wisconsinan and its late- to postglacial periods are very much a work in progress, and we clearly "stand on the shoulders" of those who came before. A spirit of cooperative collaboration prevails here today that has increased the rate at which new ideas are proposed and tested. Portions of the background that follow draw upon the comprehensive history of regional glaciation studies by W. B. Thompson (1999) and summaries of studies in the cirques by Davis (1999) and Davis, *et al.* (2003).

### **FIELD INVESTIGATIONS** **19<sup>th</sup> CENTURY TO THE PRESENT**

The alpine zone and glacial cirques on Mt. Washington and the northern Presidential Range have been the subject of inquiry and controversy for the past 170 years. Edward Hitchcock (1841) was first to publish findings from field work. At the time, the theory of glaciation had been recently proposed by Louis Agassiz (1837), but had not yet gained acceptance. Hitchcock believed that Mt. Washington (6,288 feet) had protruded about 1,000 feet above the surface of an arctic sea that inundated the region during "the ice age". He proposed that ice-bergs along its shores at about 5,200 feet created widespread patterns of distinct "ice embossment" on adjacent bedrock surfaces (later understood to be glacial striations). As supporting evidence, he cited a lack of these distinct markings above 5,200 feet and the mountain's bouldery summit cone that would have been cleared of such boulders had it been inundated. During his work, he observed similar but heavily deteriorated markings near the summit, and speculated they had been created during an earlier and deeper inundation. Hitchcock was among the last to refer to this arctic sea as the source of such markings and other effects.

A.S. Packard (1867a, 1867b) and G. L. Vose (1868) were next to publish specific observations. Each summarized unpublished striation data by others and added measurements of their own. They noted that most all striations displayed a northwest to southeast orientation and that those whose appearance unequivocally identified them as glacial striations occurred below 5,200 feet.

Meanwhile, Agassiz (1870a, 1870b) had come to the U.S. and visited the White Mountains. Among many things beyond our focus here, he proposed that ice caps existed over higher elevations of the region after the last regional glaciation and that alpine glaciers flowed downward from them through the cirques and cirque-like basins and into the region's valleys. In support, he cited the sharply-defined topography in the cirques he believed was created by these alpine glaciers, along with valley features he identified as their terminal moraines.

C. H. Hitchcock (1876, 1877, 1878) built on this, along with the work of his father. He refuted the ice cap proposal by observing that striations were not oriented in the multi-directional patterns that would arise from ice flowing outward from highland sources. He confirmed their consistent southeasterly orientation and observed that none measured to that point in time refuted his father's conclusion that abrasion was confined to surfaces below 5,200 feet. In his work around the summit of Mt. Washington, he observed the "faint" and "obscure" markings his father reported and attributed their indefinite appearance to weathering in the harsh alpine climate. Like his father, however, he was unable to determine if they were the result of the most recent or an earlier glaciation. He did conclude that all striations and similar markings showed that at least one ice sheet moving from the northwest had flowed over the summits of the Presidential Range, and he supported this conclusion by observing for the first time the presence of erratic cobbles (mainly granitics of northwesterly provenance) among the large boulders on the summit cones.

Hitchcock identified these erratics during study of the boulder fields on the peaks. He observed that their high-grade metamorphic lithologies outcropped on adjacent lower slopes, while those of the granitics were typical of areas several miles to the northwest. He also observed that the boulder fields included widely scattered deposits of more finely-textured, often clast-rich material he termed "boulder clay". From these combined observations, he concluded that moving ice had deposited "immense...angular blocks" onto the peaks from slopes immediately below and that erratics and boulder clay within that ice were subsequently deposited among the blocks. He then proposed that intense frost and weathering activity had reduced the blocks to fields of large, very heavily weathered boulders. He did not, however, consider the possible difference in weathering susceptibility among the lithologies.

J. W. Goldthwait (1913a, 1913b) undertook an expanded study of the entire Presidential Range. He agreed that the summit of Mt. Washington had been buried beneath overriding glacial ice and extended his work to the entire range with striation and erosional evidence that ice flow had been deflected around its summit cones. He re-examined Hitchcock's "boulder clay" and observed it was present mainly beneath grassy areas on the peaks and was more coarsely textured and loosely consolidated than tills at lower elevation. He disagreed that immense blocks of local lithology were transported onto the summits, noting that the boulders did not display the faceting and abrasive markings typical of entrainment in glacial ice. He suggested instead that harsh climate on the peaks had quarried them, moved them short distances, and then severely weathered them in place. He stated that this evidence, along with the lack of fresh glacial markings and erosion features above 5,200 feet, suggested the "great ice sheet" thinly overrode the range, and he considered the possibility that the severely deteriorated condition of the boulders might include weathering before the last glaciation. He also observed that granitic erratics were distinctly more common on the cones of the northern peaks (closer to their source areas), but he did not address their lightly weathered condition compared to the metamorphic boulders or when they might have been deposited.

This new investigation also included the first detailed reconnaissance of the region's cirques. Goldthwait found no striations or erosional features from local ice moving along their axes, no moraines on or beyond their floors, and evidence that the symmetrical U-shape of several had been modified by erosion of obliquely overriding ice. He also found erratic cobbles on their floors and concluded from their presence that the cirques were "carved" before and not after the last continental glaciation, presuming that any late- or postglacial cirque glaciation would have completely removed them.

Thereafter, two workers disputed Goldthwait's conclusions. D.W. Johnson (1917, 1933) proposed that lack of end moraines was not sufficient to conclude that continental ice postdated cirque glacier activity, citing alpine regions elsewhere that had never undergone continental glaciation but whose cirques lacked moraines. Ernst Antevs (1932) agreed with Johnson and proposed that the absence of moraines resulted from the lack of till deposits on the cirque floors, noting that till was rarely observed adjacent to or beneath the extensive deposits of thick talus overlying bedrock. On this basis, he postulated that alpine glaciers may have been diminutive and largely immobile; only able to undermine and steepen their cirque walls. It is noteworthy that neither of these workers addressed the presence of erratic clasts among the talus in the cirques.

Antevs (1932) also reported on detailed reconnaissance in the alpine zone. He provided the first descriptions of the periglacial features that exist there (e.g. block and turf-banked terraces, sorted nets, and stone stripes), and he replicated striation observations on and around the highest peaks. He agreed with earlier workers that fresh-appearing striations were not to be found above 5,200 feet and confirmed Goldthwait's assertion that the large boulders on the summits were not transported there by overriding ice. At numerous locations he was able to trace blocks upslope to the identically-shaped cavities from whence they had arisen, concluding that harsh postglacial conditions in the alpine zone were uniquely responsible for their creation and weathering. He cited these lines of evidence to suggest that eroding ice of the last glaciation reached an elevation of at least 5,000 feet, and he agreed that fresh-appearing erratics on the highest peaks, combined with the absence of fresh evidence of glaciation above 5,200 feet, showed the entire range was only thinly overridden by the last ice sheet.

R. P. Goldthwait expanded his father's study (Goldthwait, 1936, 1939, 1940, 1970a, 1970b). He confirmed evidence of cirque glacier activity only before the last continental glaciation and supplemented it by adding to previously reported striation data the orientations of various "groove-like features" and roche moutonnees on cirque headwalls and floors. He asserted these could have been formed only by continental glacial ice obliquely overriding the pre-existing cirques. Despite important differences in the nature and elevation of these features, he concluded they were all created by the last overriding ice sheet and that those that did not appear as fresh had simply been more severely weathered by harsh subarctic conditions. He suggested the possibility that residual ice masses could have persisted after the last ice sheet in the deeper and most favorably oriented cirques but did not present the evidence that led to this proposal.

Goldthwait (1970a& Fig. 4) was the first researcher to quantitatively compare the morphometrics of the range's cirques. This work produced estimates of firn line and bergschrund elevations, along with estimated terminus positions for cirque glaciers that would have existed in each cirque to create observed dimensions and morphology. In addition, he expanded Antevs earlier descriptions of periglacial features and conducted simple year-to-year measurements that definitively established these features were not moving under modern climatic conditions.

W. F. Thompson (1960, 1961 ) used early techniques of photogrammetry to challenge the proposition that no postglacial cirque activity had occurred on the Presidential Range or on the Katahdin massif in Maine. He argued that the sharply defined features in their cirques could only result from active alpine glaciers that post-dated continental glaciation and that any moraines in or below them had been obliterated by postglacial mass wasting. However, he did not support these assertions with independent field observations.

D.M. Eskenasy (1978) likewise challenged the lack of postglacial cirque activity. She completed photogrammetric analyses and field work in the King Ravine cirque and proposed that ice-based activity had occurred there on and within what was then proposed by some to be a relict rock glacier developed in postglacial time. She postulated its development involved talus accumulation on, and then incipient movement within, a stranded and subsequently wasting block of residual ice. The study, however, was unable to establish if the feature was a rock glacier or if any postglacial ice activity had occurred in the cirque.

D.C. Bradley (1981) also challenged the lack of postglacial cirque activity by asserting that surficial deposits below the mouth of north-facing King Ravine were a composite moraine emplaced by an alpine glacier flowing out of the cirque in postglacial time. He supported this by citing the well-known presence on the feature of boulders whose lithologies outcrop on the cirque's headwall. This proposal, its supporting evidence, and the extent and stratigraphy of the deposits in question were subsequently examined by Fowler (1984) and Waitt and Davis (1988). They independently established that these extraordinary deposits are not a moraine related to a late- or postglacial alpine glacier, but instead are a complex of massive debris-flow deposits possibly related to rapidly melting ice in the cirque.

Fowler (1984) supported this conclusion by citing rheological studies showing that entrainment of "lahar-like" movements of such large volumes of bouldery debris over similar slopes and distances requires instantaneous generation of very large volumes of water at the initiation site. Recently, based on the duration and historical frequency of extraordinarily heavy-precipitation events in the region, he has suggested (unpublished) that the closely episodic generation of such large volumes of water in the cirque was not likely from rainfall events alone. He proposes instead that supplementation of such events with coincident rapid melting of residual ice in the cirque offers a mechanism more likely to rapidly generate the volumes of water needed to initiate these large fast-moving flows. However, he notes that definitive determinations about their initiation require the ages of their emplacement be established.

D. J. Thompson (1990, 1999) re-examined what were believed by some to be moraines in the Tuckerman Ravine cirque. He concluded from the depositional fabric of their large bouldery clasts that one of the deposits could possibly be a relict rock glacier, but the others were simply talus accumulations beneath steep slopes. He further concluded their presence in the cirque did not support the presence or reactivation of postglacial ice in the cirque.

P. T. Davis (1999/Attached) expanded earlier work on the cirques of the Katahdin massif in Maine (Davis, 1976, 1989/Attached) by completing a morphometric examination of cirques in the northeastern United States. This work expanded on techniques used earlier by Goldthwait (1970a) and included the cirques in the Presidential Range. Davis continued to find no convincing evidence for postglacial activity in the region, generally postulating that postglacial regional climate warmed so rapidly that equilibrium-line altitudes rose above the cirques floors.

