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Was Mount Taylor glaciated in the Late Pleistocene? An analysis based on field evidence and regional equilibrium line altitudes

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Abstract

Since reconnaissance work in the early 20th century, the existence of Pleistocene glaciers on Mount Taylor has been recognized in compilations of Rocky Mountain glaciation. This eroded composite volcano stands alone as the most prominent topographic element of the Colorado Plateau in west-central New Mexico. Its highest elevations, however, rise only a few hundred meters above the lowest late Pleistocene equilibrium line altitudes (paleo-ELAs) in the region, and potential cirques on the mountain are at best weakly developed. The valley head most likely to be a cirque lies just northeast of La Mosca Peak. We found possible terminal moraines in this valley floor; alternative interpretations of these bouldery features as rock glacier toes or landslide deposits appear less probable, but cannot be ruled out. A search for striated clasts or bedrock in this area was unsuccessful, but fractured andesitic rocks such as those on Mount Taylor do not typically preserve such features. Using the possible moraines to reconstruct a small cirque glacier yields an equilibrium line altitude of approximately 3,220 m by the accumulation area ratio method, within the regional range of paleo-ELAs. Pleistocene glaciation on Mount Taylor remains uncertain, but is unlikely to have occurred for any significant period in the eastern amphitheater of the mountain where it was previously inferred.

Introduction

As New Mexico's only large Neogene composite volcano, Mount Taylor dominates the landscape of a major volcanic field in west-central New Mexico (Fig. 1). Several compilation maps of Pleistocene glaciation in the western USA show that Mount Taylor hosted glacial ice (Montagne 1972; Porter et al. 1983; Pierce 2004). In most of these wide-ranging reviews, the source of information for Mount Taylor is not specifically cited, but it appears to stem from the early overview of glaciation in New Mexico by Robert W. Ellis (1935). Mount Taylor's summit elevation is 3,446 m (11,305 ft), and valley heads on the peak lie between 3,200 and 3,350 m. Regional cirque floor elevations and reconstructed late Pleistocene glacial equilibrium line altitudes (paleo-ELAs) in Arizona and New Mexico commonly lie between about 3,150 and 3,400 m (Pierce 2004; Poellot 2001; this study). Thus, it is reasonable to hypothesize that Mount Taylor supported small glaciers in the late Pleistocene, or during earlier cold stages in the Quaternary period. Yet, Ellis (1935) noted that evidence for glaciation on Mount Taylor had been questioned, without reference to other work. In his classic publication on Cenozoic geology of the Colorado Plateau, Charles B. Hunt (1956, p. 38) noted simply that "in the Henry Mountains, Abajo Mountains, and Mount Taylor no moraines have been recognized," but did not cite Ellis (1935), and provided no further observations regarding glaciation on Mount Taylor. To our knowledge, no subsequent study has specifically tested Ellis' (1935) hypothesis. So the question remains—was Mount Taylor glaciated? Here we discuss recent field observations and provide regional context to address this question.

Study Area and Background

The high cone of Mount Taylor is a composite volcano constructed primarily of trachydacite to trachyandesite flows and local intrusive rocks. Lava flows and volcanoclastic sediments

predominate, with smaller volumes of rhyolitic pyroclastic rocks (Perry et al. 1990; Goff et al. 2012). Most of the rocks of the Mount Taylor volcanic field are between 3.3 and 1.5 million years old, but the bulk of the cone formed between 3.3 and 2.5 million years ago (Perry et al. 1990). The eastern side of the mountain, at the head of Water Canyon, is the site of a large amphitheater-like basin (Figs. 2 and 3). Crumpler (1982) proposed that this basin formed by a lateral blast eruption similar to the May 18, 1980 Mount Saint Helens event, which was accompanied by a sector collapse and massive debris avalanche. In contrast, Perry et al. (1990) note that the narrow mouth of the amphitheater, lack of debris avalanche deposits, and relatively gentle constructional slopes of 10–12° are inconsistent with a sector collapse. They instead suggest that the amphitheater is the result of breaching of the eastern side of a summit crater, followed by major enlargement by erosion. The maximum elevation of the summit before erosion is highly uncertain, but may have been between approximately 3,650 and 4,270 m (Crumpler 1982). Along with major denudation of Mount Taylor after construction of the composite cone, drainages in the area have downcut on average about 250–300 m in the past 3 million years (Lipman and Mehnert 1979). South of Mount Taylor, the base of the Horace Mesa basalt marks the former position of the Rio San Jose, and total relief from that level to the bedrock valley floor, which is buried in approximately 50 m of post-170 ka alluvium, is approximately 400 m (Love 1989; Love and Connell 2005).

Given the greater potential for preservation of younger glacial deposits, we consider that evidence for late Pleistocene glaciation of Mount Taylor is the most likely to exist. The late Pleistocene extends from 126 ka to 11.7 ka, encompassing marine oxygen-isotope stages (MIS) 5 through 2, and includes glacial stages 4 and 2 (Gibbard et al. 2005). The last global glacial maximum (LGM) occurred in MIS 2 between 26.5 and 19 ka, or generally ca. 21 ka, when continental ice sheets achieved their greatest volume (Clark et al. 2009). Given regional climatic differences and local intrinsic controls, however, maximum advances in the Rocky Mountains may differ significantly in timing from global glacial maxima, and occurred as late as approximately 15 ka (e.g., Gillespie and Molnar 1995; Licciardi et al. 2004; Thackray 2008; Clark et al. 2009; Young et al., 2011). For convenience, we refer to generally well-preserved glacial moraines in New Mexico and the region as late Pleistocene in age. Some of these mostly undated moraines may mark earlier advances, however, e.g. during late MIS 6 (ca. 140 ka). In the Rocky Mountains, these earlier advances were commonly somewhat more extensive than during the last glaciation (e.g., Pierce 2004).

