IMPLICATIONS OF NEW EVIDENCE FOR LATE QUATERNARY GLACIATION IN THE SPRING MOUNTAINS, SOUTHERN NEVADA

RICHARD L. ORNDORFF, Department of Geology, Eastern Washington University, Cheney WA 99004-2439; JOHN G. VAN HOESEN, Department of Environmental Studies, Green Mountain College, Poultney VT 05764; and MARVIN SAINES, Civil Works Inc., Las Vegas NV 89139

ABSTRACT
The Spring Mountains of southern Nevada rise to an elevation of 3650 m above sea level and lie parallel to the western edge of the Las Vegas Valley. For many decades scientists have questioned whether this mountain range was glaciated during the Late Quaternary. To date, however, no one has presented compelling evidence for or against the presence of alpine glaciers in the Spring Mountains. We have identified several glacial deposits in the Spring Mountains northwest of the town of Mt. Charleston and due east of Mt. Charleston peak. The deposits contain faceted and striated clasts, varying in size from gravel to large boulders. As expected in a glacial deposit, the consistency of a preferred orientation for striations increases with increasing clast size and elongation. These deposits bear the hallmark features of a glacial provenance and indicate that the Spring Mountains were the southernmost glaciated range in the Great Basin during the late Pleistocene. Existing regional correlations between latitude and full-glacial equilibrium line altitude indicate that the Spring Mountains should not have been glaciated during the last glacial maximum, approximately 20,000 years ago. The scarcity of depositional evidence seems to indicate that glaciation in the Spring Mountains occurred earlier in the Pleistocene, perhaps corresponding to Tenaya (37,000 years BP), Tahoe (118,000-56,000 years BP), or Mono Basin (older than 136,000 years BP) stages observed in the Sierra Nevada. This range may have benefited from regional recycling of water from upwind pluvial lakes, resulting in a great deal more precipitation than was previously thought to be the case.

INTRODUCTION
Geologists have discussed the possibility of Pleistocene glaciers in the Spring Mountains (Fig. 1) for at least 70 years. The lack of diagnostic evidence of glaciation has resulted in an ongoing debate. Blackwelder (1931:913), states “much more obscure and doubtful indications of glacial action, probably of the Tahoe stage, have been observed by the writer in the Sweetwater, Spring Mountain, Schell Creek, Toyabe, Humboldt, Onequi, and Beaver Ranges of Nevada and Utah.” Blackwelder (1934) reiterated the possibility of Spring Mountain glaciation and suggested the range was too far south to produce Tioga-age glaciers, although canyon morphology led him to believe that glaciers may have existed there during Tahoe or Sherwin stages. Flint (1947) references Blackwelder (1934) in stating that the Spring Mountains held one or more alpine glaciers during the Pleistocene. Flint (1957, 1971) references personal communication with C. W. Longwell to again support the presence of glaciers here, however Longwell et al. (1965) make no mention of deposits or erosional features of glacial origin in the Spring Mountains. Finally, Piegat (1980) states that while no distinct glacial deposits have been found on this range, several landforms at the head of Kyle Canyon appear to be degraded cirques, supporting Blackwelder's 1934 observations. He referenced Burchfiel et al. (1974) who used aerial photographs to map several small alluvial deposits on the east side of Mt. Charleston (located near what appear to be the heads of two degraded cirques) and suggested they may have a glacial origin, but never investigated the sites. We believe two recently discovered unsorted deposits at the head of Kyle Canyon are glacial tills, thus ending this long-standing debate (Van Hoesen and Orndorff 2000, Van Hoesen et al. 2000). Evidence of glaciation in the Spring Mountains impacts our

Figure 1. Location of the Spring Mountains, southern Nevada.
current understanding of regional trends in late Pleistocene equilibrium line altitudes (ELA) in the Great Basin and supports the ideas of local recycling of moisture and nonuniform climate change.