Davis and Davis (1980) also investigated the possibility of postglacial ice activity in cirques by obtaining minimum radiocarbon ages for their deglaciation. These attempts were frustrated by the limited number of tarns or peat bogs available for sampling. This led them to focus instead on the cosmogenic radionuclides  $^{10}\text{Be}$  and  $^{26}\text{Al}$  in samples from quartz veins in boulders and bedrock surfaces (Bierman, *et al.*, 2000; Davis, *et al.*, 2003/Attached). Samples from Tuckerman Ravine, along with cirques on the Katahdin massif and its nearby Basin Ponds Moraine, yielded results consistent with Late Wisconsinan deglaciation chronologies obtained elsewhere with radiocarbon, but one taken near the summit of Mt. Washington indicated a surprisingly old age (~ 124,000 yr BP), as did one from the summit of Mt. Katahdin (~22,000 years). These dates seem consistent with two possible scenarios: 1) the last ice sheet was thinner than generally supposed, possibly leaving parts of the region's summits exposed as nunataks through the last glaciation, or more likely 2) summits were overridden by continental ice too thin and/or frozen at its base to erode pre-existing regolith, but still able to transport and later deposit ablation debris onto these higher slopes.



Meanwhile, recent work in the wider region by W. B. Thompson (Thompson, 1998; Thompson, *et al.* 1999; Thompson, in prep) identified moraines deposited by late-glacial readvance or standstill of the Laurentide Ice Sheet less than 10 miles northwest of the Presidential Range. These deposits form part of a moraine belt extending across the northern White Mountain region. Minimum-limiting radiocarbon dates from northern New Hampshire suggested to Thompson that the moraine belt may have formed during the Older Dryas Cold Interval, about 14,000 calendar years ago. This age proposal was subsequently confirmed by the Glacial Lake Hitchcock varve chronology in the upper Connecticut River valley (Ridge, *et al.*, 1999, 2004).

B. K. Fowler (2011) completed compilation of the surficial geology of the U.S.G.S. Mt. Washington 7.5-minute quadrangle, which includes the northern Presidential Range and all its cirques. The mapping confirmed the lack of systematic moraines and ice-contact deposits in the area and clarified the process by which the late-glacial ice sheet thinned over higher areas and separated around them. The work showed that during this meltwater-rich process, loose bouldery to cobbly ablation till collapsed onto bedrock slopes. It was then winnowed on steepest slopes, sorted on intermediate slopes, and redeposited on lowest slopes as various gradational diamict facies. These diamicts range from bouldery openwork on highest slopes to clast-dominant and finally matrix-dominant units downward into surrounding valleys where they overlie and inter-finger with ablation till. No basal-ice deposits were observed in the quadrangle, and with one important exception (see below), mapping found no evidence of postglacial cirque activity.

The mapping did suggest that the terms “drift” and “till” as used by earlier workers to describe deposits in the cirques did not carry today’s more specific definitions. Since deposits there consist almost exclusively of talus or openwork boulder to cobble-dominant diamicts lying directly on bedrock (Antevs, 1932; Fowler, 2011), it seems that earlier usage referred to any deposit assumed to have been emplaced by continental glacial ice. The mapping also re-examined previously cited evidence that morphologic asymmetry in certain cirques resulted from overriding glacial erosion oblique to their axes (e.g. Great Gulf: Goldthwait, 1913; Goldthwait, 1970a). Detailed bedrock mapping of the region (Eusden, 2010) was unavailable to earlier workers, but its present application shows much of the observed asymmetry results from local rock structure and not erosion by an overriding ice sheet.

The mapping reaffirmed the sharp difference in surficial geology above and below 5,200 ft. It found abundant fresh markings from recently overriding ice below this elevation, but only uncertain or vestigial markings above. It also found that heavily weathered regolith is only present above the boundary. Earliest workers proposed this sharp divide resulted from a lack of glaciation or from thin glaciation above 5,200 feet, while later workers proposed it resulted from harsh local climate. This latter proposal is debated (Fowler, 2011) because it fails to answer two questions: 1) how can two such sharply different climatic environments coexist across such a short distance, and 2) how can the decomposition-susceptible granitic erratics be less weathered than the very-resistant but heavily weathered metamorphic boulders of local origin if both were exposed to identical weathering conditions for the same period of time (the erratics should be more seriously degraded, not less as observed)? This apparent paradox disappears if the erratics were introduced into the boulder fields more recently and the boulders exposed to harsh conditions for a longer time, perhaps including a period before the start of the last glaciation (Goldthwait, 1913a; Fowler, 2011).

These observations and the results of exposure dating (Beirman, *et al.*, 2000; Davis, *et al.*, 2003/Attached) support proposals that this sharp boundary and the condition of the erratics are the result of only thin, cold-based ice covering these higher slopes during the last glaciation. The following scenario may pertain (Fowler, 2011). As the last ice sheet approached and local climate substantially cooled, the openwork spaces between components of a pre-existing bouldery regolith were infilled with frozen precipitation and consolidated on the flanks of the peaks, creating a solid substrate over which the thin, cold-based ice could move but not erode. As the ice sheet later downwasted, fresh erratic cobbles and clast-rich diamict carried within it (“boulder clay” of earlier workers) settled into the regolith. Thus, weathering of the metamorphic boulders postdates both the Illinoian and Late Wisconsinan glaciations, while deterioration of the erratics postdates only the Late Wisconsinan. This scenario is similar to one recently confirmed by extensive and robust  $^{10}\text{Be}$  and  $^{26}\text{Al}$  exposure age datasets on Baffin Island in the eastern Canadian arctic (Beirman *et al.*, 1999; Briner *et al.*, 2003, 2006; Davis *et al.*, 2006).

Elsewhere in the quadrangle, the recent mapping identified residual till deposits 3 miles northwest of the Presidential Range that appear correlative with the earlier described late-Laurentide moraine system. Fowler (2011) proposes that near-glacial conditions created by this active ice in the immediate region may have permitted equilibrium-line altitudes to descend to those of the cirque floors for a period of time sufficient to reactivate residual ice in the most favorably sized and oriented locations. His mapping suggests two possible local responses to such conditions.

First, the mapping identified colluvial deposits closely similar to those described below King Ravine (Bradley, 1981; Fowler, 1984; Waitt and Davis, 1988) within and below the Castle, Huntington, and Tuckerman Ravine cirques (Fowler, 2011). Clast provenance and stratigraphy shows these deposits were likewise emplaced by highly mobile, water-rich debris flows that originated in each cirque. As indicated earlier, the volume of meltwater needed to successively mobilize such extensive flows suggests that significant ice masses may have existed in these cirques in late- and/or postglacial times.

The next response is suggested by two features within and below the Great Gulf cirque that are newly-interpreted to have resulted from these conditions (Fowler, 2011). The first is a group of hillocks strewn with very large boulders of rock types outcropping within and along the lower flanks of the cirque. Its location, hummocky topography, and apron of partially-abandoned distributary drainage toward the east from the cirque suggests it may be a terminal moraine. When emplaced, the feature displaced the West Branch of the Peabody River near the mouth of the cirque to the north and temporarily dammed the Peabody River at The Glen, creating an ephemeral lake. This lake quickly filled with coarsely-textured sediment and then rapidly drained through a channel eroded along the base of its easterly flank. Once beyond the feature, its flow plunged back into the river's original course at Garnet Pool. The second feature is a smaller group of similarly boulder-strewn hillocks at a higher elevation on the cirque floor. Its location, topography, and distributary drainage apron suggest it may be a recessional moraine.

Both these features are believed to postdate the Laurentide Ice Sheet because their loosely consolidated deposits could not have survived its overriding erosion. It is proposed these features originated when local climatic conditions possibly supplemented and reactivated residual ice in the cirque. The Great Gulf is uniquely suited for this because it faces directly north and has by far the largest, deepest, and best melt-protected catchment of the region's cirques. This may have permitted it to preserve a late- or postglacial residual ice mass large enough to, once reactivated, create these features while less favorably sized and oriented neighboring cirques could not.

Much work remains to be done on these features and their genesis. I. T. Dulin (2012, 2012a/Attached) is conducting work on the lower feature that includes analysis of clast provenance to determine if it was deposited from wasting Laurentide ice in Pinkham Notch or from postglacial ice activity to the west in the cirque. This study also includes the construction of possible glacier profiles based on the cirque's morphology and dimensions (e.g. Ackerly, 1989). These will assess if an ice mass of a size sufficient to create these possible moraines could have existed within the cirque. Cosmogenic dating of boulders on these features is being investigated by others. Meanwhile, alternative interpretations to be considered include the possibility the features were deposited at slightly different times from late Laurentide ice during a complex "stagnation-zone" retreat in Pinkham Notch.

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Mt. Adams (elev. 5,774 ft.) with the Madison Gulf “feeder cirque” below. View looks west northwest from the lake bottom surface at The Glen (elev. ~ 1,565 ft.). Photograph, B. K. Fowler.

# 75<sup>th</sup> Annual Reunion, Northeastern Friends of the Pleistocene

Pinkham Notch, New Hampshire

June 1 - 3, 2012

## **GENERAL HANDOUT** **PROPOSED GREAT GULF MORAINES**

### **Late-Glacial Local Climate Change & Possible Effects**

Early workers in this region generally believed its local climate warmed very rapidly following the Late Wisconsinan glacial maximum (LGM), promoting swift deglaciation of its landscape and quickly raising equilibrium line altitudes (ELA) above the floors of its cirques so neither residual ice masses nor incipient cirque glaciers could exist. However, the development of systematic climate proxy studies since shows the rate of warming between the LGM and the Oldest Dryas Cold Interval was less dramatic than previously assumed, and that only thereafter did it dramatically increase in spite of interruption by significant cooling events. Figure 1 (first but not labeled) presents this well-established warming pattern, while Figure 2 presents its detail since the start of the Oldest Dryas (Stuiver, et al., 1995).

This slower rate of warming suggests that glacial to near-glacial climate conditions persisted in this region as its highlands slowly emerged above locally downwasting (Goldthwait, 1970a; Fowler, 2011) and more slowly diminishing regional ice (Fowler, 2011). This also suggests that regional ELA's did not rise above the cirque floors as early or as completely as previously assumed, likely permitting residual ice masses to linger in favorably positioned highland locations.

This pattern of slower deglaciation and more gradually warming local climate also suggests that the Littleton-Bethlehem Moraine, emplaced just 3 to 5 miles northwest of the Presidential Range (Thompson, 1998; Thompson, et al., 1999; Fowler, 2011; Thompson, in prep) could represent a stillstand of slowly retreating Laurentide ice rather than a readvance over previously deglaciated terrain. If so, reactivation of favorably positioned residual ice masses in highland locations like the Great Gulf could have been facilitated by the increased precipitation and persistent sub-arctic temperatures sustained by the nearby presence of active Laurentide ice.

### **Proposed Terminal & Recessional Moraines**

Figure 3 is a portion of Fowler, 2011 showing the Great Gulf cirque complex and the two features below and within it newly proposed to be terminal and recessional moraines. For convenience, Unit descriptions shown in the figure are presented below (Fowler, 2011).

#### **Qtym: Till, Late-Stage, Late Wisconsinan - Younger Than Older Dryas (Pleistocene)**

Ice-contact, collapse-emplaced, hummocky, heavily dissected morainal complex with down-cirque slopes as steep as 35°. Composed of tan to light brown, clast and matrix-supported sandy to gravelly, sometimes silty till with abundant often very large (25 m<sup>3</sup>; 800 ft<sup>3</sup>), angular to subangular boulders. Predominant clast provenance from cirque above.