Mount Taylor has two main peaks: the main summit at 3,446 m elevation, and La Mosca Peak at 3,360 m, 1.8 km to the northeast (Figs. 2 and 3). La Mosca Peak is the site of a fire lookout and several radio towers. In his brief discussion of evidence for glaciation on Mount Taylor, Ellis (1935) focuses on the large east-facing amphitheater below these summits. Without giving specific locations, he notes steep valley heads on the western and southwestern slopes of the amphitheater (i.e., those with east to northeast aspects), and states that, "it is the opinion of the writer that they are cirques" (p. 23). Ellis also notes that, "no sure morainic deposits are found in the valleys below,

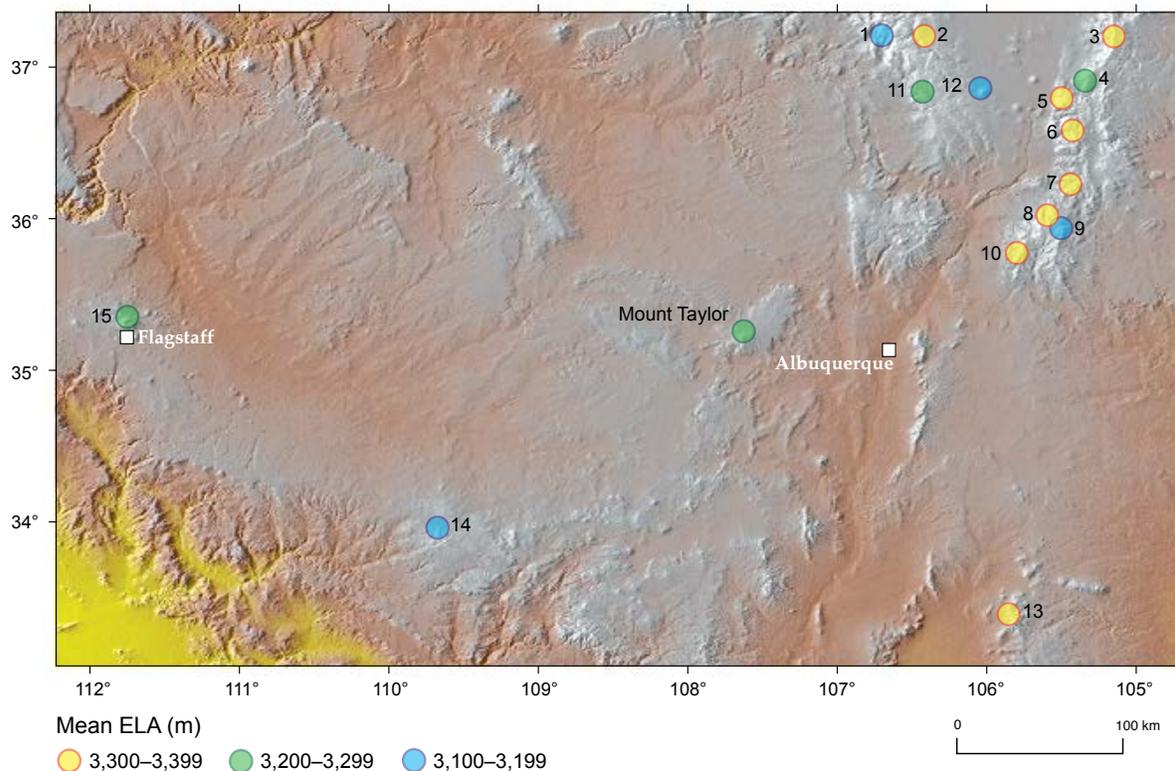


Figure 1—Digital shaded relief map showing location of Mount Taylor, and mean equilibrium line altitudes (ELAs) generalized for north- to east-facing small late Pleistocene glaciers 448 in mountain areas in the surrounding region. Numbered areas are 1—Navajo River and 2—Conejos River areas, San Juan Mountains; 3—Culebra Range; 4—Costilla Peak; 5—Latir Peak; 6—Taos Mountains-Wheeler Peak; 7—Cerro Olla; 8—Truchas Peaks; 9—Gascon Point; 10—Santa Fe Range; 11—Grouse Mesa; 12—San Antonio Mountain, where glaciation and ELA are tentative; 13—Sierra Blanca; 14—White Mountains; and, 15—San Francisco Peaks. ELA data are from Refsnider et al. (2009) for 1–3; from this study for 4–14, aided by mapping of Richmond (1962) for 13 and Merrill and Péwé (1972) for 14; and from Poellot (2001) for 15.

although there are alluvial deposits that resemble glacial drift” (p. 24). This description leaves his interpretation of depositional process quite uncertain, and no specific location or description of the morphology of these deposits is given. Thus, observations by Ellis (1935) supporting glaciation on Mount Taylor are limited to possible cirque-like valley heads, and the overall discussion is largely inconclusive.