**METHODS**

Between the spring of 2000 and the summer of 2002, we investigated the valleys and ridges above Kyle Canyon for evidence of glaciation. This included fieldwork and interpretation of aerial photography, both black and white at a scale of 1:24,000 and true color at a scale of 1:19,900. This lengthy examination yielded two deposits that we believe to be glacial till (Fig. 2). Bulk sediment samples were collected from the deposits for textural analysis following the guidelines of Gee and Bauder (1986) and Shoenberger et al. (1998). Limestone clasts were collected from the tills for macro-scale analysis and microtextural analysis using a JEOL 5600 scanning electron microscope in the Electron Microanalysis and Imaging Laboratory in the Department of Geoscience at the University of Nevada, Las Vegas. Orientations of surface striations were analyzed using the method outlined by Van Hoesen and Orndorff (2003). Land surface analysis was conducted using GIS to identify areas with the greatest potential for perennial snow accumulation.

**EVIDENCE FOR GLACIATION**

Fieldwork and interpretation of aerial photographs support previous interpretations suggesting the high valleys of Kyle Canyon contain degraded bowl-shaped features that may be cirques. The presence of these large-scale erosional landforms and several unsorted, unstratified deposits with striated clasts supports our hypothesis that the Spring Mountains experienced Pleistocene glaciation.

**Erosional Features**

Many of the early scientists who hypothesized a glacial history for the Spring Mountains based their reasoning on the presence of broad valleys and bowl-shaped depresions at the heads of those valleys. The most prominent and well-preserved such feature is located above the Big Falls nickpoint at approximately 3100 m above sea level. It faces northeast and exhibits a steplike morphology. The bedrock headwall itself lacks unequivocal evidence of glaciation such as striations, chatter marks, and crescentic gouges. There is also an absence of glacial deposits in the upper valley. The upper section of this valley exhibits a U-shaped morphology typical of glaciated terrain. This U-shaped morphology ends abruptly at Big Falls, a nickpoint that we hypothesize to be the retreating margin of a hanging valley. Below Big Falls, the valley exhibits a classic v-shaped morphology that we attribute to fluvial entrenchment.

There are other cirque-like features located at the head of Kyle Canyon. They are not as well preserved and appear to have been exposed to greater rates of weathering and erosion than the Big Falls cirque. There are no striations, chatter marks, or crescentic marks preserved in the bedrock. However, these valleys do exhibit the typical bowl-shaped morphology of glacial cirques. These features are located at approximately 2900 m above sea level, slightly lower than the elevation of Big Falls.

**Kyle Canyon Till**

The first deposit occurs in a northeast facing exposed cutbank in Kyle Canyon, Spring Mountains (Fig. 3). The cutbank, which we believe to be a recent feature resulting from flood runoff within the last several years, is found at the base of a steep north-facing cliff and is at the distal end of a valley that terminates in a stream drainage. It is approximately 14 m thick and extends downslope for approximately 50 m. The lowest portion of the deposit exhibits little evidence of bedding or stratification and contains poorly sorted limestone clasts ranging in size from 0.5 cm to 1 m. Textural analysis of a bulk sediment sample from the face of the deposit indicates it is silt with lenses of gravelly sand.

Most of the limestone clasts contain facets and striations independent of clast size. Thirty clasts were collected from the exposed face of the till deposit, and striation orientations from 15 of these clasts were measured and entered into rose diagrams using the methodology of Van Hoesen and Orndorff (2003). These plots indicate distinct preferred orientations that are parallel to sub-parallel with the primary axes of the clasts (Fig. 4a-c). The consis
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Microtextural Evidence of Glaciation

Previous research concerning the micromorphology of tills primarily focused on individual quartz grains (Mahaney et al. 1991, Mahaney 1995, Mahaney and Kalm 1995, Mahaney et al. 1996, Mahaney and Kalm 2000). Surface textures from these quartz grains were used to determine local ice transport vectors, ice thickness, and depositional environment. Prior studies established that sediment affected by glacial erosion, transport, and deposition exhibits distinct microtextural characteristics. However, these textures are not isolated to glacially derived quartz grains. Almost all of the limestone clasts sampled from the Kyle Canyon till exhibit strongly polished and faceted surfaces containing micro-scale chatter marks, conchoidal fractures, crushing steps, and micro-striations.

