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POSSIBLE POST-LAURENTIDE CIRQUE GLACIATION IN THE GREAT GULF PRESIDENTIAL RANGE, NEW HAMPSHIRE

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INTRODUCTION

This trip continues to explore the possibility that active local glaciers existed in the cirques on the Presidential Range after departure of the Late Wisconsinan Laurentide Ice Sheet (LIS), a subject debated for now more than 145 years (Fig. 1; Fig. 2). Debate arises because the surficial geologic features of these cirques are not consistent with those generally considered together as diagnostic of recent cirque glaciation: 1) fresh, sharply-defined cirque basins and 2) associated moraines within and below them. Here the cirques are sharply-defined, but so far associated moraines are missing.

Figure 1: Tuckerman (r) and Huntington (l) Ravines; glacial cirques, eastern flank of Mt. Washington. Bradford Washburn photograph used by permission.

Over the years, debate has been prolonged by difficult field access in and below the cirques that hampered the search for moraines. Recently however, recreation trail development improved such access below the Great Gulf cirque and permitted new mapping there. This work, together with laboratory-based petrographic study of stone clast provenance and recently published post-LIS regional climate indications, led to the identification of landforms that may be moraines. If confirmed by further study, the presence of these features will combine with the freshness of the cirque's morphology as the first consistent evidence of active cirque glaciation in the region following departure of the LIS.

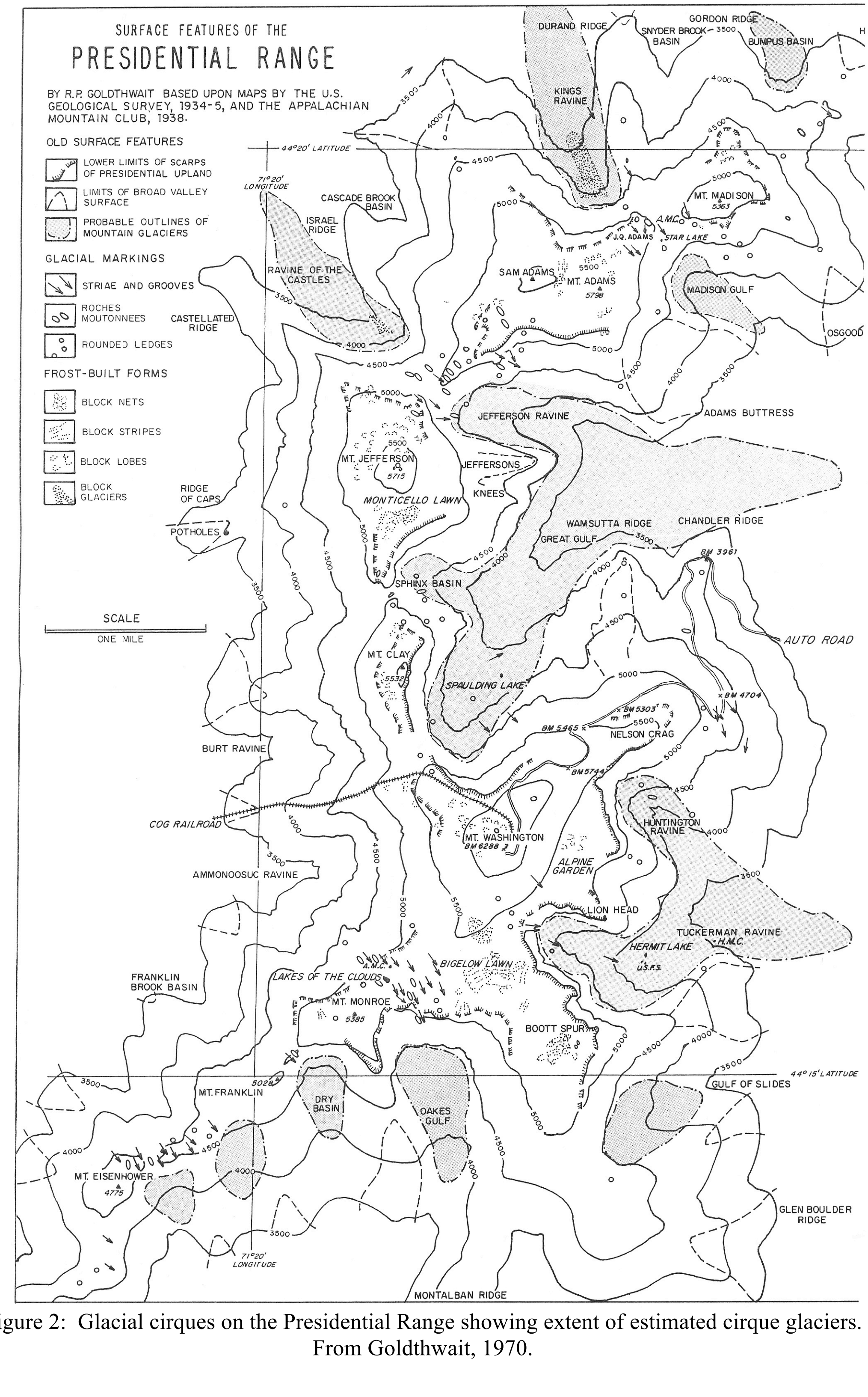

Figure 2: Glacial cirques on the Presidential Range showing extent of estimated cirque glaciers. From Goldthwait, 1970.