Based on precipitation maps generated by the PRISM model (Daly et al, 2008) from the Western Regional Climate Center <http://www.wrcc.dri.edu>, modern mean annual precipitation on the higher elevations of Mount Taylor is estimated at ca. 800–900 mm, similar to the high Taos Mountains in the Sangre de Cristo Range of New Mexico. The closest SNOTEL site to Mount Taylor is at Rice Park in the Zuni Mountains 60 km to the west, at 2,579 m elevation. There, mean annual precipitation is about 540 mm, with about 35% of this total contributing to snowpack accumulation between December 1 and March 1. The greater potential for snow accumulation on Mount Taylor is clear from its substantially higher elevation; it is also supported by casual observations of a more persistent snow pack, and of NEXRAD radar maps, which commonly show precipitation centered there at the same time that neighboring areas, including the Zuni Mountains, show little precipitation.

Methods

We conducted field reconnaissance of the higher elevations of Mount Taylor in search of glacial erosional and depositional features. Possible moraines and other features were located with a handheld GPS, and measurements of height and slope angle were made using a Brunton compass. Longitudinal profiles of possible cirques were constructed using digital topographic maps with 20-foot contour intervals. Analysis of late Pleistocene

paleo-equilibrium line altitudes (paleo-ELAs) included data compiled and generalized for all known glaciated ranges in New Mexico, Arizona, and southernmost Colorado, including the Culebra Range of the Sangre de Cristo Mountains and southern San Juan Mountains (Fig. 1). Published late Pleistocene paleo-ELA data were used where available (Poellot 2001; Refsnider et al. 2009). We estimated other paleo-ELAs by interpretation of glacial erosional features and late Pleistocene moraines on 1:24,000 scale digital topographic maps, allowing mapping of paleoglacier perimeters, aided by published maps of moraines where available (Richmond, 1962; Merrill and Péwé, 1972). Reconstructed paleoglacier areas were measured using topographic map software, and paleo-ELAs were estimated using the accumulation-area ratio method (AAR), assuming an accumulation area equal to 0.65 of the total glacier area (e.g., Meier and Post 1962; Meierding 1982; Locke 1990).

Observations and Interpretations

Possible Glacial Erosional Features

We initially examined the eastern amphitheater of Mount Taylor for evidence of cirque morphology. Some of the higher-elevation valley heads are somewhat rounded in map view, but none shows the characteristic smoothly concave long profile of a cirque that reflects a steeper headwall and gentler floor (Figs. 2 and 3), and rounded valley heads alone are also found in a wide variety of nonglacial geomorphic environments. The highest valley head, in a small, narrow east-facing drainage directly below the main summit of Mount Taylor, has neither rounded form nor