Chatter marks are rare but present on the striated clasts. They are visible with both a stereo-microscope and scanning electron microscope (Fig. 4d-g). They are typically oriented parallel to the e-axis, but do occur with a sub-parallel to perpendicular orientation. They are preserved in small lenses of micrite and on surfaces of well-polished clasts. Conchoidal fractures are common on all sampled clasts. Crushing features are the most common microtexture seen on the sampled clasts. They exhibit a strong step-like morphology with little evidence of dissolution and weathering.

SPATIAL ANALYSIS

The Spring Mountain tills indicate that at least two glaciers were present in the Spring Mountains during the late Pleistocene. The exact extent of the glaciers that deposited this material is not known, though spatial analysis provides some clues as to potential locations. Analysis of a conjoined USGS DEM (digital elevation model) with a 30-m grid cell spacing indicates the presence of cirque-like depressions at the head of the main valley and several of its tributaries, features noticed by early researchers who proposed a glacial history for the Spring Mountains. We used GIS to analyze characteristics of the landscape that may have played a role in the accumulation and preservation of perennial snow and ice. This analysis allowed us to predict probable locations for glaciers based on the co-occurrence of favorable topographic characteristics (Orndorff and Van Hoesen 2001). We used GIS to determine slope, aspect (facing direction), and curvature (the second derivative of surface elevation) from the DEM. Large-scale orography itself is an important control because high elevations in a given locality experience cooler temperatures and greater precipitation than lower elevations. This leads to the pres-
Figure 4. Polished, faceted clasts (a-c) from the Kyle Canyon till with rose diagrams illustrating preferred orientation of striations. Microscale features (d-g) on clast surfaces. Structures of glacial provenance include microstriations, crushing steps, crescentic gouges, and chattermarks.
ence of modern snowbanks in Kyle Canyon, which overlooks the extremely arid Las Vegas basin, into late June and even early July.

At the head of Kyle Canyon, slope varies from 0° to 75°. Figure 5a shows a large, curvilinear ridge (which includes Mt. Charleston) defining what may be an ancient cirque. The very steep slopes in the center of the valley outline recent stream incision into the older hypothesized glacial trough. At the very head of the incised portion of the valley we see an east-facing amphitheater and a south-facing amphitheater, separated from one another by a headward-eroding channel; these may be two small cirques and may be related to the Kyle Canyon till. At the head of Big Falls Valley we see two stepped amphitheatres; Big Falls itself represents the upper limit of modern stream incision.

North, northeast, and northwest-facing slopes are shown in darker shades of gray in Figure 5b. At 36° N latitude, these surfaces receive the least solar energy and thus represent optimal zones for preserving snowpack. During the accumulation season in glacial stages, insolation would have been low, presumably leading to deep, compact, perennial snowfields. Of the two bowl-shaped depressions at the head of the incised channel, the east-facing depression lies within the shaded zone, hence it is more likely to have preserved perennial snow and ice than the south-facing depression. Big Falls Canyon lies entirely within the shaded zone. Positive curvature values delineate convex features, and negative curvature values delineate concave features. Figure 5c shows convex peaks and ridges (in black) from which snow is removed by wind and gravity and the concave hollows (in white) into which it collects. Big Falls Valley and the head of the incised channel in Kyle Canyon are concave features that serve as stable catchments for falling snow. The
high, sharp ridge that borders Kyle Canyon is a convex feature. Winds between 30° and 60° N latitude blow predominantly from the southwest, hence snow that falls on the high ridge is most likely to be carried into Kyle Canyon by strong winds, which increase in velocity with increased elevation, and subsequent avalanches.

Figure 5d shows the logical intersection of favorable criteria for preserving snow and ice in white, superimposed on the DEM. White areas are concave, north-facing slopes less than 35°. The head of Kyle Canyon, the stepped bowls in Big Falls Canyon, and Hanging Canyon all have favorable characteristics for collection and preservation of perennial snow. GIS analysis illustrate a surface topography that is not inconsistent with an inferred history of glaciation followed by fluvial incision.