#### **Qdc: Colluvial Diamict, Late-Stage, Late Wisconsinan (Pleistocene > Holocene)**

Post glacial, matrix-supported diamict dominated at the surface and variably downward to ~ 6 m (20 ft) by subangular to rounded, variably weathered boulders and cobbles that grade further downward to cobbly, often chaotic mixtures of till and clayey to silty diamict and poorly sorted gravel. Clast lithologies on surfaces and in abandoned distributary drainages show provenance from alpine and subalpine slopes above via episodic colluviation initiated by outbursts of meltwater from locally extensive residual ice in cirques and run-off from adjacent slopes after the Late Wisconsinan ice sheet had left the region. Unit overlies Qt and bedrock and is up to 30 m (100 ft) thick.

**Qlsp: Glaciolacustrine Deposits, Glacial Lake Philbrook, Late-Stage, Late Wisconsinan-Older Dryas (Pleistocene)**

Post glacial, horizontally interbedded sand and sandy-to-silty, fine to occasionally medium gravel deposited in and graded to estimated water surface elevations of ancestral Glacial Lake Philbrook at ~ 482 m (1,580 ft) and ~475 m (1,560 ft). Heavily dissected by local tributaries of the Peabody River. Up to 46 m (150 ft) thick. Present floodplain variably overlain by 0.3 to 1.0 m (1 to 3 ft) of sandy-silty Holocene alluvium and hydric soils.

**Qtocm: Till, Late-Stage, Late Wisconsinan – Older Dryas (Pleistocene)**

Ice-contact, collapse-emplaced, hummocky, heavily dissected possible morainal complex overlying Qt. Composed of tan to light brown, clast and matrix supported, sandy to gravelly, sometimes silty till with abundant, often very large (25 m<sup>3</sup>; 800 ft<sup>3</sup>) angular to subangular boulders. Predominant clast provenance from cirque above. Proposed to be coeval with the Older Dryas Littleton-Bethlehem Moraine System (~ 12,000 <sup>14</sup>C yr BP or ~ 14,000 Cal yr BP).

**Qc & Qct: Colluvial Debris, Late-Stage, Late Wisconsinan To Recent (Pleistocene > Holocene)**

Post glacial to recent, randomly distributed, bouldery to cobbly, clast and matrix-based diamicts and talus on (Qc) and beneath (Qct) unstable slopes subject to frequent rockfall and debris/winter avalanche.

**Qt: Till, Late Wisconsinan (Pleistocene)**

Ice-contact, ablation/collapse-emplaced, bouldery to cobbly ground moraine with mixed matrix of tan to dark grayish brown, unsorted to poorly-sorted, loose to moderately compact clay, silt, and sand. Generally less than 6 m (20 ft) thick but up to 30 m (100 ft) thick beneath local hillocks. Clast lithologies show mixed north and northwesterly provenance of 15 to 40 km (10-25 mi). No certain ice basal deposits have been observed.

**Proposed Terminal Moraine**

This feature consists of a group of hillocks whose distinctive morphology stands out from surrounding terrain and whose constituent deposits suggest emplacement after continental glaciation (Fig. 2; Qtocm). Its hummocky surfaces are frequently strewn with atypically large unweathered boulders of lithologies that outcrop on the lower walls of the cirque, and its location, topography, and apron of mostly-abandoned distributary drainage away from the cirque suggests it may be a terminal moraine.

The feature's emplacement appears to have displaced the bedrock-based channel of the West Branch of the Peabody River to the north, just below the mouth of the cirque. Its emplacement also temporarily dammed the Peabody River at The Glen, creating an ephemeral lake (Fig. 2, Qlsp). This lake quickly filled with coarsely-textured sediment and then rapidly drained through a channel eroded along the base of the feature's easterly flank once its damming mechanism had been breached. The flow returned to the river's original channel at Garnet Pool (Fig. 3; Fowler, 2011).

Evidence this feature postdates Late Wisconsinan glaciation and is related to activity in the cirque includes: 1) its loosely consolidated gravelly deposits could not have survived overriding erosion; 2) the local provenance, angularity, and lack of weathering and striations on its larger sized boulders and cobbles suggests only short-term entrainment in moving ice; 3) its apron of largely abandoned, easterly directed distributary drainage and coarsely-textured granular deposits require substantial drainage from above and to the west; and 4) the provenance of stone clasts within and outside its boundaries suggests its clasts of more local provenance were superimposed on those of regional provenance associated with earlier glaciation.

Alternate proposals that this feature was emplaced by readvance of Laurentide ice in Pinkham Notch are not well supported. Both earlier and more recent mapping in the Peabody valley to the north has failed to detect evidence of readvance between the feature's location and the deeply till-buried glaciolacustrine deposits south of Gorham (Thompson & Fowler, 1989; Thompson, et al., 1999; Fowler, 1999; Fowler, in prep). In addition, stone clast provenance studies on the feature have failed to detect elevated percentages of particular rock types from the valley to the north over which readvancing ice would have passed.

Similarly, alternate proposals that the feature was deposited from stagnating ice in its immediate vicinity are poorly supported. Its loosely consolidated deposits and large unweathered angular boulders and cobbles free of evidence of long-term entrainment are distinctly different from the more densely consolidated and heavily deteriorated deposits typical of masses of previously active ice. Also, the well-developed easterly directed distributary drainage pattern across the feature is not consistent with the more random patterns of drainage typical in the vicinity of wasting ice masses (Goldthwait and Mickelson, 1982). Recent mapping in the immediate vicinity (Fowler, in prep.) failed to detect such drainage patterns or deposits attributable to masses of wasting ice.

### **Proposed Recessional Moraine**

This feature, locally known as “The Bluff”, consists of a similar but laterally less extensive group of hillocks whose isolated morphology higher on the slopes below the cirque is also distinctively different from surrounding terrain and whose constituent deposits could not have survived overriding continental glaciation (Fig. 2, Q<sub>1</sub>cm). Its location, unique and isolated topography, rugged surface of large and unweathered boulders, steep distal slope, and partially abandoned distributary drainage apron suggest it may be a recessional moraine. All evidence cited above for the proposed terminal moraine applies to this feature as well. However, detailed subsurface or clast provenance studies have not been conducted due to regulatory restrictions. To date only observations of stream-cut sections and surficial hand samples have been made.

### **Future Work**

More work is needed to confidently establish the genesis and late- to post-glacial climatic significance of these features. More study of clast provenance is needed on both features to confirm these proposals, and further construction of possible glacier profiles based on the cirque’s morphology and dimensions (Ackerly, 1989; Davis, 1999; Dulin, 2012) will help determine if a cirque ice mass of sufficient size could have existed. The lack of organic material in their coarsely-textured deposits requires that cosmogenic dating be conducted to establish the times and sequence of their respective emplacement.



Mt. Jefferson (center; elev. 5,712 ft.) and its Six Husbands faceted spur above the Great Gulf cirque with the Jefferson Ravine “feeder cirque” below to its right. Flat surface across the main cirque floor (immediately left of lone pine at photo center) is the crest of the proposed recessional moraine. View looks west from just south of Great Angel Station (elev. ~ 1,620 ft.). Photograph, B. K. Fowler.



# 75<sup>th</sup> Annual Reunion, Northeastern Friends of the Pleistocene

Pinkham Notch, New Hampshire

June 1 - 3, 2012

## Field Trip Itineraries

### Introduction

The field trips for this Reunion update glacial, geomorphological, geochronological, and paleo-climate investigations within and below the alpine zone of Mt. Washington and the northern Presidential Range. These field trips are the first return of The Friends to this area since the 33<sup>rd</sup> Reunion in 1970.

**These field trips cover some tree-less alpine terrain with often very cold, windy, and wet conditions that can be unsafe if you are not properly equipped with sturdy water-resistant footwear, hat with ear protection, warm gloves or mittens, extra sweater or fleece, warm jacket, and wind/water-proof outer shell and pants. Wind-driven rain, sleet and snow are frequent on Mt. Washington in all seasons of the year.**

Because of rugged terrain and possibly unfavorable weather conditions, the field trip itineraries for this Reunion do not repeat those covered during the 33<sup>rd</sup> Reunion in 1970. They visit only locations where new or updated information can be reviewed and discussed. Readers interested in all information covered in this region by the earlier field trips should consult the collection of Reunion Guidebooks and related materials on the Friends website at: <http://www.geology.um.maine.edu/friends/>.

### The Great Gulf Cirque & Its Post-Late Wisconsinan Features

This field trip covers some very rugged terrain with difficult footing and some strenuous climbing. Participants must be properly equipped and in excellent physical condition. Hiking group size in the Great Gulf Wilderness is limited to 10.

Drive to and then hike from ~ 5,900 ft. on the MWAR approximately 1.2 mi. down ~ 300 ft. to the headwall crest of the Great Gulf cirque on the northern slope of Mt. Washington to view the results of its multiple cirque glaciations. Then, hike back up ~ 300 ft. to the MWAR (cum. mi.: 2.4) and drive down to its 2-Mile Post at ~ 2,600 ft. From there, hike up ~ 100 ft and then down ~ 500 ft. in ~ 3.0 mi. to the newly-proposed recessional moraine in the Great Gulf cirque (Fowler, 2011). Then retrace this route back to the MWAR (cum. mi.: 8.4; elev. gain & loss: 1,600 ft), and drive back to the base of the MWAR and welcoming activities for the Reunion. Alternate access to the proposed recessional moraine will be via the Great Gulf Trail from NH Rte. 16, about 2 mi. north the of the Auto Base Lodge. The round trip hike via this route is a less-rugged 5.6 mi.

### Mt. Washington & The Alpine Zone of The Presidential Range

Drive up the MWAR to the flat area known as "Homestretch", just before the road steepens for its final ascent to the Summit of Mt. Washington. At approximately 7.5 mi., turn right off the MWAR paved surface and onto a short dirt road leading to a +/- 50-foot square concrete slab. Park on or near the slab, and walk from its south side toward the trestle of the Mt. Washington Cog Railroad, about 125 ft. from the slab.

#### **Stop 1:** Alpine Zone Test Pit

Proceed back to vehicles and continue up the MWAR to the south side Upper Parking Area, located to the left of the prominent wooden staircase. Assemble at the base of the westerly slope above the Parking Area.

#### **Stop 2:** Upper Diamict: its development, significance, and likely age.

Ascend the wooden staircase and turn left at its top and proceed left around the MWAR Stage Office (formerly Camden Cottage; site of the first weather Observatory on Mt. Washington and the location where the highest wind ever recorded by Man was observed in 1934 – 231 mph.) to the trail sign for the Crawford Path. Follow the Crawford Path downslope about 75 ft. and then fork off of it to the left to the bedrock promontory visible ahead, known locally as “Goofer Point”.

**Stop 3:** The “5,200-Foot Boundary” and Cosmogenic Dating Results/Prospects

Retrace steps to the trailhead for the Crawford Path and proceed thence to the entrance to the Sherman Adams Building. Once inside, proceed around its curved rotunda to the entrance to the Mount Washington Observatory at the northerly end of the building.

**Stop 4:** Lunch, “Pit Stops”, Observatory tours, & Summit visits. View vestigial glacial markings and typical bedrock on and near the Summit itself.

Proceed back to vehicles and drive down the MWAR to the “Cragway Curve” at roughly the 5 ½-Mile mark where the Nelson Crag Trail intersects the roadway (white sign on the right going down). Park where space is available and walk ~ 300 ft. around the right-hand shoulder of the MWAR to the larger of two pull-out areas along the easterly shoulder of the MWAR.