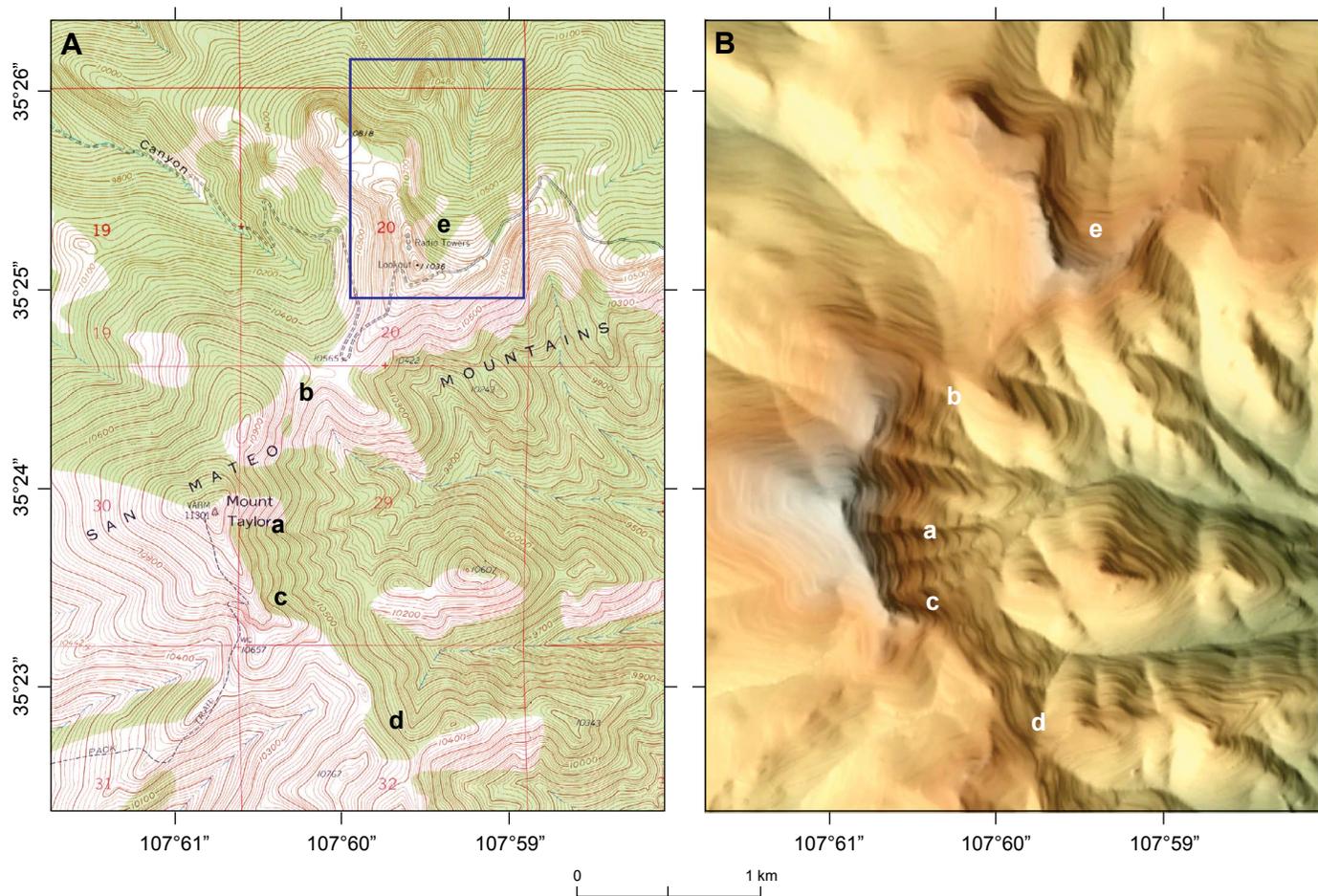


Figure 2—A—Topographic map of the higher elevations of Mount Taylor, including the main summit and La Mosca Peak. Base from USGS Mount Taylor and Cerro Pelon 7.5' quadrangles in Terrain Navigator software. B—shaded relief image of the area in A generated from 10 m DEM. Locations a–d (discussed in text) are valley heads in the eastern amphitheater, the general area where Ellis (1935) inferred that cirques exist (considered unlikely in this study). Location “e” is the La Mosca valley head; blue box encloses area of Figure 4.

headwall-floor morphology (Figs. 2 and 3, location a). The most rounded valley head has an almost directly south-facing aspect, highly unfavorable for ice accumulation, and the relatively dry microclimate there is also reflected in a lack of forest cover (Figs. 2 and 3, location b). Other valley heads with more favorable aspects are not rounded (Figs. 2 and 3, location c), or have little long-profile concavity and lie at significantly lower elevations (Figs. 2 and 3, location d).

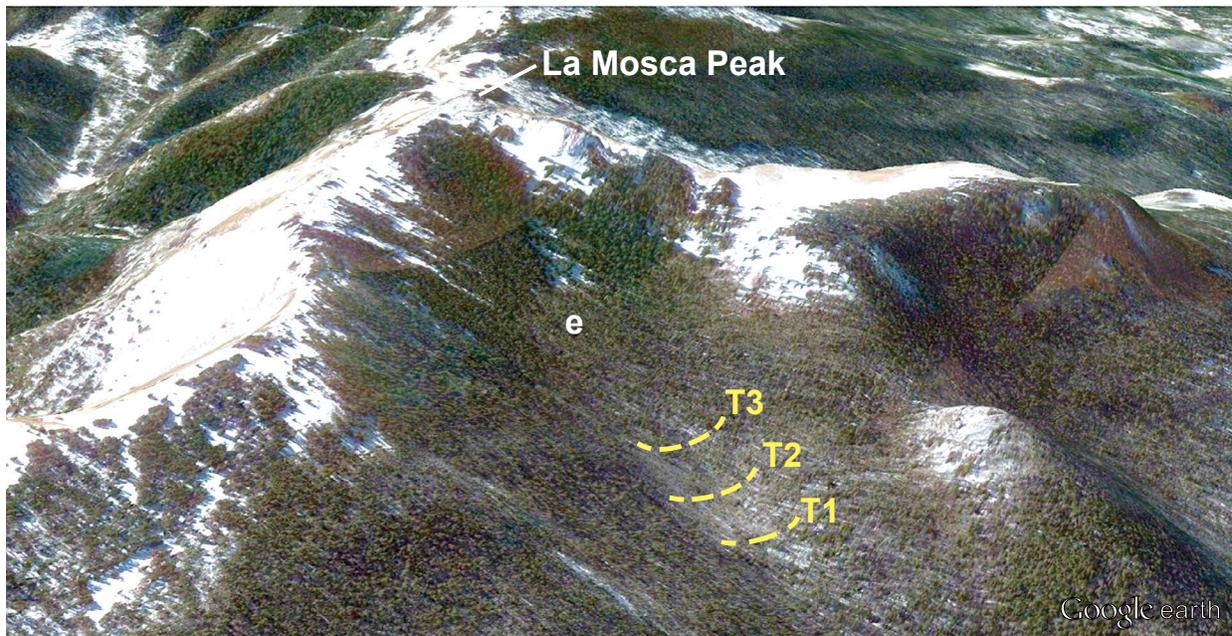
Along with a lack of cirque morphology, upper slopes in the eastern amphitheater are almost entirely mantled by colluvium with a substantial fine-grained component, with very little bedrock exposure or blocky, openwork talus. This suggests that if glacial erosion has ever occurred in the past, it was long ago and small in magnitude, such that slopes have since stabilized and established a colluvial soil cover that includes significant fines from eolian dust deposition, as is well documented in the Jemez Mountains to the northeast (McFadden et al. 1996; Eberly et al. 1996; Watt 1996). Thus, despite the conclusions of Ellis (1935), we see little if any suggestion of significant glacial erosion in the eastern amphitheater.