PREVIOUS STUDIES

Louis Agassiz (1870) proposed that ice caps existed over the region's higher elevations after the LIS and that alpine glaciers flowed downward from them through the cirques and cirque-like basins into the region's valleys. In support he cited their sharply-defined morphology along with valley features he proposed were their terminal moraines.

C. H. Hitchcock (1876, 1877, 1878) performed field work on the region's highest peaks and refuted this ice cap proposal, citing the lack of striations oriented in the multi-directional patterns that would arise from such ice caps. However, he did not further consider the formation of the cirques.

J. W. Goldthwait (1913) undertook field reconnaissance in the cirques, concluding that no post-LIS activity had occurred within them. He observed no striations or erosional features produced by local ice moving along their axes, no moraines on or beyond their floors, and evidence that the symmetrical U-shape of several had been last modified by erosion he asserted could only be attributed to the obliquely overriding LIS. He also found erratic cobbles on their floors and inferred from their presence that the cirques were formed before and not after the LIS, postulating that post-LIS cirque glaciation would have removed them. Later (1916), he convincingly reinterpreted the deposition of Agassiz's terminal moraines, showing they were related to the LIS and not alpine glaciers flowing downward from regional ice caps.

Ernst Antevs (1932) questioned Goldthwait's conclusion regarding post-LIS cirque glaciation. He proposed that the absence of moraines resulted not from a lack of post-LIS activity but from a lack of till deposits on their floors, noting that till was rarely observed adjacent to or beneath abundant deposits of thick talus. He postulated that cirque glaciers may have been diminutive and largely immobile; only able to undermine and steepen their basins.

D.W. Johnson (1933) agreed with Antevs arguing that lack of end moraines was not sufficient evidence to conclude no post-LIS activity had occurred. He cited alpine regions elsewhere that had never undergone continental glaciation but whose cirques lacked moraines.

R. P. Goldthwait (1936, 1940, 1970) performed further field work in the cirques. He confirmed the conclusion that no post-LIS cirque glacier activity had occurred within them by adding to his father's evidence the northwest to southeast orientations of various "groove-like features" and roche mountonees on cirque floors and headwalls. Despite important differences in the nature and elevation of these features, he asserted they could have been formed and preserved only if the overriding LIS was the last erosional agent to affect the pre-existing cirques. At the same time, however, he suggested the possibility that residual ice masses might have persisted after departure of the LIS in the deeper most favorably oriented cirques. In 1970, he prepared the first morphometric comparison of the cirques, estimating firn line and bergschrund elevations along with estimated terminus positions for their possible glaciers (Fig. 2).

W. F. Thompson (1960, 1961) used early techniques of photogrammetry to argue the sharply defined morphology in the cirques could only result from active cirque glaciation that post-dated the LIS and that any moraines in or below them had been obliterated by intense wasting. He did not, however, support these assertions with field observations.

D.M. Eskenasy (1978) completed photogrammetric analyses and field work in the King Ravine cirque and proposed that residual ice-based activity had occurred there on and within what was then proposed by some to be a relict rock glacier developed in post-LIS time. The study was, however, unable to establish if the feature was a rock glacier or if any post-LIS glacial activity had occurred in the cirque.

P.T. Davis and R. B. Davis (1980) and later P.R. Bierman, et al. (2000) and P.T. Davis, et al. (2003) investigated the possibility and timing of post-LIS activity in the cirques first using minimum radiocarbon ages from the limited number of available tarns and peat bogs and later cosmogenic nuclide ages from quartz veins in boulders and bedrock surfaces in the cirques. Samples from Tuckerman Ravine (near the Great Gulf; Fig. 2) yielded an age range consistent with regional dates for deglaciation by the LIS but not sufficiently specific to establish if post-LIS cirque activity had occurred there.

D.C. Bradley (1981) challenged the absence of post-LIS cirque activity by proposing that surficial deposits below the mouth of the north-facing King Ravine cirque were a composite moraine emplaced there by a local glacier flowing out of the cirque in post-LIS time. He supported this by citing the well-known presence on the feature of boulders whose lithologies outcrop on the cirque's headwall, along with the postulation that such deposits could not have survived overriding erosion by the LIS and thus must post-date it.

B.K. Fowler (1984) and R.B. Waitt and P.T. Davis (1988) independently examined this proposal and its supporting evidence. They each concluded the deposits are not a moraine related to a post-LIS cirque glacier, but are instead a complex of massive debris-flows likely related to rapidly melting residual ice in the cirque.