**Stop 5:** Bedrock Geology of the Presidential Range, The “5,200-Foot Boundary”, and the Great Gulf Moraines Overlook

Return to vehicles and proceed further down the MWAR to “The Horn” at roughly the 4 ½-Mile mark and park as space is available in the areas on the right side of the roadway.

**Stop 6:** Subsidiary Cirques of the Great Gulf System and the northern Presidential Range

Return to vehicles and proceed to the base of the MWAR and Reunion Headquarters.

### **Upper Peabody River Valley & Its Post-Late Wisconsinan Features**

Walk to the North Parking Lot at the MWAR Base Lodge and its viewpoint to the west across the site of the former lake and into the mouth of the Great Gulf.

**Stop 1:** Discuss possible terminal moraine & former moraine-dammed lake.

Walk across NH Rte. 16 to the MWAR/Great Glen Trails Maintenance Building (large red metal building) on the right about 200 ft. off the roadway where access to the Great Glen Trails cross-country ski system can be made.

**PLEASE NOTE** that because of frequent trail maintenance activities and unfavorable weather conditions, parties interested in foot access must check-in and obtain an up-to-date trail system map at the MWAR Base Lodge before setting out. Figure 4 is provided here so the following trip stops can be located.

Proceed along a combination of ski trails passing trail Intersections 4, 5, 8, 14, 19, 27, 33, 51 and 55 to the Great Angel Station at the northwesterly end of, and at highest point on, the trail system (see system map).

**Stop 2:** Discuss view into the Great Gulf, its proposed recessional moraine, and the terrain just traversed over the surface of the proposed terminal moraine.

Go back to Intersection 55 and proceed along the ski trail to Intersection 56 and the Drifter Pit Site.

**Stop 3:** Discuss Drifter Stone Count Site

From Intersection 56, proceed along a combination of ski trails passing Intersections 49, 44, 40, 50, and 54 toward 38 to the Thumper 2 Site.

**Stop 4:** Discuss Thumper 2 Stone Count Site

Proceed toward Intersection 38 along a combination of ski trails passing Intersections 38, 40, 33, and 27 to the Libby Site.

**Stop 5:** Discuss Libby Stone Count

Proceed along the Libby Trail to Intersection 19 to the very large boulder ahead.

**Stop 6:** Discuss the Rangeley Boulder & adjacent boulder fields.

From Intersection 19, proceed along a combination of ski trails passing Intersections 14, 8, 5, and 2 and then proceed north about 200 yards up the Clementine Wash Trail.

**Stop 7:** Discuss existing river channel, its history, and recent flooding.

Proceed back to Intersection 2, on to Intersection 1 around the MWAR Maintenance Building to the paved surface. Turn left on the paved roadway and proceed to the intersection of the MWAR and NH Rte. 16. Turn left onto NH Rte. 16 and proceed ~ 1.0 mi. to the 19-Mile Brook Trailhead. Park as space is available, and walk together off the westerly shoulder of NH Rte. 16 down and into Garnet Pool in the Peabody River.

**Stop 8:** Discuss Garnet Pool, its erosion features, and role in lake drainage.

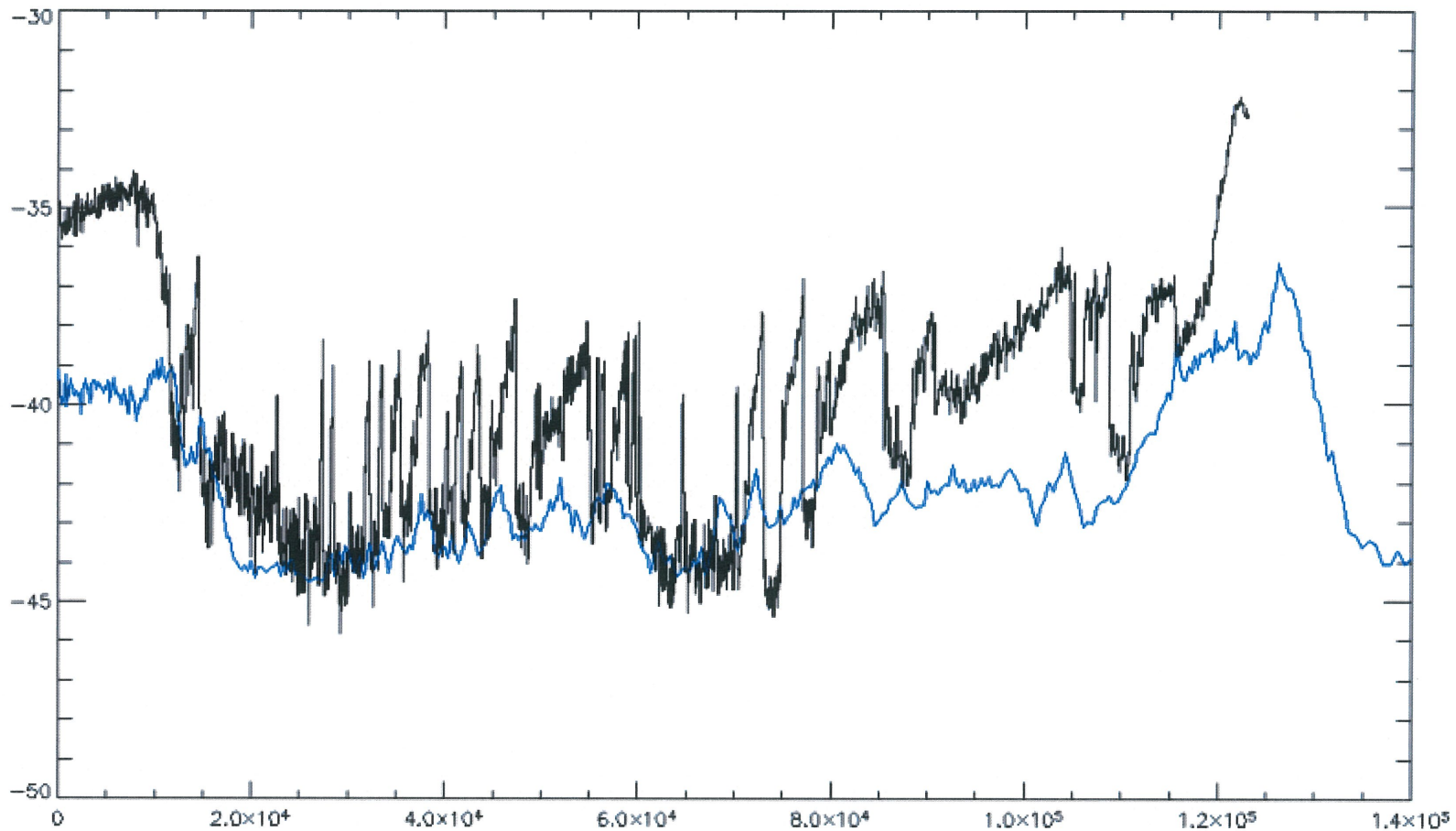
Walk back to the 19-Mile Brook Trailhead and proceed on that trail ~ 0.3 mi. to the distal edge of the proposed terminal moraine.

**Stop 9:** Discuss distal extent of proposed terminal moraine and significance.

Return to the MWAR Base Lodge. Total mileage on the Great Glen Ski Trail network is approximately 5 miles. When walking these stops, various “short-cuts” on crossing trails are possible.

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## FIGURES & HANDOUTS>>>



Time (from present to >120,000 yrs BP)

NGRIP (North Greenland) ice core record in black with EPICA (Antarctica) ice core record in blue. Delta-O-18 is a temperature proxy, with higher values indicating warmer temperatures. The left hand side shows the current Holocene interglacial. The right hand side is the previous Eemian interglacial, which is incomplete in the NGRIP data. During the glacial period, the NGRIP core shows clear signs of Dansgaard-Oeschger events, which are muted in the EPICA core. The two dramatic drops in the NGRIP data at about 15-14 ka and 13-12 ka are the Older Dryas and Younger Dryas cool intervals, respectively. Figure and parts of caption from Wikipedia Commons (by William M. Connolley).

(Modified from Stuiver, et al., 1995, Fig. 11)