**REGIONAL IMPLICATIONS**

Dohrenwend (1984) presented correlations for modern and last glacial maximum nivation threshold altitude (NTA) and equilibrium line altitude (ELA) versus latitude for a Great Basin transect centered on 117° W longitude (Fig. 6). This correlation indicates that the LGM ELA for the Spring Mountains (36° N latitude, 118° W longitude) was 3700 m above sea level. Mount Charleston, the tallest peak in the Spring Mountains, is 3658 m above sea level; based on the regional correlation no glaciers should have formed in this range 20,000 years ago. Pelto (1992) connected late Pleistocene cirque-floor elevations to draw maritime and continental ELA transects from northern North America to southern South America. His continental transect indicates a late Wisconsin ELA of approximately 3500 m above sea level at 36° N latitude; the hypothesized cirque floor in Kyle Canyon lies at 2600 m above sea level, once again too low to host LGM glaciers based on regional trends in ELA (Fig. 6). Based on these correlations it seems unlikely that glaciers formed in the Spring Mountains during the latest Pleistocene.

The nature of the deposits certainly seems to indicate old age; no organic material was found in the limited exposures for direct C-14 dating. Yount and La Pointe (1997) discuss the geomorphology of glacial moraines in the Sierra Nevada with respect to glacial stages in the late Pleistocene. Tioga-age (25,000 BP to 10,000 BP) glacial deposits feature intact terminal moraines with only minor stream erosion. Tenaya-age (37,000 BP) terminal moraines are less prominent than Tioga moraines and are often breached by streams, while Tahoe-age (118,000 BP to 56,000 BP) terminal moraines have been mostly removed with remaining sections heavily gullied. Mono Basin (131,000 BP) terminal moraines are found only where later glaciers followed different paths, and Sherwin-age (760,000 BP) glacial deposits are described as surface erratics and shapeless till remnants. We have two recognizable glacial deposits, one that is marginal to the
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Figure 7. Upwind pluvial lakes (only major basins are shown) that may have contributed moisture to the Spring Mountains during the late Pleistocene.

During the late Pleistocene, the jet stream was split by the Laurentide Ice Sheet with the southern arm carrying abundant moisture into the northern Great Basin (Bartlein et al. 1998). Hostetler et al. (1994) discussed lake/atmosphere feedback effects in the Bonneville and Lahontan basins at 18 ka, roughly equivalent to the last glacial maximum. They conducted GCM (Global Climate Model) simulations of 18 ka climate assuming (a) lakes were not present and (b) lakes were present to assess impacts of Lake Bonneville and Lake Lahontan on local temperature, precipitation, and evaporation. Results demonstrated that atmospheric conditions were strongly influenced by the presence of these bodies of water. At 18 ka, Lake Bonneville had a surface area of 47,800 km², and Lake Lahontan had a surface area of 14,700 km². Hostetler et al. (1994) showed that both basins saw more equitable seasonal temperatures with lakes than without them. The lakes produced much greater evaporation in both summer and winter than did a landscape bare of lakes. The impact of local recycling of water back into the lake was greater in the Bonneville Basin due to catchment and runoff from the downwind Wasatch Range. Evaporated water from Lake Lahontan did little to help maintain the lake as it was carried eastward by predominantly westerly winds.

The Spring Mountains may have benefited from local recycling of evaporative moisture from upwind pluvial lakes. At 36° N latitude, this mountain range is south of many of the ranges that have benefited most directly from southern deflection of the jet stream, and it lies far west and north of those that have received appreciable moisture from Gulf Coast monsoons. However, it lies east of numerous basins that held large bodies of water at various times during the late Pleistocene (Fig. 7). At the last glacial maximum, the Owens River system consisted of Owens Lake, a lake that filled both China and Searles Basins, and a small lake in Panamint Valley. This cascading system, with a combined surface area of about 1,900 km² at about 18 ka (these lakes were significantly larger during several pre-LGM pluvial stages), received the majority of its moisture as orographic precipitation from the Sierra Nevada. These low elevation and low latitude basins may have produced greater rates of evaporation per unit area than the more northern Lahontan and Bonneville basins due to their higher average temperatures. Atmospheric moisture would have traveled eastward until trapped as orographic precipitation by mountain ranges in Nevada, the first and largest of which is the Spring Mountains. Other basins west and southwest of the Spring Mountains