In our view, the most cirque-like feature on Mount Taylor lies at the head of San Mateo Canyon, directly northeast of La Mosca Peak (Figs. 2 and 3, location e; Fig. 4). As it still lacks truly diagnostic cirque morphology (documented below), we refer to this as the La Mosca valley head. With a mean aspect of about 015°, the La Mosca valley head has relatively low insolation and thus a favorable orientation for glaciation; a northeast aspect is the most common facing direction for cirques in the Sierra Nevada and Rocky Mountains, and in the Northern Hemisphere

in general (e.g., Gilbert 1904; Graf 1976; Evans 2007). As with La Mosca Peak, a summit to the southwest also aids in shading the potential accumulation area (Graf 1976). Based on data from the Grants airport (Western Regional Climate Center, <http://www.wrcc.dri.edu>) westerly winds prevail around Mount Taylor during winter months. Assuming similar westerlies during the late Pleistocene, this would aid wind loading of snow in the La Mosca valley head, in the lee of the sharp ridge that bounds the western valley side north of La Mosca Peak (Figs. 2, 3, and 4). The La Mosca valley head is clearly arcuate in plan view, and the western side has a modestly concave long profile, bounded by a steep cliff at its upper end (Figs. 3, 4, and 5). The cliff is at least partly a function of the resistant trachydacite intrusion that makes up La Mosca Peak and the ridge north of the summit, so is not clearly a function of cirque headwall erosion; however, the trachydacite intrusive rocks extend below the cliff and underlie part of the valley floor as well (Goff et al. 2012). The eastern valley side formed on more erodible trachyandesite lava flows, and has little concavity and no upper cliff or headwall (Figs. 3, 4, and 5). The valley floor remains broad down to about 3,060 m elevation, below which it has a clearly V-shaped cross-profile. A length:width ratio of approximately 1.1–1.5 for this valley head uses length measured to the point where the valley becomes V-shaped, as this possible cirque lacks a lip or clear downvalley end point. Although these values are consistent with length:width ratios of many Rocky Mountain cirques (Graf 1976), the measurements are somewhat subjective, and are a non-unique characteristic of cirques. Overall, the modest long-profile concavity and distally sloping floor are consistent with a weakly



A



B

Figure 3—Google Earth views of Mount Taylor and La Mosca Peak using Landsat imagery taken January 20, 2013. A—View from the southeast of the eastern amphitheater of Mount Taylor. Valley heads a–e are also shown in Figure 2 and are discussed in text. Note that in this year with a low snowpack, south-facing slopes in valley head b and elsewhere are free of snow. B—View from the northeast of location “e,” the La Mosca valley head. Yellow dashed lines marked T1, T2, and T3 show locations of bouldery steps discussed in text and mapped in Figure 4.

developed cirque (Gordon 1977; Evans 2007), but not diagnostic of a glacial origin. Thus, the case for glaciation based on valley-scale erosional morphology is equivocal.

The very limited bedrock exposure along the La Mosca valley floor limits the ability to observe erosional features on outcrops. We also found no glacial striations or polish on cobbles and boulders in the valley or on the bouldery steps described below. While some boulders exhibit locally smooth surfaces and possible faceting, most have a rough and pitted weathered exterior (Fig. 6). Whether in outcrop or on clasts, the flow-foliated and fractured trachyandesite and trachydacite in this valley (Goff et al. 2012) are poorly suited to preserving striations and polish, and it is unclear whether these features would be present, even with

unambiguous glaciation. Similarly, Poellot (2001) found no striations on the andesitic rocks of the San Francisco Peaks, despite the fact that multiple glaciations have been well documented in that and previous studies (e.g., Sharp 1942).

Possible Glacial Depositional Features

In investigation of the La Mosca valley head, we found a series of three bouldery steps that cross the valley floor between 3,080 and 3,140 m elevation (10,100 and 10,300 ft; Figs. 3, 4, and 6). The risers of these steps are 5 to 9 m-high, and their steep downvalley (distal) slopes have angles measured between 22° and 28°. Trachyandesite and trachydacite boulders up to 2 m