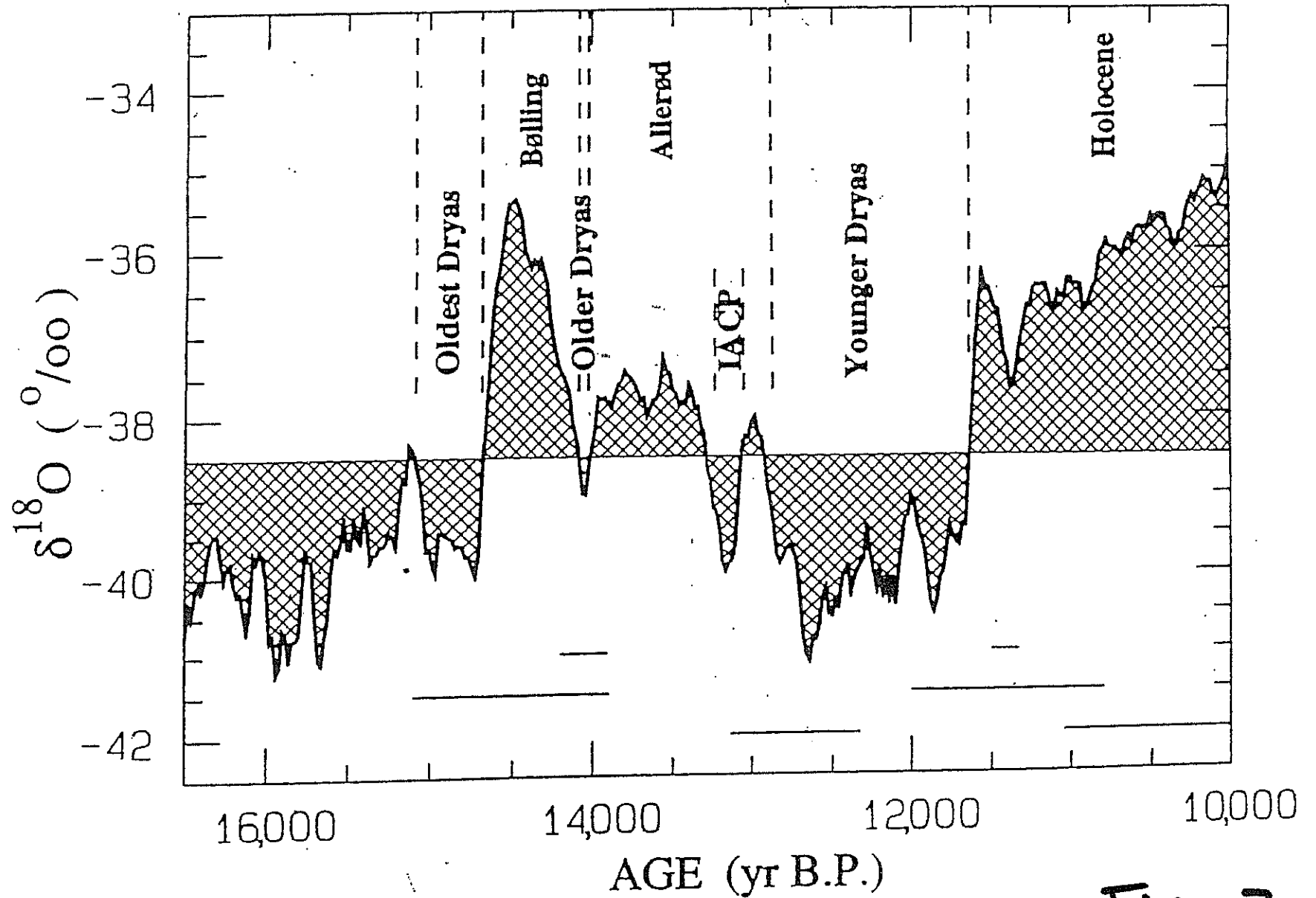


Fig. 2

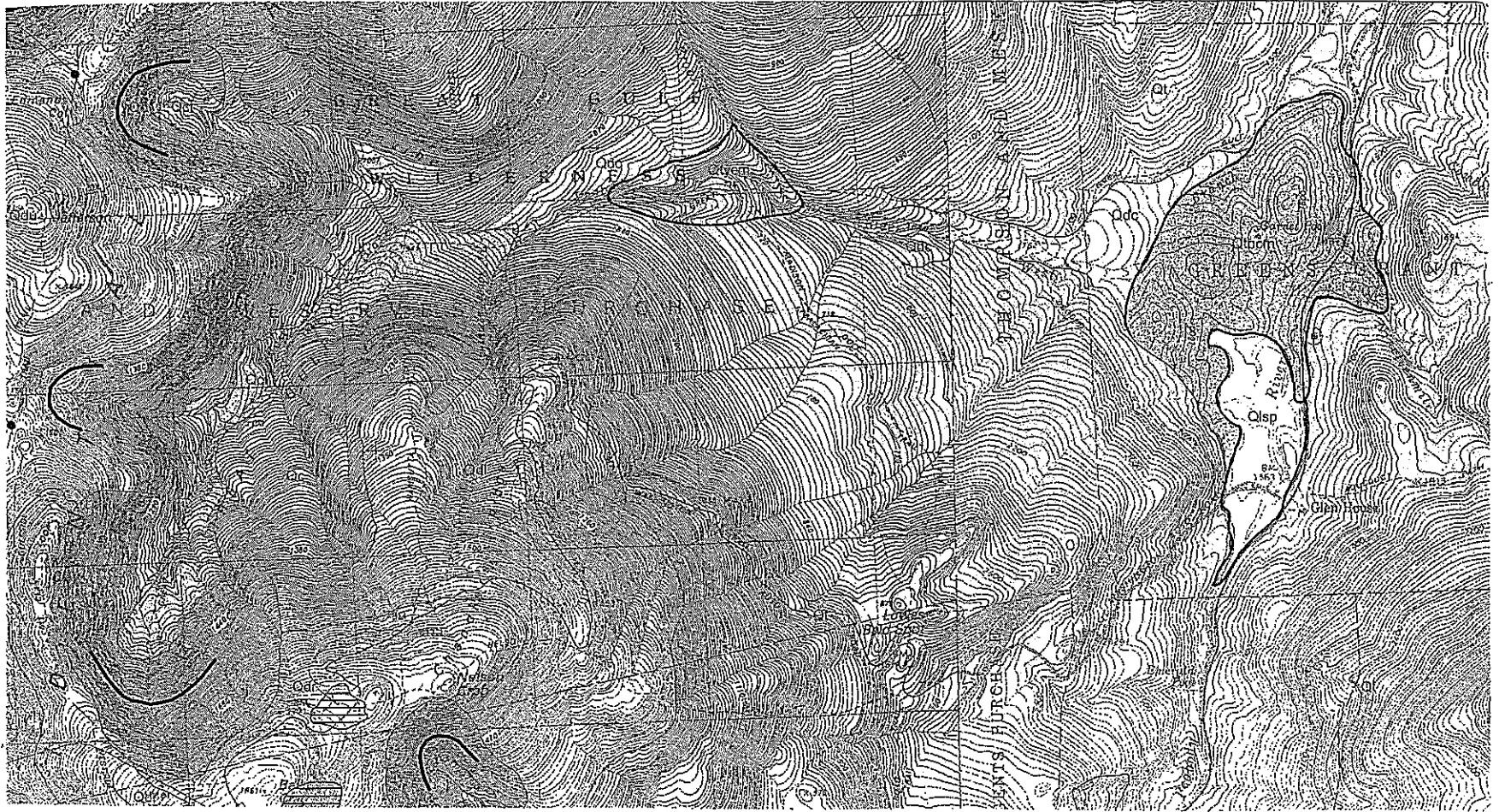


Fig. 3



**HANDOUTS**  
**FOR**  
**P. THOMPSON DAVIS**

**Tabulation**

**Comparative Cirque Morphometry, Cirques of the Presidential Range  
(Davis, 1999)**

**Abstract**

**Late Quaternary Glacial History of Mt. Katahdin and the Nunatak Hypothesis  
(Davis, 1989)**

**Abstract**

**Old Surfaces on New England Summits Imply Thin Laurentide Ice  
(Bierman, Davis, and Caffee, 2000)**



# CIRQUES OF THE PRESIDENTIAL RANGE, NEW HAMPSHIRE, AND SURROUNDING ALPINE AREAS IN THE NORTHEASTERN UNITED STATES

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TABLE I

*Cirque morphometric characteristics, New England area, U.S.A.*

Cirque Name	Cirque Grade <sup>1</sup>	Cirque Aspect (°) <sup>2</sup>	Schrund Altitude (m) <sup>3</sup>	Schrund Altitude (m) <sup>3</sup>	Aver. Height (m) <sup>4</sup>	Aver. Width (m) <sup>5</sup>	Cirque Length (m) <sup>6</sup>	Average headwall slope (°) <sup>7</sup>	Aver. floor inclination (°) <sup>8</sup>	Length: Height Ratio	Length: Width Ratio	Headwall: Floor Slope Ratio	Cirque Volume (km <sup>3</sup> ) <sup>9</sup>
<b>Presidential Range, N.H.</b>			<b>RPG</b>										
1. Ammonoosuc Ravine	4	-80	1080		530	1370	1525	30	10	2.88	1.11	3.00	0.55
2. Burt Ravine	4	-95	1170		630	990	1830	27	13	2.90	1.85	2.08	0.57
3. Castle Ravine	3	-45	1095	1067	585	840	1525	30	13	2.61	1.82	2.31	0.37
4. Cascade Ravine	4	-45	990		435	610	1065	29	11	2.45	1.75	2.64	0.14
5. King Ravine	2	-20	1230	1165	660	915	1525	36	17	2.31	1.67	2.12	0.46
6. Bumpus Basin	3	5	990	964	360	535	1065	27	10	2.96	1.99	2.70	0.10
7. Madison Gulf	3	120	1260	1214	420	535	1145	32	13	2.73	2.14	2.46	0.13
8. Jefferson Ravine	3	105	1260	1262	570	990	1675	38	11	2.94	1.69	3.45	0.47
9. "Sphinx Basin"	4	100	1470	1409	270	535	610	31	21	2.26	1.14	1.48	0.04
10. Upper Great Gulf	1	10	1350	1342	650	1065	2135	42	9	3.28	2.00	4.67	0.74
11. Huntington Ravine	1	135	1260	1287	630	610	1525	43	11	2.42	2.50	3.91	0.29
12. Upper Tuckerman Ravine	1	110	1365	1378	285	535	610	38	11	2.14	1.14	3.45	0.05
13. Lower Tuckerman Ravine	1	50	1200	1232	435	685	915	27	6	2.10	1.34	4.50	0.14
14. Gulf of Slides	3	65	1280	1262	340	1065	990	30	12	2.91	0.93	2.50	0.18
15. Upper Oakes Gulf	2	160	1230	1275	385	915	1415	32	3	3.68	1.55	10.67	0.25
16. "Monroe Basin"	4	165	1320	1342	310	685	915	35	9	2.95	1.34	3.89	0.10
17. "Franklin Basin"	4	160	1340		340	455	990	33	17	2.91	2:18	1.94	0.08
<b>average</b>	<b>2.8</b>	<b>52.9</b>	<b>1228.8</b>	<b>1246.1</b>	<b>452.5</b>	<b>751.4</b>	<b>1222.5</b>	<b>33.6</b>	<b>11.2</b>	<b>2.70</b>	<b>1.64</b>	<b>3.62</b>	<b>0.25</b>
<b>standard deviation</b>	<b>1.2</b>	<b>87.8</b>	<b>131.3</b>	<b>124.1</b>	<b>137.6</b>	<b>257.4</b>	<b>424.7</b>	<b>5.0</b>	<b>4.2</b>	<b>0.42</b>	<b>0.44</b>	<b>2.08</b>	<b>0.21</b>
											<b>total volume</b>		<b>4.21</b>

<sup>1</sup> Grade follows classification of Evans and Cox (1995), whereby 1 = classic, with all textbook attributes, 2 = well-defined, with headwall and floor clearly developed and headwall curves around cirque floor, 3 = definite, with no debate over cirque status, but one characteristic may be weak, 4 = poor, some doubt, but well-developed characteristics compensate for weak ones, 5 = marginal, with cirque status and origin doubtful.

<sup>2</sup> Aspect is direction faced by central headwall perpendicular to long axis of cirque measured to nearest 5° azimuth (negative values increase from 360° to 180°).

<sup>3</sup> Schrund altitudes in left column measured as most obvious break in slope denoted by contour lines, following method of Evans and Cox (1995), whereby headwall slopes generally more than 35° and floor slopes generally less than 20°, with limit between the two at 27°; schrund altitudes in right column measured by method of Goldthwait (1970), with initials of workers for particular areas as explained in text.

<sup>4</sup> Height measured from average top of headwall to lowest floor altitude (to nearest 5 m).

<sup>5</sup> Average width determined by numerous measurements from top of sidewall to top of opposite sidewall along long axis of cirque (to nearest 5 m).

<sup>6</sup> Length measured from top of headwall to cirque mouth, or where sidewalls abruptly end or drop in altitude (to nearest 5 m).

<sup>7</sup> Average headwall slope measured from top of headwall to cirque mouth, or where sidewalls abruptly end or drop in altitude (to nearest 5 m).

<sup>8</sup> Average floor inclination measured below schrund altitude.

<sup>9</sup> Volume calculated by: (height × width × length) / 2.

## Late Quaternary Glacial History of Mt. Katahdin and the Nunatak Hypothesis

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### ABSTRACT

Most workers agree that Mt. Katahdin was covered by ice at some time, but no indisputable evidence exists to support the common notion that cirque glaciers postdated continental ice recession from Mt. Katahdin. Erratics of northern provenance near its summit indicate that Mt. Katahdin was overridden by continental ice centered north of the mountain. These unweathered erratics, as well as generally unweathered bedrock and weakly developed soils on the Table Land, suggest that upland areas were covered by continental ice during the late Wisconsinan. Theoretical ice-surface profiles constructed along flow lines that lead inland from a dated ice-front position near the present coastline also suggest that overriding occurred during late Wisconsinan time. Roches moutonnées with chattermarked stoss sides facing down-cirque and ragged sides facing up-cirque, along with till of a northern provenance on the Northwest Basin floor, suggest that erosion and deposition by continental ice were the last late Wisconsinan events that occurred on Mt. Katahdin. The lack of end moraines on all cirque floors suggests that cirque glaciers did not reform following ice sheet recession. Lateral moraines on the east and south flanks of Mt. Katahdin were formed by continental ice during the final stages of deglaciation when Mt. Katahdin became a nunatak. The nunatak hypothesis suggests that some life forms survived late Quaternary glaciations on nunataks, refuges not completely covered by ice. However, for at least part of the late Wisconsinan, Mt. Katahdin was probably completely inundated by an ice sheet, therefore offering little or no support for the nunatak hypothesis.