D. J. Thompson (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 did not support the presence or reactivation of post-LIS glaciation in the cirque.

P. T. Davis (1999) re-examined the morphometry of the cirques by expanding the techniques used earlier by Goldthwait (1970). He continued to find no convincing evidence for post-LIS cirque activity in the cirques, generally postulating that post-LIS regional climate warmed so rapidly that equilibrium-line altitudes rose too quickly above the cirques floors to support cirque glaciers.

Thompson and Fowler, 1989; Thompson et al., 1999; Fowler, 1999, 2011, 2012; and Thompson et al., 2017 established that moraines deposited by late-glacial readvance or standstill of the LIS 5 to 8 km northwest of the Presidential Range are part of the White Mountain Moraine System (Fig. 3) that extends irregularly west to east across the region. Minimum-limiting radiocarbon ages and direct correlation to the North American Varve Chronology (Ridge, et al., 2012) demonstrate these moraines were deposited after the departure of the LIS from the immediate region during the Older Dryas Cold Interval (~14.0 cal ka BP).

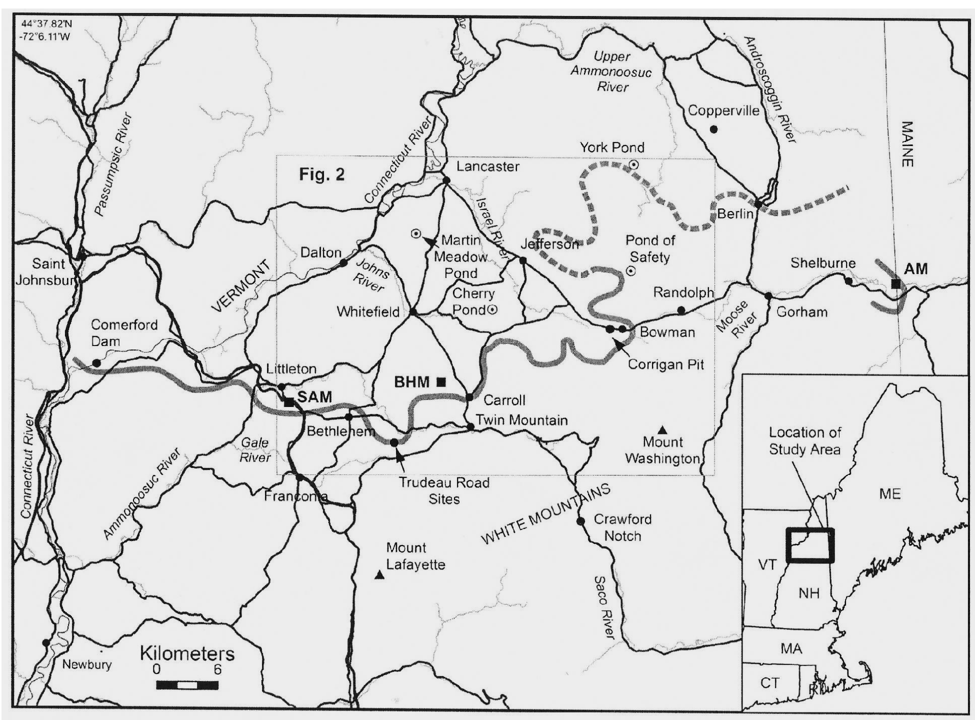

Figure 3: Location and extent of the White Mountain Moraine System (gray-shaded solid and dashed line) and its proximity to Mt. Washington and the Great Gulf Cirque complex. From Thompson, et al., 2017.

B. K. Fowler (2011) completed compilation of the surficial geology of the Mt. Washington East 7.5-minute quadrangle that includes the region's most prominent cirques. This work located for the first time landforms below the Great Gulf that may be moraines related to active glaciation in the cirque after the departure of the LIS. The mapping also established that morphologic asymmetry in the Great Gulf cirque itself results from local rock structure and not erosion by an overriding ice sheet. The work also demonstrated that moraines located northwest of the Presidential Range are part of the White Mountain Moraine System.

I. T. Dulin (2011) completed field and laboratory work that established that the provenance of a significant percentage of stone clasts in the lower landform identified by Fowler (2011) lies within the Great Gulf cirque complex. He concluded that this evidence suggests the lower landform was deposited by ice moving out of the cirque and not from wasting ice masses nearby.

NATURE AND GENESIS OF THE POSSIBLE GREAT GULF MORAINES

There are two landforms proposed to be moraines, one near the mouth of the Great Gulf cirque complex and the other in the lower central area of its principal cirque basin (Fig. 4).