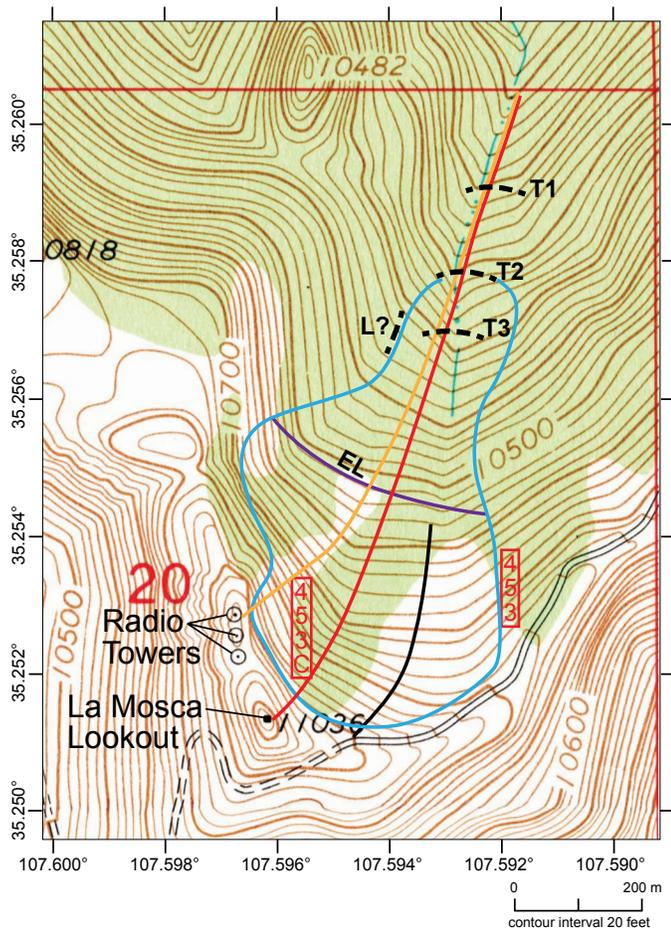


Figure 4—Topographic map of the La Mosca Peak area and valley head to the northeast (a possible cirque basin, labeled “e” in Figures 2 and 3). Yellow lines show bouldery steps that may be terminal (T1, T2, T3) and lateral (L?) moraines. Blue line shows the reconstructed glacier perimeter using the possible lateral moraine and associated possible terminal moraine as the best indicators of a terminus location. Purple line (EL) is the reconstructed equilibrium line. Orange, red, and black lines are locations of longitudinal profiles in Figure 5. Base from USGS Mount Taylor and Cerro Pelon 7.5' quadrangles in Terrain Navigator software.

in diameter are common on these distal slopes (Fig. 6), much more so than on the rest of the valley floor. The boulders are predominantly subrounded to subangular and show possible facets, but again are weathered and pitted and no diagnostic striations were observed. Thus, we infer that glacial transport of these boulders is possible but uncertain. Surface runoff is actively cutting a few gullies up to 2 m deep through the steps, which produce knickpoints along the small ephemeral streams draining the valley (Fig. 6B). Upvalley of the steps, the gullies expose dominantly poorly sorted sandy-silty sediment, including larger clasts to boulder size. Gully walls within the steps themselves are thickly mantled by colluvium and fallen trees, but an unstratified and unsorted texture was observed in limited exposures and excavations, consistent with but not unique to till (Fig. 6B). We observed no clear soil horization in the upper part of these deposits, and only some minimal apparent reddening. This suggests a relatively young age, although it may reflect pedogenesis in a mantle of younger eolian and local alluvial material rather than soil development in the boulder deposits themselves. We have observed that horization is also quite weak even in relatively stable footslope colluvial deposits exposed in roadcuts on the upper mountain.

Based on the above observations, the bouldery steps may represent terminal moraines; however, none stands as a cross-valley ridge, and only a minor flattening of slope is present on the proximal side of the steps. If the steps are terminal moraines, any

depression or relief on their proximal side has been entirely filled in by later alluvial sedimentation (Fig. 6b). It is also possible that the lack of distinct moraine crests resulted from slow ablation of a strongly debris-covered glacier snout (e.g., Clark et al. 1994).

Rather than terminal moraines, the step-like morphology may instead represent the steep toes of rock glaciers or largely debris-covered glaciers. Other characteristic morphologic features of rock glaciers such as steep flanks and lateral and transverse pressure ridges (e.g., Clark et al. 1994; Blagbrough 1999) were not observed; however, we note that dense forest prevents observation of valley floor morphology from higher vantage points, or on air photos, and views through the trees are limited (Figs. 3 and 6). The pervasive blocky texture that typifies rock glacier surfaces is essentially absent, although rock glacier deposits may have abundant fine matrix in the subsurface (Wahrhaftig and Cox 1959). Cliffs and talus slopes for generation of the voluminous frost rubble necessary for rock glacier formation are restricted to a small part of the western valley head. The talus is quite limited in area, has abundant fine-grained matrix and eolian mantle, and appears to represent limited rockfall activity. We did locate a small talus flow deposit composed predominantly of subangular trachyandesite boulders to approximately 1 m diameter on the valley side northeast of the bouldery steps, and other localized boulder concentrations on that slope, but none of these were directly linked with the steps.

Interpretation of the steps as the fronts of large landslides is also problematic, again because no lateral deposit margins were discerned, and the surface upvalley of the steps has a lower frequency of large boulders. There are also no mapped mass movement deposits in the La Mosca valley head (Goff et al. 2012). We have not observed any landslide headscarps above the steps, nor any sackungen indicating deep-seated instability. We also considered the possibility that the steps represent ledges of weathered material formed by resistant flows in the volcanic stratigraphy, but they have no corresponding expression on the valley sides and appear entirely formed of unconsolidated material, with no indication of bedrock outcrop, including near the crest where exposure is most likely. The subrounded boulders are also inconsistent with a local bedrock outcrop.