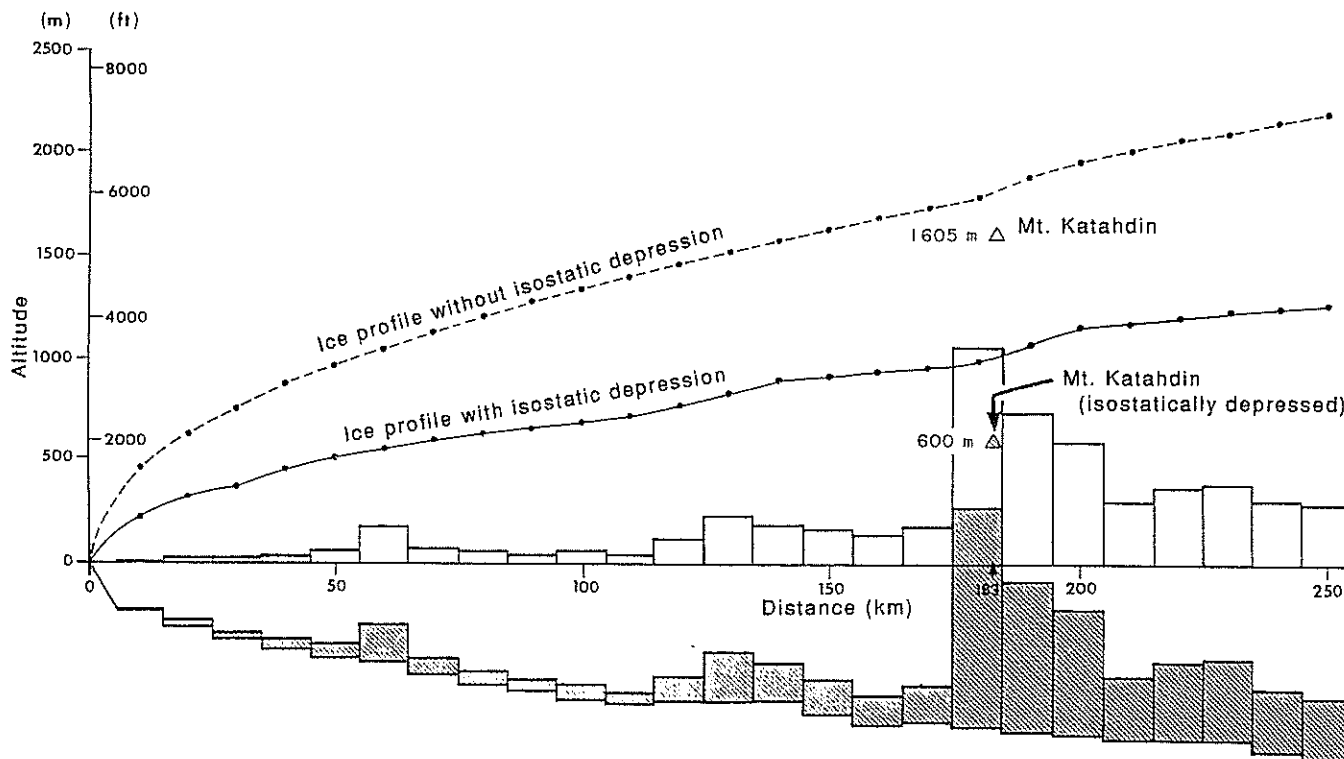


Figure 19. Late Wisconsin ice-surface profile along N20°W transect from Frenchman Bay to north of Mt. Katahdin (see Fig. 1 for location). This parabolic profile is derived from the empirical formula  $h_m = 4.0 \times l^{1/2}$ , where  $h_m$  is the thickness of ice in meters (Nye, 1952, p. 529). This formula assumes a glacier basal shear stress of 0.7 bar, characteristic of a "warm-base" glacier. The profile also provides a correction factor for bedrock topography (Nye, 1959, p. 502). The dashed line profile and blank topographic blocks represent an undepressed crust. The solid line profile and shaded topographic blocks simulate an isostatically depressed crust. Elliptical ice-surface profiles derived from empirical formula in Paterson (1972, p. 889; 1981) also show Katahdin covered with ice during the late Wisconsinan.

Bierman, P.R., Davis, P.T., and Caffee, M.W., 2000, Old surfaces on New England summits imply thin Laurentide ice. *Abstracts with Programs, Geological Society of America*, vol. 32, no. 7, p. A-330.

### **11:30 AM** Bierman, Paul R.

#### OLD SURFACES ON NEW ENGLAND SUMMITS IMPLY THIN LAURENTIDE ICE

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The abundance of  $^{10}\text{Be}$  and  $^{26}\text{Al}$  in frost-riven bedrock samples collected from the summits of Mt. Washington in New Hampshire and Mt. Katahdin in Maine is much higher (1.5 to 8 times) than expected had the peaks been covered by active, erosive ice during the last glacial maximum (LGM) about 21.5 ky calibrated  $^{14}\text{C}$  years ago.

Samples from the summits of Mt. Washington have  $^{10}\text{Be}$  model exposure ages of 124 and 22 ky; one sample from Mt. Katahdin has a model age of 25 ky (assuming production rates of Nishiizumi et al., 1989). In contrast, other near-summit samples ( $n=3$ ) and boulders ( $n=5$ ) from the Basin Ponds moraine on Mt. Katahdin have an average age of  $12.7 \pm 0.7$  ky.

A single boulder from the well-dated Pineo Ridge moraine complex in coastal Maine (13.2 to 14.0 cal  $^{14}\text{C}$  ky BP) can be used to estimate integrated  $^{10}\text{Be}$  and  $^{26}\text{Al}$  production rates of 5.8 to 6.1 and 38.3 to 40.7 atoms/(g\*yr) at 60 m asl and 44 degrees N.

The mountain-top samples are consistent with two different scenarios, both of which have significant implications for understanding the spatial and temporal pattern of glaciation and glacial erosion in New England: 1) LGM Laurentide ice was thinner than previously supposed leaving the top of Mt Katahdin exposed since early stage 2 and parts of Mt. Washington's summit exposed since stage 6, 2) both summits were covered by glacial ice during the LGM, but the ice was thin enough to be frozen to its bed. Thus, the cold-based ice was unable to erode much rock, allowing nuclides to be inherited from prior periods of exposure. In either case, Laurentide ice in New England during the LGM was thinner than previously believed, consistent with low basal shear stresses and/or the presence of active ice streams.

**HANDOUTS**  
**FOR**  
**IAN T. DULIN**

**Extracted Text, Tables, and Graphics**  
**New Evidence of a post-Laurentide local cirque glacier on Mt. Washington, New**  
**Hampshire**  
**(Dulin, 2012)**

NEW EVIDENCE OF A POST-LAURENTIDE LOCAL  
CIRQUE GLACIER ON MOUNT WASHINGTON,  
NEW HAMPSHIRE

An Honors Thesis

Presented to  
The Faculty of the Department of Geology  
Bates College

In partial fulfillment of the requirements for a  
Degree of Bachelors of Science

By  
Ian T. Dulin

Lewiston, Maine  
March, 2011

# Abstract

As global temperatures warmed and the last North American continental ice sheet receded there were several climate reversals during which time mean temperatures in New England were significantly reduced. Decreased temperatures in combination with increased precipitation may have supported the formation or reactivation of local mountain glaciers in pre-existing cirques on Mt. Washington, New Hampshire. Evidence supporting the existence of a local cirque glacier would provide important constraints on climatic conditions during the late-glacial Pleistocene transition. Preliminary mapping done in the area has identified a potential terminal moraine associated with a local valley glacier in the Great Gulf, the largest cirque on Mount Washington. The presence of this deposit is significant because any pre-Wisconsin evidence of valley glaciers in the Great Gulf would likely have been expunged by the presence of continental ice.

In order to determine the origins of the possible moraine, representative samples of the till were collected by digging five test pits across the feature, sampling ~50 hand-sized stones from each pit, and determining the provenance of individual stones. Results indicate that the landform is composed of unsorted clasts with provenances of both local and regional origin. Clasts sourced within the Great Gulf support the interpretation that they were deposited by processes dependent on the presence of a local mountain glacier during a post-Wisconsin climate reversal. Stones of more distant origins may be attributed to residual till, associated with a continental ice mass that occupied the cirque at the time of local glacier reactivation. These data show that the landform was deposited from glacial processes taking place within the Great Gulf, and the pronounced topography and volume of the landform would support its interpretation as a terminal moraine.

By reconstructing the glacier using the feature as the terminus, a paleo-ELA was calculated and climate conditions necessary to promote the growth of an icemass were ascertained. This ELA represents the altitude at which the mean annual isotherm at which the climate is considered suitable to support an icemass. Comparing this climate to the contemporary allows us to evaluate the magnitude of late-Pleistocene climate reversals in the White Mountains. A paleo-ELA of ~850m was calculated and the contemporary climate at that altitude was 6-8°C warmer than the minimum conditions necessary for a glacier to exist with no significant increase in precipitation. This tells us that if a glacier did occupy the cirque after the recession of the continental ice sheet, the late-Pleistocene was a little colder/wetter than previously thought in the White Mountain region of New Hampshire.

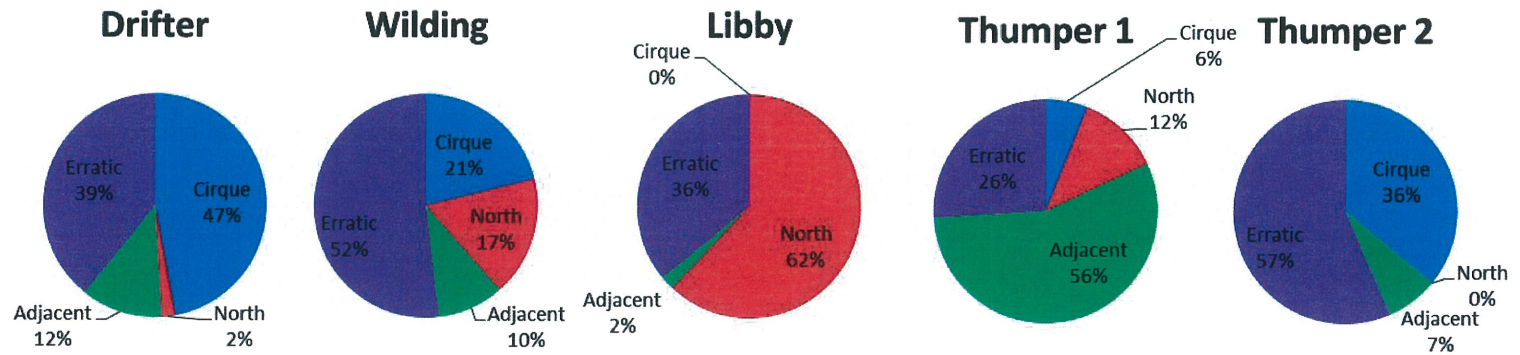


FIGURE 17. (Above) The source-classified results from the stone counts.