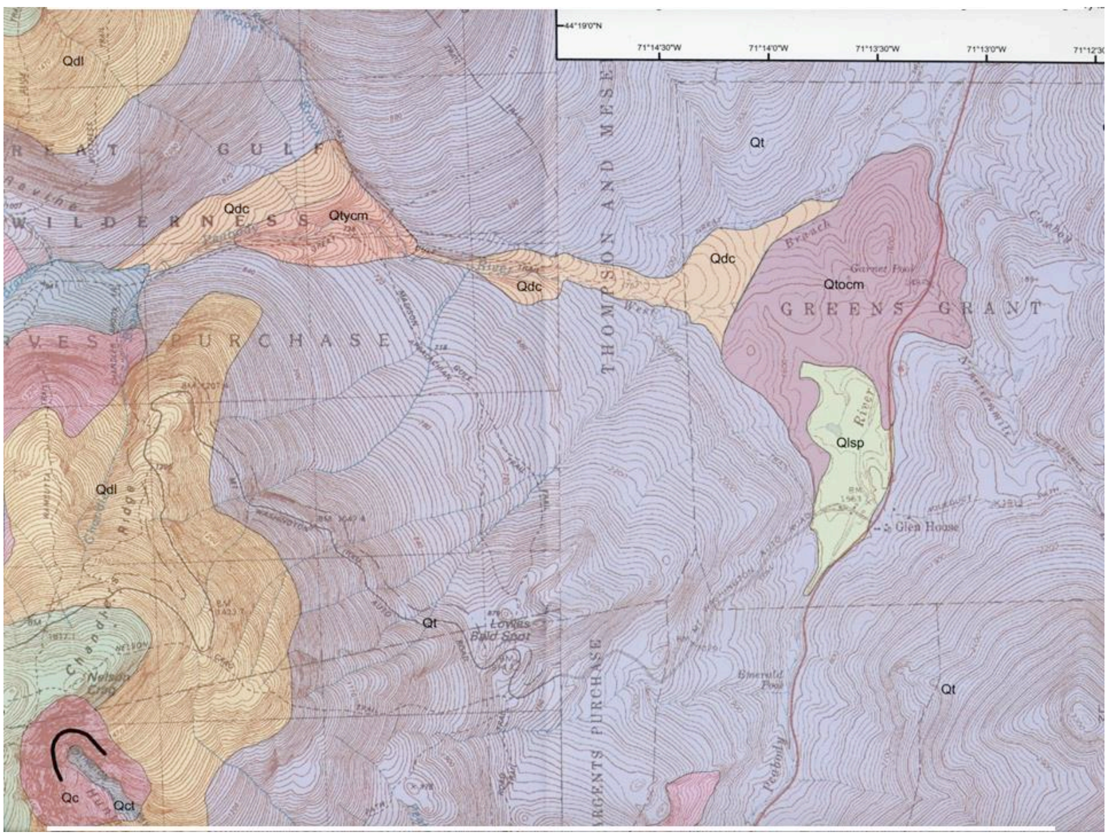

Figure 4: Surficial geology, central and lower Great Gulf showing proposed terminal moraine (Qtocm), deposits of the ephemeral lake dammed at its base (Qlsp), and proposed recessional (Qtycm).

The lower elevation landform is an extensive group of cross-valley hillocks strewn with very large, sharply to moderately faceted boulders (to 20 ft. diameter) of rock types outcropping within the cirque above. Its deposits consist of loosely consolidated, poorly to moderately sorted, sandy till and well sorted coarse to medium sandy gravel with scattered lenses of silty sand that could not have survived overriding erosion by the LIS. Thus, its location, hummocky cross-valley topography, loosely-consolidated deposits, and apron of abandoned distributary drainage away from the cirque mouth suggest it could be a terminal moraine emplaced by a cirque glacier after departure of the LIS from the area. This proposal is also supported by evidence below the landform on the valley's floor. Deposits there show its emplacement displaced and temporarily dammed the pre-existing Peabody River creating an ephemeral lake. This lake quickly filled with deposits of moderately well-sorted loosely-consolidated sand and gravel derived from the feature's nearby slopes that could similarly not have survived overriding LIS erosion (Fowler, 2011, 2013; Fig. 4).

The higher elevation and less extensive landform is a group of similarly boulder-strewn (to 12 ft. diameter) gravelly hillocks that form a cross-valley ridge on the central floor of the cirque (Fig. 4; Fig. 5). Its deposits again consist of loosely consolidated, poorly to moderately sorted, sandy till and well sorted coarse to medium sandy gravel and silty sand. Its location, hummocky cross-valley topography, and abandoned down-cirque distributary drainage apron suggest it could be a recessional moraine deposited after departure of the LIS and during retreat of the cirque glacier.

Figure 5: View west from Great Angel Station, Great Glen Trails system. Proposed recessional moraine is visible as the flat cross-valley feature to the immediate left of the lone pine tree in the right-center of the image. B.K. Fowler photograph.