If the steps indeed represent terminal moraines, a possible associated lateral moraine exists along the western valley margin upvalley of the middle step. This feature slopes gently downvalley and has more abundant boulders than the valley floor in general, but is more like a lateral step or terrace than a ridge, again indicating that any pre-existing depression between it and the valley side has been largely filled in. Overall, the floor of the La Mosca valley head is continuously mantled by poorly sorted surficial deposits, mostly with a silty to sandy matrix. A significant amount of this fine-grained matrix likely represents younger eolian materials (e.g., McFadden et al. 1996). These observations indicate that talus and colluvium are not being generated at high rates at present, but that periglacial activity was likely much greater during the late Pleistocene (Blagbrough 1999). They also suggest that subsequent dust deposition rates were high. Although the steepness of the bouldery steps and lack of clear soil development in the associated deposits suggest a relatively young age (e.g., Colman and Pierce 1986), it may also be that if glaciation of this valley occurred, it was prior to the last glaciation (MIS 2), allowing subsequent modification by periglacial, alluvial, and eolian processes.

Relation to Regional Equilibrium Line Altitudes

As noted above, the highest elevation valleys on Mount Taylor lie near equilibrium line altitudes estimated for late Pleistocene glaciers in New Mexico and Arizona. To address the potential for glaciation in the La Mosca valley head, we reconstructed a small glacier there via the AAR method, again assuming an accumulation area of 0.65 times total area, and using the middle step and

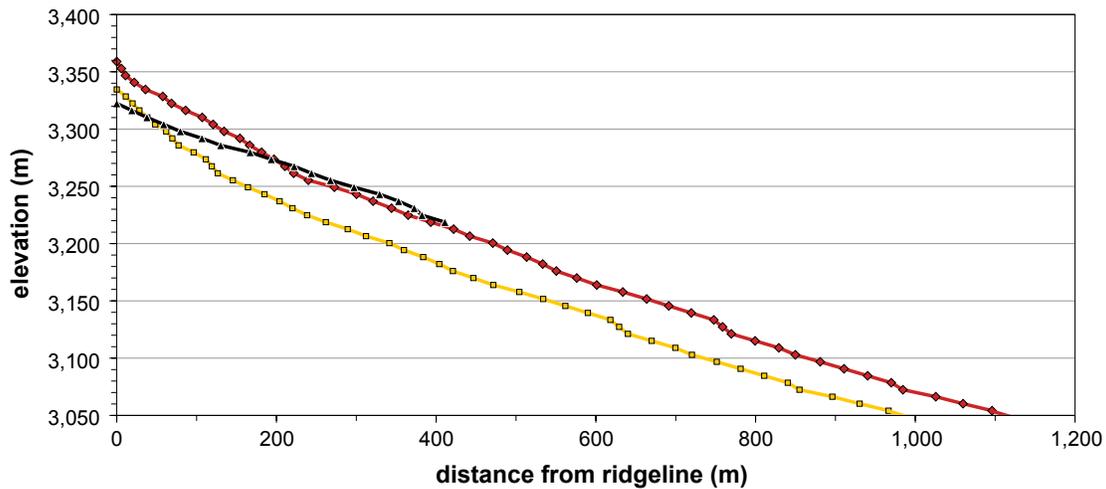
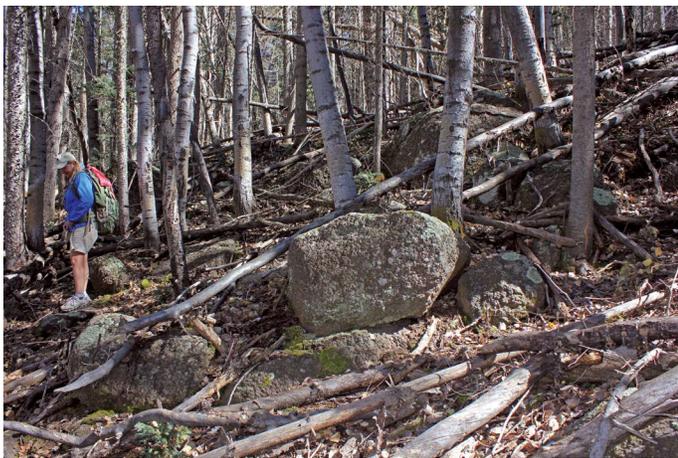


Figure 5—Longitudinal profiles along the La Mosca valley head derived from the USGS Cerro Pelon 7.5' quadrangle; locations are shown with corresponding colors in Fig. 4. Steps in profiles at approximately 3,125 m elevation lie just above the T2 bouldery step, and may not represent the observed step, as dense forest cover over the valley floor (Fig. 3) appears to limit accuracy of topographic contours.



A



B

Figure 6—Photographs of the T2 bouldery step in the La Mosca valley head, used to locate the terminus of the reconstructed glacier in Figure 4. A—Midslope area of the central step showing large trachyandesite boulders. B—View up gully in the eastern side of the T2 step, showing unsorted deposit with subrounded to subangular boulders and finer-grained matrix, and the dominantly fine-grained deposit located up gully from crest of step and main bouldery deposit.