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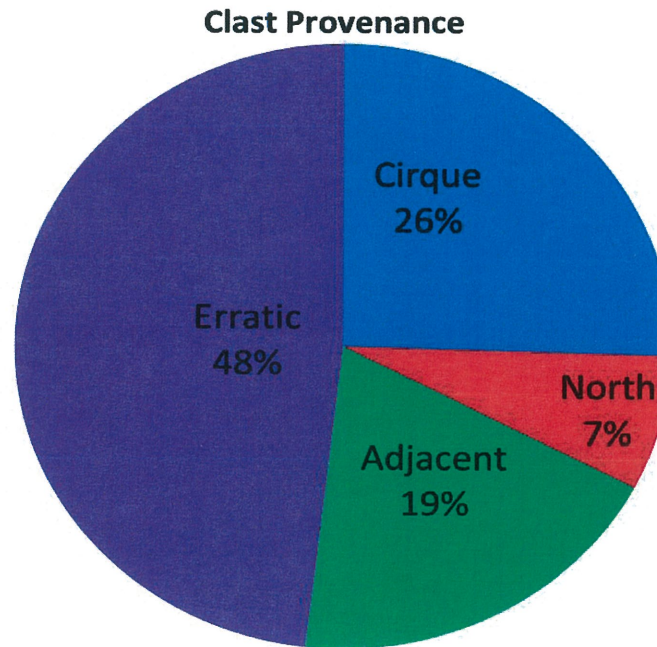


FIGURE 18. (Right) The compiled, source-classified results from the stone counts, excluding Libby.

TABLE 2. The stone count from the Libby pit.

#	Long	Intermedia	"Size"	Roundess	Lithology	#	Long	Intermedia	"Size"	Roundess	Lithology
						26	7	4	28	2	DCTmg-F
1	11.5	6	69	2	Basalt						
2	13	5.5	71.5	1	DCTmg-k	27	6	5	30	3	Single Granite
3	8.5	7	59.5	1	Basalt	28	6.5	5.5	35.75	2	Basalt
4	9	6	54	2	DCTmg	29	6	4.5	27	2	DCTmg-k+
5	9.5	5.5	52.25	1	DCTmg-k	30	6	5	30	2	DCTmg-F
6	9	6	54	1	DCTmg-k	31	6	6	36	2	DCTmg-k
7	9.5	7	66.5	1	DCTmg	32	6	4	24	2	DCTmg-k
8	10	6.5	65	2	DCTmg	33	6.5	4.5	29.25	3	Single Granite
9	9	8	72	1	DCTmg	34	6	4	24	3	DCTmg
10	9	6.5	58.5	2	DCTmg-F	35	6	5	30	2	Other Dark Foliated
11	8	7	56	2	DCTmg-k+	36	6.5	4	26	2	Other Dark Foliated
12	7	5.5	38.5	1	Other Granitoid	37	6	4	24	2	Single Granite
13	8	6	48	1	DCTmg	38	6	3	18	2	DCTmg-k+
14	8	6	48	1	Single Granite	39	5.5	4	22	2	Single Granite
15	9	6	54	2	Other Dark Foliated	40	5	4.5	22.5	3	DCTmg-F
16	7.5	4.5	33.75	1	DCTmg	41	5.5	3.5	19.25	2	DCTmg-k+
17	6	6	36	2	DCTmg-k+	42	6	5	30	2	DCTmg
18	7.5	5.5	41.25	1	Other Granitoid	43	6	5	30	1	DCTmg-k+
19	7.5	5	37.5	2	DCTmg-k+	44	5	4	20	2	DCTmg-k+
20	7.5	5	37.5	2	Pegmatite	45	5.5	5	27.5	2	Other Granitoid
21	8.5	5.5	46.75	2	Quartz	46	6	3.5	21	3	Single Granite
22	7	5	35	2	DCTmg-F	47	6	4	24	3	Sr
23	6.5	4	26	3	Single Granite	48	6	4	24	3	DCTmg-k+
24	6	4	24	2	Single Granite	49	4	3	12	1	DCTmg-k+
25	7.5	4	30	2	DCTmg-k+	50	5	4.5	22.5	3	Other Granitoid



TABLE 4. The stone count from the Drifter pit.

#	Long	Intermedia	"Size"	Roundess	Lithology	#	Long	Intermedia	"Size"	Roundess	Lithology
1	9.5	7.5	71.25	1	DI	26	12	8.5	102	1	Fine-Grain Schist
2	8.5	7	59.5	1	DI	27	12	3	36	2	DI
3	11	5	55	2	Other Dark Foliated	28	13	10	130	3	Fine-Grain Schist
4	11	8	88	1	Other Granitoid	29	13	12.5	162.5	1	Fine-Grain Schist
5	9	5.5	49.5	2	Src	30	14	7	98	2	Basalt
6	9	6	54	1	DI	31	9	7	63	2	Pegmatite
7	9.5	6	57	2	Other Granitoid	32	7.5	5	37.5	3	Dwd
8	8	7.5	60	1	DCTmg	33	7	6.5	45.5	4	Ssf
9	10	7.5	75	3	DI	34	7	5.5	38.5	2	Sr-c
10	9.5	6	57	1	Pegmatite	35	7	6	42	1	Fine-Grain Schist
11	8.5	6	51	2	Non-local anomoly	36	8	6	48	2	Basalt
12	12.5		0	3	DI	37	7	4.5	31.5	3	Single Granite
13	8	8	64	1	Single Granite	38	7	5	35	2	DI
14	9	6.5	58.5	3	DI	39	6	3.5	21	3	Sr
15	11.5	8	92	1	DI	40	7	5	35	2	DI
16	10	7	70	3	DI	41	6	5	30	1	Single Granite
17	9	7.5	67.5	1	DI	42	6	4	24	1	Sr
18	10	8	80	2	Fine-Grain Schist	43	5	4	20	3	Single Granite
19	9	8	72	2	DI	44	5	4	20	4	Ssf
20	9.5	6	57	2	Fine-Grain Schist	45	4.5	4	18	2	DI
21	10	8	80	2	Src	46	14	12	168	3	DI
22	7.5	5	37.5	2	Other Dark Foliated	47	16.5	11.5	189.75	2	Other Granitoid
23	10	7	70	3	Single Granite	48	17	14	238	1	DI
24	12	9	108	1	DI	49	18	12	216	2	Pegmatite
25	12	8.5	102	1	DI	50	18	10	180	1	Other Granitoid

TABLE 6. The stone count from the Thumper 2 pit.

#	Long	Intermedia	"Size"	Roundness	Lithology	#	Long	Intermedia	"Size"	Roundness	Lithology
1	14	14	196	4	Src	27	8	7	56	2	DI
2	22	17	374	4	Sr	28	7	6	42	2	Single Granite
3	13	10	130	4	Pegmatite	29	8	7	56	2	DI
4	11	9	99	1	Other Granitoid	30	8	6	48	1	Basalt
5	9	7	63	3	DI	31	7.5	5	37.5	3	Ssf
6	10	7	70	1	Pegmatite	32	8.5	6	51	4	Sr
7	10	7	70	2	Other Granitoid	33	7	6	42	2	Fine-grain Schist
8	8.5	7	59.5	2	Basalt	34	7	5.5	38.5	3	Basalt
9	11	5.5	60.5	3	Ssf	35	6	5	30	1	Other Granitoid
10	14	7	98	4	Ssf	36	8.5	5	42.5	2	Non-local anomoly
11	10	7	70	4	Non-local anomoly	37	6.5	5	32.5	2	Pegmatite
12	8.5	7	59.5	1	Non-local anomoly	38	6	5	30	3	Other Granitoid
13	8.5	6	51	3	Other Granitoid	39	7	4.5	31.5	3	Other Granitoid
14	7	5	35	2	Other Granitoid	40	7	4	28	2	Non-local anomoly
15	10.5	7	73.5	3	Fine-grain Schist	41	7	4	28	3	Other Granitoid
16	10	6	60	3	Ssf	42	8	5	40	3	Other Dark Foliated
17	8	7	56	2	Ssf	43	6	4	24	2	Dwd
18	8	6	48	2	Pegmatite	44	5	4	20	3	Basalt
19	9	7.5	67.5	2	DI	45	5	4	20	2	Other Granitoid
20	9	4	36	3	Src	46	6	5	30	4	Other Granitoid
21	9	6.5	58.5	3	Pegmatite	47	6.5	5	32.5	3	Other Granitoid
22	9	5.5	49.5	2	Other Granitoid	48	6	4.5	27	4	Quartz
23	8	6	48	1	Single Granite	49	6.5	4.5	29.25	3	Sm
24	8.5	5	42.5	2	Other Granitoid	50	5.5	3.5	19.25	2	DI
25	8	6.5	52	3	Pegmatite	51	5.5	4	22	2	Other Granitoid
26	7	6.5	45.5	1	Basalt	52	4.5	3	13.5	2	Other Granitoid
						53	5	5	25	4	Pegmatite