floor of Kyle Canyon and a second that is buried by alluvium at the mouth of a hanging valley. We see none of the distinctive crests of terminal moraines left behind by Tioga and Tenaya glaciers in the Sierra Nevada. Our lower deposit is likely the distal remnant of a terminal moraine that has been mostly removed by stream erosion; we see so little of the upper deposit that it is hard to make any statements about its shape. The Spring Mountain tills best fit the descriptions of Tahoe and Mono Basin deposits in the Sierra Nevada. It seems unlikely to us that the Spring Mountain deposits are remnants of Sherwin-age glaciers based on the fine state of preservation of striations on individual limestone clasts.

Zielinski and McCoy (1987) developed relationships between modern snowpack and late Pleistocene ELA in formerly glaciated Great Basin mountain ranges. Full glacial ELA values predicted from modern snowpack failed to accurately portray actual ELA values, leading the authors to conclude that temperature and precipitation did not change uniformly across the Great Basin during the late Pleistocene. The Spring Mountains are very dry compared to most other ranges of equivalent size in the Great Basin; annual precipitation averages only 48 cm per year, less than half the annual precipitation of Yosemite Valley, CA. The Spring Mountains may be an area where regional trends in climate fail to accurately portray late Pleistocene climate change. Perhaps there is another source of water that enhanced moisture in the Spring Mountains and produced glaciers during Tahoe or Mono Basin stages.

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held large pluvial lakes that may have contributed moisture to air masses traveling to the northeast. These include Lake Tecopa, Manix Lake, and Lake Mojave.

There is evidence of greatly increased moisture in the Spring Mountains during the late Pleistocene. Szabo et al. (1994) discuss a 120,000-year record of climate change in Devils Hole, Nevada, a submerged cave system in the Ash Meadows basin (approximately 12,000 km²). The principle contributors of recharge to this system are thought to be the Spring Mountains and the White River groundwater flow system. Uranium-series dating of calcite deposits in a cave chamber called Browns Room indicate that the water table was 5 to 9 m higher than the present level between 44 ka and 20 ka. The water table was at least 5 m above the modern water table from 116 ka to 53 ka; the authors supplied a minimum increase for this time period and stated that they were uncertain as to the maximum water table rise due to methodological limitations. Quade and Pratt (1989) and Quade (1986) studied stratigraphy of valley deposits east of the Spring Mountains and found evidence of increased groundwater discharge and marsh formation from 60 ka to 40 ka and from 30 ka to 15 ka. Periodic increases in water supply in the valleys east and west of the Spring Mountains support the idea that the Spring Mountains were intercepting substantial quantities of atmospheric water during the late Pleistocene.

**CONCLUSIONS**

Most of the glacial record in the Spring Mountains has been destroyed or buried over time through fluvial and mass wasting activity. However, fluvio-glacial material covering the Kyle Canyon till may have been responsible for preservation of the remaining fraction of the overall deposit, just as alluvium has protected the Hanging Canyon till. We hypothesize that the glacier that deposited the Kyle Canyon till formed at the head of Kyle Canyon itself, which explains the southwesterly dip (away from the central axis of the valley) of the capping fluvio-glacial deposits. The presence of the ice and associated deposits forced drainage to the outside of the valley, resulting in the inactive channel that lies between the deposit and the western valley wall. Later drainage breached the deposit and returned the active channel to the central valley. We do not rule out the possibility that small glaciers also formed contemporaneously within higher valleys above Big Falls.

Evidence for glaciation in the Spring Mountains indicates that this range represents the southernmost extent of late Quaternary glaciation in the Great Basin and ends the long-standing debate over whether the range was in fact glaciated. Based on existing ELA correlations, the Spring Mountains are too low to have experienced LGM glaciation. Poor preservation of the deposits is consistent with an earlier episode of glaciation, perhaps of Tahoe or Mono Basin age. We present the potential for regional recycling of moisture from upwind pluvial lakes as a mode of creating and sustaining glaciers in this southern Nevada mountain range.

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**LITERATURE CITED**