nearby possible lateral moraine as the best available evidence to locate the terminus (Fig. 4). The reconstructed paleoglacier has an area of 0.22 km², and an equilibrium line altitude of about 3,220 m (approximately 10,570 ft; Fig. 4). To check on this paleo-ELA reconstruction, basal shear stress (τ_b) near the equilibrium line was estimated using the equation:

$$\tau_b = \rho g h \sin \alpha F \quad (1)$$

where ρ is ice density, g is gravitational acceleration, h is ice thickness, α is ice surface slope approximated by valley slope, and F is a glacier shape factor to account for drag along valley walls (Paterson 1994). About 3–5 m of postglacial sediment infilling of the valley floor was assumed based on the lack of relief above the bouldery steps, adding to the estimated ice thickness. The resulting basal shear stress of about 50–55 kPa is at the low end of the range of typical values for an alpine cirque glacier (Paterson 1994; Sanders et al. 2010), but is not unreasonable for a thin slab-like ice mass approximately 21–23 m thick with minimal drag on valley sides, as indicated by topography and a shape factor close to 1. Another consideration is that a partial debris cover would slow ablation and allow a lower ELA than on a bare-ice glacier (Clark et al. 1994), thus making the La

Mosca paleo-ELA a minimum estimate. Given the small glacier size, however, the paleo-ELA could only have been some 10s of meters higher.

To compare the La Mosca valley head paleo-ELA with southwestern USA regional values, we used paleo-ELAs for glaciers with similar aspects and sizes, i.e., those in north- to east-facing cirques and small glacial valleys. Most such paleo-ELAs lie between about 3,100 and 3,500 m (Fig. 1), bracketing the estimate for the La Mosca valley head glacier. To the north, in the central and northern Rocky Mountains, Pleistocene paleo-ELAs and cirque floors as well as modern glacier altitudes decline northward in elevation at a rate of about 200 m per degree of latitude (Meier 1961; Porter et al. 1983; Locke 1990). Southwestern paleo-ELAs, however, show no northward trend of lowering even over nearly 4° of latitude. In fact, paleo-ELAs for north- to east-facing glaciers in the Sangre de Cristo Range in northernmost New Mexico and adjacent Colorado lie mostly between 3,300 and 3,450 m (Refsnider et al. 2009), near the high end of the regional range. High variability exists at this latitude, however; for example, relatively low paleo-ELAs between 3,100 and 3,200 m are found on the western side of the southern San Juan Mountains in Colorado, where the mountain front faced into an inferred prevailing westerly moisture transport in the late

Pleistocene (Leonard 1984; Refsnider et al. 2009). To our knowledge, San Antonio Mountain, a large, isolated volcanic dome on the Taos Volcanic Plateau in northernmost New Mexico, has not been previously recognized as glaciated (Fig. 1). Based on topographic map interpretation, however, we infer that the high, doubly concave basin just east of the summit may be a cirque. An estimated paleo-ELA for a glacier there is 3,190 m, but should be considered tentative pending field investigation.

Perhaps surprisingly, some of the lowest paleo-ELAs (approximately 3,150 m) are found in the White Mountains of Arizona, in the southwestern part of the region. The southernmost late Pleistocene glacier in the conterminous USA was on Sierra Blanca Peak in the Sacramento Mountains of New Mexico (Ellis 1935). The glacier had an ELA of approximately 3,350 m based on mapped terminal moraines considered to mark the maximum Pinedale advance, and approximately 3,260 m for the maximum Bull Lake advance (Richmond 1962; Shroba 1991). These relatively low southern paleo-ELAs, and the apparent lack of an obvious latitudinal control, suggest that local to regional temperature differences and (or) precipitation patterns were an overriding influence on southwestern USA glaciation. Increased late Pleistocene precipitation was likely a major influence. Paleoclimatic reconstructions using pluvial lake levels and paleo-ELAs indicate that Last Glacial Maximum precipitation in New Mexico was up to twice that of present, a probable result of southward displacement of the polar front jet stream (Menking et al. 2004; Leonard 2012). The westerly flow of moisture carried by the jet stream may also explain why ranges such as the White Mountains had relatively low ELAs, as they lie farther west, closer to Pacific moisture sources. Episodes of substantially increased precipitation could thus have been a major factor in promoting late Pleistocene glaciation on Mount Taylor, and help to support the paleo-ELA of approximately 3,220 m estimated for the La Mosca valley head glacier, a moderate to low value for the region.

Summary

Although regional paleo-ELAs suggest that late Pleistocene glaciation is plausible on Mount Taylor, direct field evidence for glacial erosion or deposition remains inconclusive. Glaciation in the upper eastern amphitheater is improbable (cf. Ellis 1935) given the lack of glacial erosional or depositional forms there. It is certainly possible that glacial ice may have existed on favorable aspects in the upper amphitheater, but over such a short period that no diagnostic landforms developed. The possible cirque northeast of La Mosca Peak has an elevation and aspect more conducive to glaciation, but its lack of significant long-profile concavity indicates a very weakly developed cirque, if glacial erosion was active. Bouldery steps may represent terminal and lateral moraines in the La Mosca valley head, but these lack clear crests, and cannot be considered uniquely glacial landforms, at least in light of our current observations. Airborne LiDAR imagery would be quite useful in viewing the valley-floor morphology in a more detailed and continuous manner, assuming that the dense forest cover could be filtered out to produce a bare-earth digital elevation model of sufficient resolution. It is also possible that shallow geophysical techniques might also shed more light on the depth and character of deposits.

It might be speculated that the Mount Taylor was glaciated during some period in the early Pleistocene (2.6–0.78 Ma) when the summit area was 200–800 m higher, but it is difficult to envision how this might ever be tested. For now, we conclude that the case for middle or late Pleistocene glaciation on Mount Taylor requires further investigation

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