Fowler (2013) proposed these landforms are moraines using the following rationale. Earlier but just recently published findings of Thompson, et al. (2017 and Fig. 3), suggest that near-glacial conditions may have existed in the region immediately following departure of the LIS and due to its close proximity during the now confirmed nearby stillstand. Such conditions may have permitted equilibrium-line altitudes to remain beneath the floors of the favorably oriented higher elevation cirques of the Great Gulf complex for time sufficient to maintain or reactivate residual ice movement. The cirques in the complex (Fig. 2; Great Gulf, Sphinx Basin, Jefferson Ravine, and Madison Gulf) have the highest elevations and areally largest composite basins in the region and their individual cirque axes face away from maximum solar isolation. Thus, the newly identified landforms below and within the complex could be moraines related to post-LIS cirque glaciation, especially since their cross-valley topography and loosely consolidated deposits could not have survived, and thus must post-date, its overriding erosion.

Fowler (2013) investigated and preliminarily discarded two alternate proposals for the emplacement of these landforms (Fig. 6). The first was that the lower feature was emplaced by readvance of LIS ice in the valley below the cirque. This was rejected for three reasons. First, surficial mapping there failed to detect evidence of readvance between the feature and the White Mountain Moraine System to the north (Fowler, 2012). Next, reconnaissance observation of stone clast provenance on the landform failed to detect elevated percentages of the distinctive two-mica granite over which readvancing ice would have passed (Dulin, 2011; Fig. 6). And finally, the loosely-consolidated deposits of the ephemeral lake dammed by the landform could not have survived erosion by such a valley readvance.

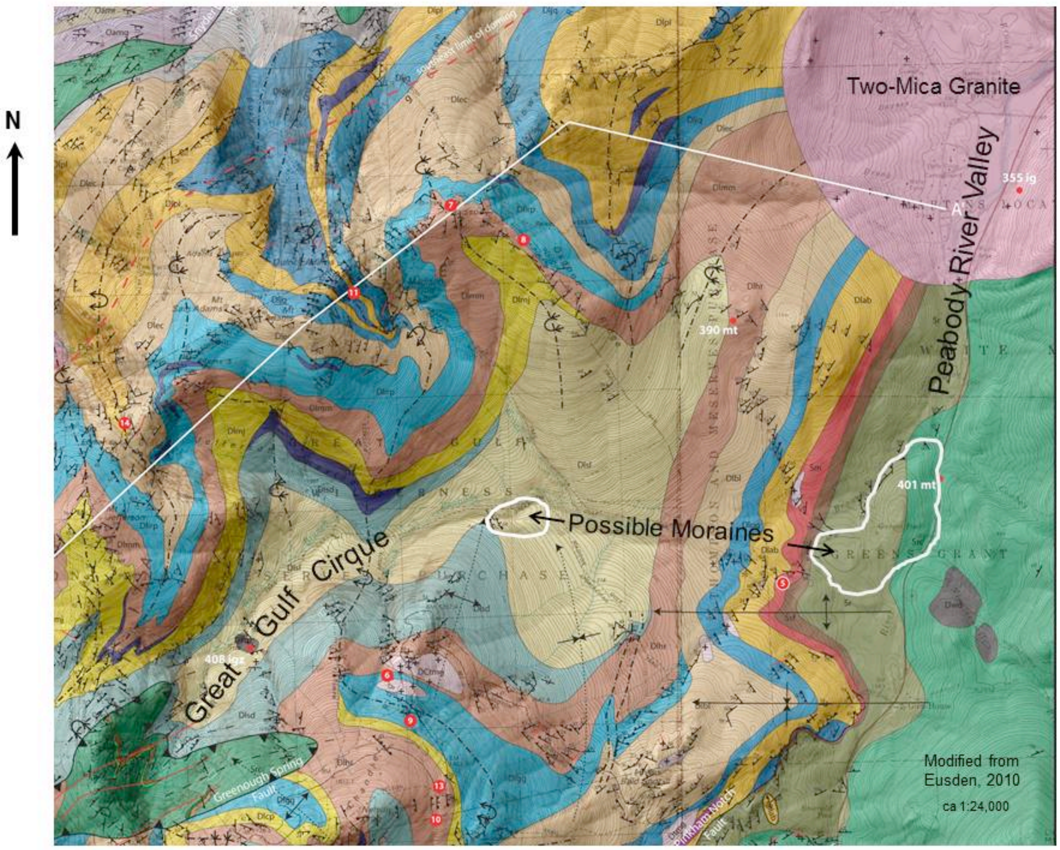

Figure 6: Bedrock geology, lower Peabody River valley showing the locations of the proposed terminal moraine and the circular body of two-mica granite to its north northeast in the valley through which any LIS readvance would have passed. From Fowler, 2013.