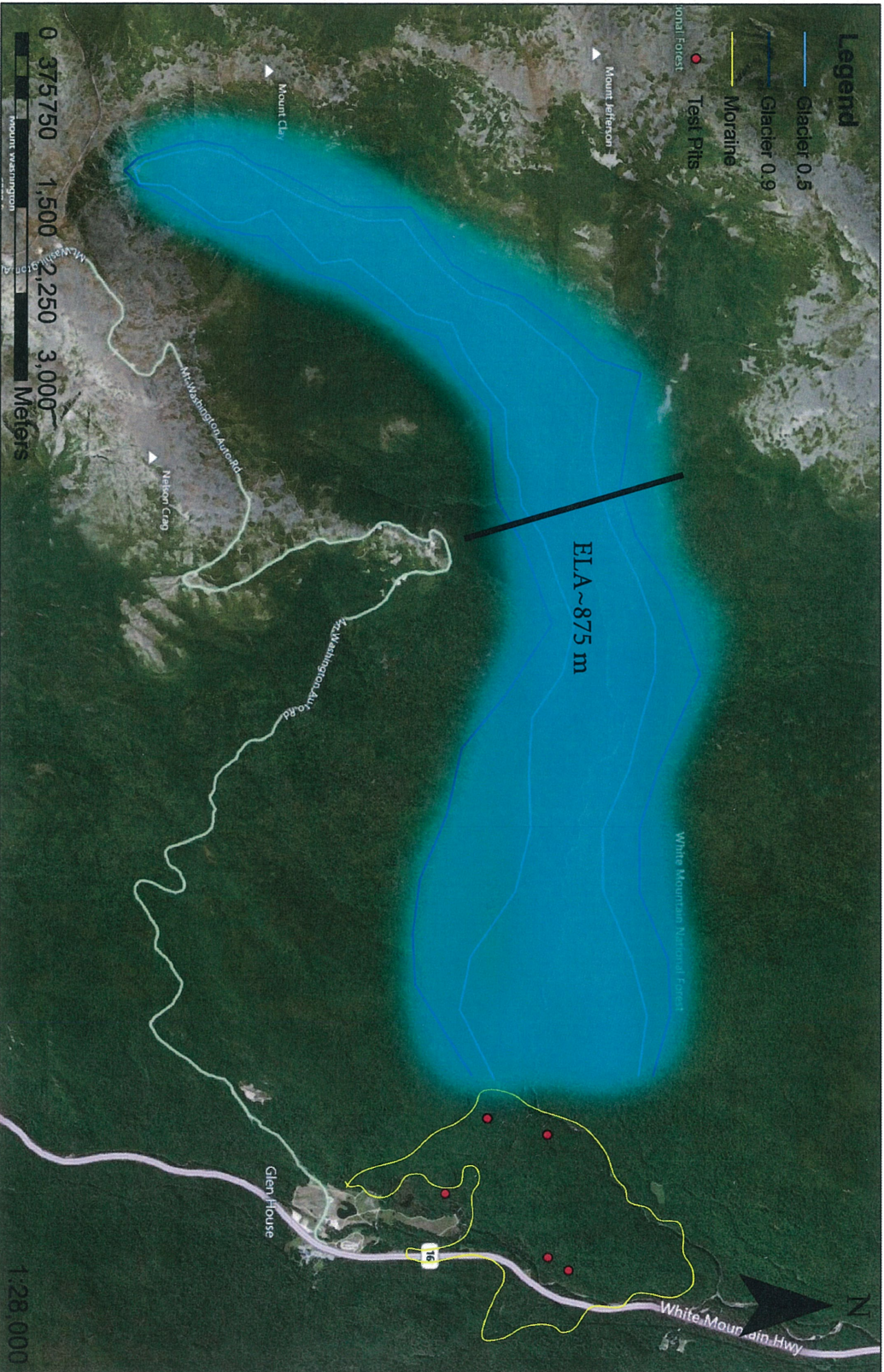


FIGURE 16. The reconstructed glacier using the 0.9 bar reconstruction. Note the test pits (red dots), the outline of the landform (yellow), and the ELA (black).

### 3.2.1 Paleo-ELA

The glacier was reconstructed using 0.5 bar and 0.9 bar values for basal shear stress in order to get a minimum and maximum value for ice thickness. This ice thickness, on average, was about 50 and 100 m, respective to the 0.5 ad 0.9 bar reconstructions, but did vary by as much as 25 m depending on the slope of the bed below the ice (Figure 15). After constraining the ice mass using 30 cross sections, the reconstructed ice mass was plotted on a topographic map in order to determine a paleo-ELA.

The elevation of the toe of both reconstructed glaciers was 495 m. The headwall altitude of the glacier reconstructed using 0.5 bars of shear stress was 1,364 m. The headwall altitude of the glacier reconstructed using 0.9 bars of shear stress was 1,474 m. Using the THAR method, the paleo-ELAs of the glacier reconstructed using 0.5 and 0.9 bars were  $822 \pm 22$  m, and  $842 \pm 25$  m, respectively. Using the AAR method, the paleo-ELAs of the glacier were 860 m and 900 m, respectively (Table 7).

TABLE 7. Results of the various ELA reconstruction methods.

<b>Glacier</b>	<b>THAR (m)</b>	<b>AAR (m)</b>	<b>Avg (m)</b>
<b>0.5 Bars</b>	$822 \pm 22$	860	841
<b>0.9 Bars</b>	$842 \pm 25$	900	871

From page 51 of Ian Dulin's honors thesis at Bates College, 2012, "New Evidence of a Post-Laurentide Local Cirque Glacier on Mount Washington, New Hampshire."

### 3.2 Glacier Reconstruction

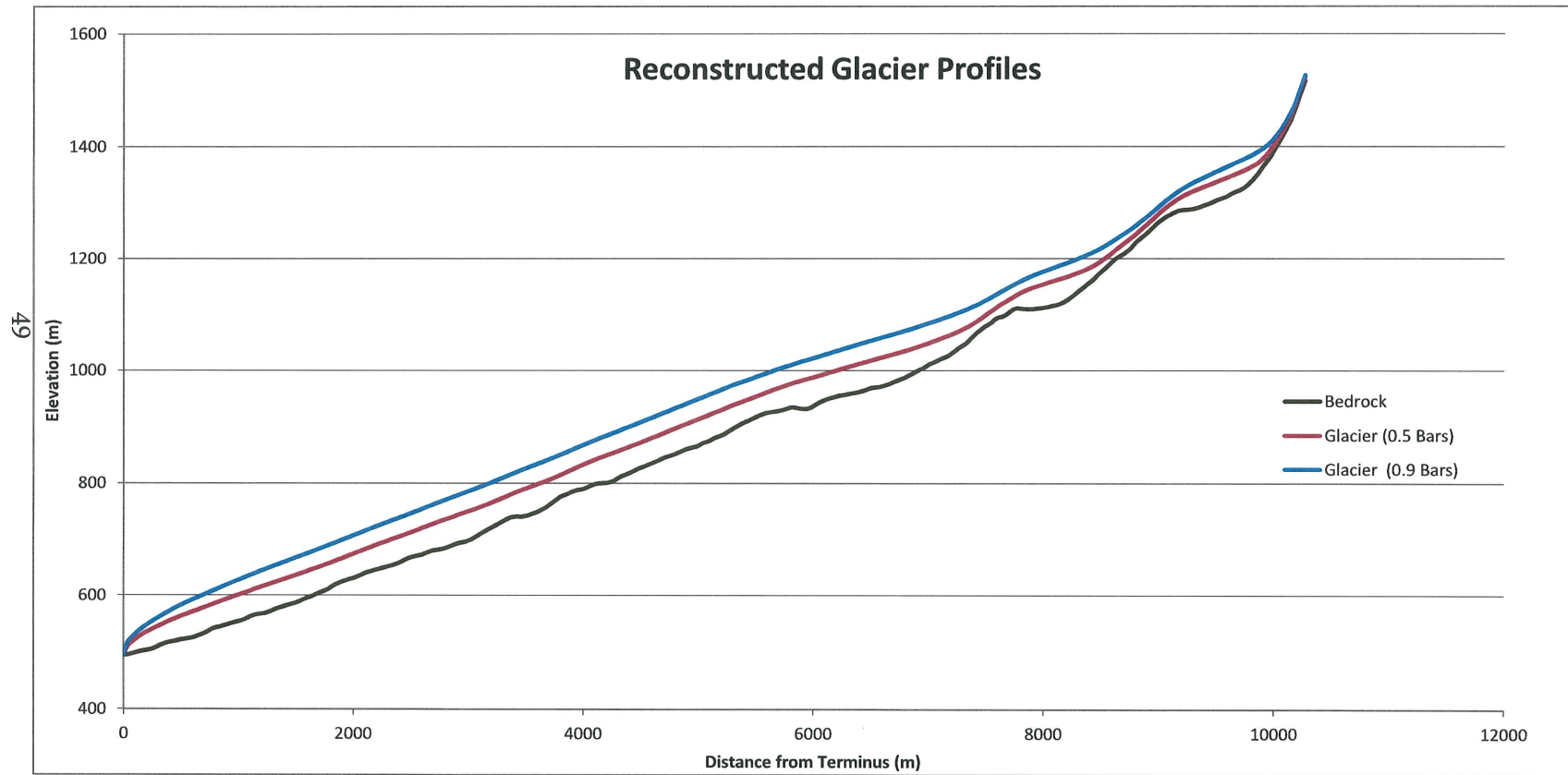


FIGURE 15. The reconstructed ice mass profiles, with 0.5 bar reconstruction in red, the 0.9 bar reconstruction in blue, and the bed in brown.



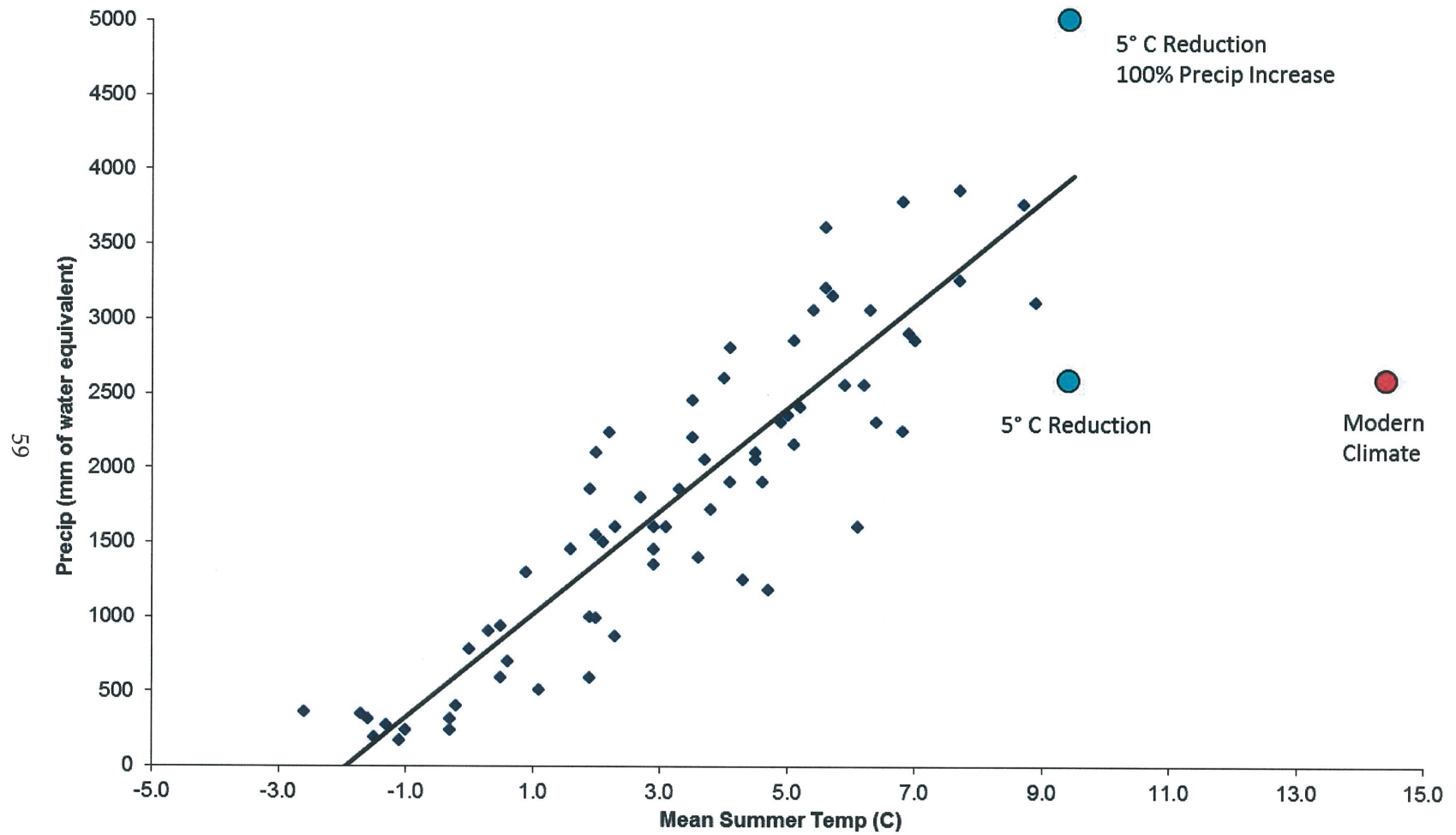


FIGURE 19. Data compiled from Ohmura et al. (1992) with modern-day climate (red), as well as 5 degree Celcius reductions, one with a 100% increase in annual precipitation (blue), shown.