The second proposal was that the lower landform was deposited from masses of stagnating LIS ice in its immediate vicinity following retreat of the ice sheet (Fowler, 2013). This idea was also discarded for three reasons. First, the very large angular boulders on its surface do not reflect the degree of comminution and surface abrasion typical of long-term entrainment in an ice sheet. Next, its constituent deposits are not the largely unsorted, densely consolidated, and heavily comminuted till typically created within an ice sheet. And finally, the well-developed, unidirectional distributary drainage pattern across the feature is not consistent with the multi-directional patterns typically observed in the region where large masses of stranded ice are known to have down-wasted (Goldthwait and Mickelson, 1982).

Meanwhile, Dulin (2011) completed a stone clast provenance study of samples taken from till across the lower landform. The study included 250 unsorted clasts from 5 locations and determined their provenance by laboratory comparison with known lithologies in the region as established by Eusden (2010; Fig. 6). Results showed that the clasts include lithologies of both local and regional provenance, but clasts uniquely sourced from within the Great Gulf cirque support the interpretation that they were deposited by processes dependent on the presence of a local glacier in the cirque after the departure of the LIS as proposed by Fowler (2013). The study concluded that its results along with the pronounced topography and cross-valley location of the lower landform support the interpretation that it is a terminal moraine.

Much work remains to be done on these landforms and their genesis. Further stone clast provenance studies are being considered, as is cosmogenic nuclide exposure dating of boulders on the features to determine the date of their melt-out and emplacement. The coming availability of LiDAR imagery for the region will be of great value for further mapping and interpretation.

FIELD TRIP HIKING LOG

The trip consists of an easy to sometimes moderate ~ 4.5 -mile roundtrip hike to the Great Angel Station Lookout on the Great Glen Trails System to examine landforms traversed by the hike and visible from the Lookout (weather-permitting) that may represent terminal and recessional moraines in the cirque. The trip begins in the North Parking Lot at the Mt. Washington Auto Road (MWAR: 322363.00 m E / 4906302 m N) Base Lodge on the east side of NH Rte. 16, 8 miles south of Gorham, NH. Figure 7 shows this location along with the trail stops included in the field trip.

PLEASE NOTE:

Motorized vehicles are not permitted on the Great Glen Trails System. Because of frequent trail maintenance, periodic sporting events, and sometimes unfavorable weather, parties interested in foot access to the system must check-in and obtain an up-to-date trail system map at the MWAR Base Lodge.

Sturdy footwear and a backpack with water, snack items, and clothing appropriate for the day and potential seasonal weather are required for this trip.

Meanwhile, the following geologic maps will be helpful:

Bedrock Geology of the Presidential Range, New Hampshire (Eusden, 2010)

Surficial Geology, Mount Washington and the Presidential Range, New Hampshire (Fowler, 2011).

Stop 1: MWAR North Parking Lot.

This Stop provides a dramatic view into the lower reaches of the Great Gulf cirque complex and of the surrounding peaks of northern Presidential Range (left to right: Mt. Washington, 6,288 feet; Mt. Jefferson 5,712 feet; Mt. Adams 5,774 feet; and Mt. Madison, 5,367 feet). Refer to the text above for general descriptions of the Great Gulf cirque complex, possible local glaciation within the complex, the nature and formation of the possible moraines, and the ephemeral lake the lower landform dammed during its emplacement.

Walk south to the MWAR Base Lodge building and then right to its west side and enter the pedestrian tunnel under NH 16. After emerging from the tunnel, follow short but intersecting segments of Nordic ski trails across the bottom of the now-dry bottom of the ephemeral lake to Intersection 2 (see Fig. 7). From this Intersection, continue along a combination of Nordic ski trails over the surface of the proposed terminal moraine landform, passing trail Intersections 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 and the proposed terminal moraine (see Figs. 4 and 7).

Stop 2: Great Angel Station.

This Stop provides a viewpoint into the central portion of the Great Gulf cirque complex and in particular of the cross-valley location of the proposed recessional moraine (see Figs. 4 and 5). Refer to the text above for descriptive information. Here the West Branch of the Peabody River has been diverted to the north by a bedrock outcropping and the ice-proximal slope of the landform that appears to have been emplaced against it.

Return to Intersection 55 and proceed along the ski trail to Intersection 56 and Stop 3.

Stop 3: Drifter Stone Count Site.

This Stop and Stops 4 and 5 visit sites typical of clast provenance in cirque-ice proximal and distal locations on the proposed terminal moraine and then at a location outside its topographic limits (see Figs. 6 and 7, Eusden, 2010, and Dulin, 2011). The following information is pertinent to each of these Stops.

In order to determine where the material in the landform was derived, the study conducted by Dulin (2011) attributed stone clast provenance to Cirque, Northern, Adjacent, or Erratic sources based on their petrography compared with those mapped in the region by Eusden (2010). The two-mica granite that outcrops directly to the north of the landform was used as the Northern indicator (Fig. 6; DCtmg). The Rangeley Formation (Sr and Src) was used as the Adjacent indicator even though it outcrops both within the cirque and to its immediately adjacent north. Only lithologies outcropping exclusively within the cirque were used for the Cirque indicator. These include the Littleton (Dl), Madrid (Sm), Smalls Falls (Ssf) Formations, a granite-diorite (Dwd), and various pegmatites. Clasts not identifiable or not associated with these indicator lithologies were considered erratic as shown in Table 1 and discussed below.

Table 1

Clast Provenance - Proposed Terminal Moraine

(%)

Test Pit	Erratic	Cirque	North	Adjacent
Drifter	39	47	2	12
Wilding	52	21	17	10
Thumper 1	26	6	12	56
Thumper 2	57	36	0	7
Combined	48	26	7	19
Libby*	36	0	62	2
* Off The Landform			Data Per Dulin, 2011	

The relatively high percentage of erratic clasts in the landform is attributable to the presence of residual LIS till left within and near the cirque. If post-LIS cirque activity took place, this till would be eroded out of the cirque first and before any of its bedrock, and would thus make up a significant part of the material in a post-LIS landform.

Adjacent clasts (e.g. Rangeley Fm.) are located both north of the landform and on its cirque-side suggesting they could have been deposited by either or both the LIS and post-LIS cirque activity. Thus such clasts are not diagnostic of either mode of deposition, and reliance must be placed instead on percentages of Cirque and North clasts to establish the source locations.

The Libby Site is presented separately at the bottom of Table 1 to show clast provenance typical of terrain that lies beyond the mapped limits of the proposed terminal moraine. The Site's clasts are dominated by those of northerly provenance, principally two-mica granite (see Fig. 6; DCtmg), suggesting they were deposited by the LIS as it advanced into the area from the north. This contrasts distinctly with the Combined results (Table 1) of samples from the landform which show a marked paucity of two-mica granite and an abundance instead of clast types related to emplacement processes that appear unrelated to the LIS. If the landform were emplaced by the LIS moving from the north in a readvance, the provenance of clasts across its surface would resemble the Libby Site's distribution.

The Drifter and Wilding Sites are located at positions that would have been proximal to glacial ice possibly advancing out of the cirque, with the Wilding Site (not visited by this trip) located several hundred meters south southwest of Drifter. Clasts at both Sites show a distinct abundance of Cirque clasts, but both also show the presence of clasts likely arising from residual till.

The Thumper 1 and 2 Sites are located at positions that would have been distal to glacial ice advancing out of the cirque, with the Thumper 1 Site (also not visited) located a few hundred meters northeast of Thumper 2. Clasts at Thumper 2 show an abundance from the Cirque, while those at Thumper 1 show abundance from residual till and nearby outcrops.

When results from the Drifter, Wilding, Thumper 1 and 2 Sites are combined (Table 1), the influence of cirque ice appears more clearly. Clasts of Cirque origin comprise 26% of the total with only 7 % clasts of North origin and 19% of Adjacent origin. This significantly higher percentage of Cirque clasts as compared to North clasts supports the proposal that the landform was emplaced by active ice processes within the Great Gulf as opposed to a readvance of the LIS from the north.

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

Stop 4: Thumper 2 Stone Count Site.

Please refer to Table 1 and discussion above.

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

Stop 5: Libby Stone Count Site.

Please refer to Table 1 and discussion above.

From Intersection 27, proceed along the Libby Trail to Intersection 19 and Stop 6.

Stop 6: Rangeley Boulder and Adjacent Boulder Fields.

This enormous boulder is comprised of rusty schist of the Lower Silurian Rangeley Formation (Sr and Src), whose closest outcrops capable of producing such a massive block are located on open cliffs approximately 1/2 mile to the west along the lower southerly walls of the cirque mouth. Its moderately subdued facets and generally but lightly abraded surfaces, along with its moderately weathered appearance, suggest it was not transported to its present location by a fast-moving mechanism like a debris flow. Blocks within such flows in the region generally appear much more sharply faceted, with only locally abraded areas on their surfaces, and with little surficial weathering. The process that transported this block appears to have consisted of a much slower-moving mechanism that permitted the block's original facets to be moderately subrounded, its surfaces to be generally not locally abraded, and in contact with sufficient moisture to begin weathering its iron-bearing minerals. Being plucked from or otherwise falling onto, and then becoming incorporated within, a mass of active glacial ice moving toward the east from a cliff location appears a more viable candidate for this deposition mechanism with the time spent in the moving ice sufficient to create the features and general condition observed.

Meanwhile, smaller boulders found on boulder fields scattered elsewhere on this landform consist of this same lithology along with erratic lithologies that outcrop at locations higher up in the lower portion of the cirque (see Eusden, 2010). Most distinctive of these are members of the Devonian Littleton Formation (Dl), some of which have been transported to locations east of NH 16 in the vicinity of Nineteen Mile Brook (see Fig. 7 and Fowler, 2011). As indicated, much work remains to be done related to these "relocated" and erratic boulders before their use as positive evidence for post-LIS cirque glacial activity can be confidently established.

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: The Peabody River Channel.

This Stop provides a viewpoint across the present-day channel of the Peabody River that was relocated to this position by the emplacement of the proposed terminal moraine and then eroded to nearly its current dimensions at the time the ephemeral lake catastrophically drained. The residual and largely flat bottom of the lake is located immediately south of the Stop, and the loose gravelly nature of the deposits eroded by the drainage process can be observed on the channel slopes.

From Stop 7, proceed back to Intersection 2 and turn left onto the “Glen Meadows Sluice” trail (see Fig. 7) and follow it to its intersection with the “Geepers” trail on the right. Turn right on this trail and follow it south to the pedestrian tunnel which leads back to the MWAR Base Lodge and parking lot.

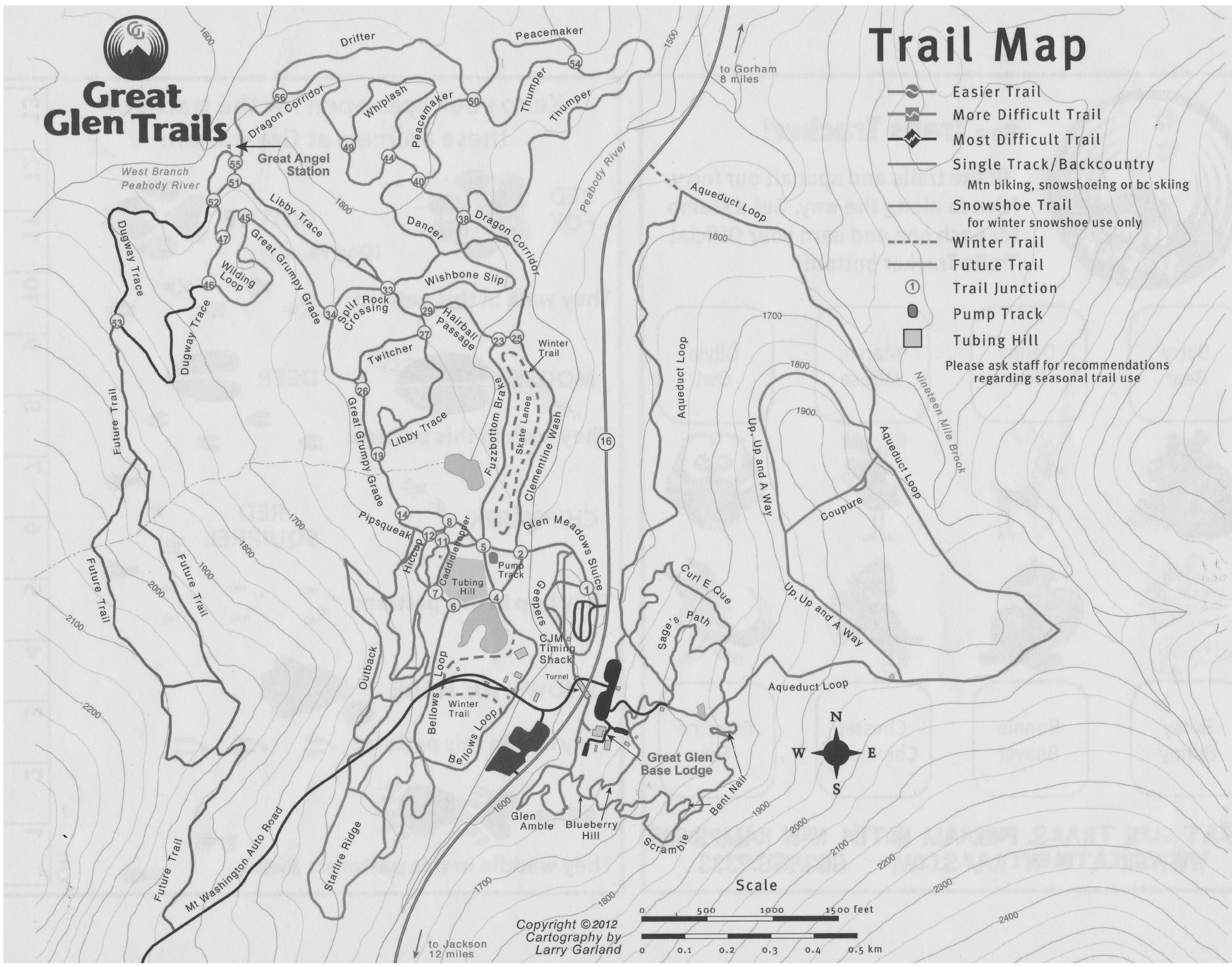

Figure 7: Map of the Great Glen Trails System.

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